REVEGETATION OF SOIL AFFECTED BY SALTWATER

By

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CHAPTER I

INTRODUCTION

Enhanced recovery methods of hydrocarbon extraction often require and encompass handling large volumes of brine water. These brine waters are often introduced upon the land as a result of equipment and human failures and extenuating circumstances. Water that is predominantly made up of dissolved sodium chloride by volume will often kill all vegetation in its pathway (28).

Oilfield cleanup techniques are often primitively done with the use of vacuum trucks attempting to pick up all accessible brine waters, and later discharging freshwater over the contaminated area. The water is then picked up once more, as a means of flushing the chlorides (4) from the upper layer of the soil.

Restoration of areas polluted by saltwater requires restoring the permeability of the contaminated soil and is considered a success when the surface zones are free of salts and dispersion (9). Sodium toxicity or the inability of plant roots to uptake water may reduce or stop the growth of vegetation (3).

poultry manures, grass hay, wheat hay, wood chips, and cattle manures change the "soil biota" by providing an energy source for the survival and modification of the physiological structure of the soil (6). Manures provide a effective source of nutrients for soils, as stated by Olsen and others (17), and the use of gypsum as a source of calcium to replace the sodium in reclaiming sodic soils is a proven method.

Natural succession can be time consuming requiring decades for plant re-establishment to an optimum state. The addition of organic materials and reseeding for crop cover may reduce the revegetation time with an immediate increase in production. The success or failure of the revegetation task may depend upon: climatic conditions, seedbed preparation, stand and soil management, and the ability of crops to adapt to environmental conditions.

The objectives of this thesis are: 1) to determine what levels of manure and gypsum are needed to amend a brine effected soil, 2) to determine levels of favorable soil properties needed to accomplish soil renovation.

CHAPTER II

LITERATURE REVIEW

With the aging of oil fields comes the depletion of pipeline and material handling structures through corrosion, creating an increased likelihood of spills. Reclamation techniques on brine soils, vegetation patterns of re-establishment, and the different types of organic materials for soil rehabilitation may provide a better understanding for the revegetation task.

Known oil reserves represent a very attractive source of available energy (24). The advent of new technologies for enhanced recovery of oil by injection processes of carbon dioxide, saltwater, and steam are efficient, making known reserves attractive in comparison to slim chances of "wildcat" discovery of new sources of petroleum (12).

Diversity of Effects

Halvorson and Lang (9) stated that brine waters may have diverse effects on different plant species, with the range of tolerance being dependent upon salt concentration within the brine water. The inland salt grasses, western wheat grasses, and blue gamma grass are the most tolerant species to salt water, and complete eradication of these species in an area may lead to potentially serious erosion problems. Halvorson and Lang (9) learned from their experimentation that the ability of plant roots to take up water or sodium saturation by the plants may slow growth in salt affected soils.

Fauna and Flora

Overall the slow growth or death of plants is non-specific and is more dependent upon the absorption factor or stress by the total amount of dissolved salts than on the individual ion content (11).

Brine waters in north-western Pennsylvania at the Alleghany Forest completely eradicated a hardwood stand of hemlock, red maple, red oak, black cherry, and yellow and sweet birch over a half acre area. Rapid death occurred first for hemlock, then all other species. By the third growing season all vegetative species were killed except some shallow rooted ferns on small hills or on the logs which had been left to rot, making these plants free from the soaking of brine water (28).

Hoffman and Shannon (11) stated that woody perennials and trees may be specifically sensitive to chlorides, which causes a growth suppression greater than that of similar concentrations without chloride. Symptoms in chloride-sensitive plants appear as a leaf burn or drying of the leaves, which often is accompanied by defoliation.

Soil Physiology

Salinity does not always influence the use of essential nutrients by plants, in some instances if the ratio of calcium to sodium becomes either overly high or overly low, nutritional imbalances may occur reducing the plant growth below that expected from osmotic effects alone (11).

Maas and Hoffman (13) stated that physiologically soil classified as normally saline may affect plants little, but soils classified as extremely saline showed overt injury symptoms.

The most apparent affect to plants is a general stunting of growth, and as the concentration of salt increases above a threshold level the growth rate and overall size of most plants will progressively decrease, with the top growth of plants often suppressed more than root growth.

High concentrations of sodium may cause the eventual deterioration of soil structure. If the amount of absorbed sodium exceeds 10% of the total cation exchange capacity, soil mineral particles tend to disperse and hydraulic conductivity decreases. Low permeability becomes a problem when the rate of soil-water infiltration is reduced to the point where a plant is not adequately supplied with water.

Sodium may also add to crop difficulties caused by surface crusting of seed beds and temporary saturation of surface soil, which in turn may contribute to disease, weed, oxygen, nutritional, and salinity problems (11). Halvorsan and Lang (9) studied an oil drilling site in western North Dakota which left an entire area devastated because of a brine water blowout. Following two years of intensive reclamation efforts through the use of a soluble calcium chloride distributed through an irrigation system, the area was revegetated to a 75% cover over the reclaimed area, as compared to the unreclaimed half covering only 57%.

Procedures and Results

Comparative to the plight of an oil field blowout disaster and the revegetation task which proceeds it, is the complete eradication of a coal mine spoil area in New Mexico which was left barren by the removal of the top soil from a soil which was already saline, sodic, and low in organic matter. The revegetation task at this particular experimentation required the use of organic amendments in the form of pine bark and barley straw mulches incorporated into the soil in order to establish a more acceptable production rate for the re-establishment of a useful grass stand. The incorporation of the mulches was done through deep disk furrowing. Scholl and Pace (22) found that the SAR and soluble Na were 18 times higher in the sodic soil test plot area than at comparable spoil areas.

Bernstein and others (2) related the effects salinity has on yields when fertility is suboptimal because in most cases, studies are done under managed and optimal conditions. Moreover, Bernstein and others (2) concluded that nutritional deficiencies may be brought on by the salinity itself. An inbalance in cation nutrition was observed, with supplemental fertilization helping some salinity-induced calcium deficiencies in susceptible crops. The major emphasis was placed on the use of phosphorous and nitrogen, because they enhance salt tolerance in many crops.

In a crop-soil situation the relative benefits of reclamation and fertilization in treating nutrient deficient saline soil depends on the two most limiting conditions, salinity level and fertility. Bernstein and others (2) stated that, in general, fertilization to levels required to maximize yields is likely to yield poor return because of the overriding factor of salinity depressing yield by 50% or more which causes fertility to be relatively ineffective. Conversely, when fertility rather than salinity problems predominate, a greater response will come from fertilization than from reclamation.

Maximal effects of reclamation and fertilization are, however, achieved only when both factors are made nonlimiting. Because of leaf burn symptoms and high levels of phosphate accumulation, Bernstein and others (2) attributed phosphorous toxicity to impaired plant-water relationships. He suggested an accumulation of toxic ions (Na and Cl) may cause leaf burn in susceptible species by inhibiting stomatal closure. Phosphorous toxicity symptoms indicate an intensification of salinity-induced water stress that causes leaf burn.

Plice (18) studied eight field plot areas of a loamy sand and clay content. Sodium chloride content of the water added was 98.7% by volume, and total dissolved salts were by volume 23.2%. Ten field crops were planted in the area with sorghum and cotton least affected and beans and peas most affected. In the following two years the plots were subjected to 90 centimeters of precipitation, leaching the salts downward and creating a hard surface by the time the drier season had begun, limiting plant growth and productivity.

Check plots of the same soil were planted in an equal manner as the salt affected soils, and found to be equal in crop yield when subjected to moistening by sprinklers to keep the crust of the soil from drying out. Plice (18) concluded that absorbed salt did not entirely damage the crops if the plants could germinate at all.

Poor physical condition of the soil from high sodium chloride content may produce continual injury to vegetative species by limiting root penetration because of the poor structure of the plant itself. Any addition of salts from laboratory experimentation by Plice (18) indicated that raising the pH by two units or more over 6.5 had detrimental effects by hardening the soil and making it impermeable to air.

Gypsum as a Soil Amendment

A laboratory experimentation study done by DeJong (5), contaminated soils with a sodium chloride solution and added amendments to the solution. Gypsum mixed with the soil had beneficial effects when applied on the top of the soil; and exchangeable sodium was replaced with the addition of the gypsum. Similar studies concerning gypsum incorporation with soil required different amounts of gypsum be added. A 1978 study by Prather and others (19) required (39 kg/ha) be added, Plice (18) required (4.5-6.8 kg/ha), and Schmerbauch (21) (11.3 kg/ha), showing a vast differentiation in rate.

Differences in the structure of various soils tested and exchangeable sodium percentage differences in relation to the A and B horizon of the soils tested by DeJong (5) showed the percolation rate through brine contaminated B horizons was much higher than the uncontaminated sample of the A horizon. This reflected the differences in exchangeable sodium percentage between the soils, and possibly a difference in the soil macrostructure.

Amundson and Lund (1) investigated the chemical environment of a soil classified as a saline-sodic soil. The soil was treated over a period of years with amendments of gypsum and elemental sulphur, and the author concluded that with reclamation techniques the soil structure can be altered to a more favorable state. The study involved pedons reclaimed in a field study experimentation over a period of 0,5,8,15, and 25 years, with the level of bulk soluble salts being removed over a period of five years of intensive cultivation through leaching. After fifteen years, an attainable steady state composition of the soils structure was met as stated by Amundson and Lund (1).

When economics are a concern for reclamation procedures in incorporating gypsum to the soil, Elshout and Kamphorst (7) demonstrated the differences in varying grades of gypsum and distribution differences in particle size. Total time was proven to increase with particle size and less water would be needed to dissolve the finer grades. In conclusion the time over particle size had a correlation in the case of reclamation (12).

Experiments by Elshout and Kamphorst (7) in Pakistan involved two types of studies: in phase one soil was mixed with mined gypsum, of fraction limits from less than .15mm to 5mm in size, and incorporated into the soil to evaluate the leaching relationships regarding the grade of gypsum, and time required for dissolution. Leachates were collected to determine the sodium removed as an indicator of time potential for the reclamation of the soil properties and dissolving of the gypsum particles. The second phase tested the various methods of incorporation of the gypsum, first completely mixing, second mixing with the upper half, and third mixing 90% completely and putting the remaining 10% on top of the soil columns. Total amount of gypsum was the same in all three stages. Elshout and Kamphorst (7) concluded that the upper layer mixing with upper half of the soil was less effectively reclaimed and recommended that mixing 90% on the upper layers and 10% on the top part of the soil could be utilized beneficially and would avoid restriction of water on the soil column.

Calcium Chloride Soil Conditioners

Reclamation of brine contaminated soils by calcium chloride application to replace exchangeable sodium was studied by Merril et al (16). They mixed the upper part of columns (16 cm) and leached the materials with distilled or saline groundwaters. Efficiency of the study reflected a 89 to 92% removal throughout the upper 16 centimeters of the soil column. Reversal of dispersion in the soils created a much more permeable soil and resulted in the alteration and removal of sodium. Areas of moderately saline water may have an advantage in reclamation efforts because of the permeability throughout the leaching process.

Merril et al (16) studied the procedures of reclamation in soil columns prepared with a calcium chloride solution. These columns were leached by percolation of water simulating snow or rainfall of a solution similar to that which would be introduced upon North Dakota aquifers, they concluded that in the columns leached with distilled waters the electrical conductivity and chloride values were relatively constant at depths less than 12 cm and increased rapidly with depths below 28 centimeters, concentrations of which would be about half of that of a brine contaminated soil. The saline water treatment showed soluble salt levels were relatively constant above 24 centimeters and increased with depth in the soil column. The upper 16 centimeters showed a much higher level of soluble salts in the saline water sample than the distilled water samples, and were markedly lower below 24 centimeters.

In summary Merril et al (16) stated that the addition of calcium chlorides to brine soils decreased the puddling of water on the surface. This occcured at 0.54 pore volume of distilled water and 0.68 pore volume with saline water showing a 88.6% compared to 99.0% of the original chloride content being removed from the upper 32 centimeters of the soil column.

Modification of the Soil Mass

The interdependent balance of mineralization and decomposition in soils are both factors relevant to the nutrient status of soils. Competition of soils for plant nutrients occurs when the complex subsystem of the nutrient cycle is altered by some outside condition. Reclamation may require more than the incorporation of a sole inorganic material such as calcium chloride or gypsum. Soil nutrient status may require modification by the addition of a recalcitrant as a source of energy to be retained for several years (12). Application of organic fertilizers has the potential of increasing plant yield to an extent above that resulting from the application of equivalent nutrients by inorganic fertilizers, as stated by Senesi (23).

Data gathered by Senesi (23) showed the potential for a more efficient nutrient utilization, with higher nutrient availability and a steeper crop-yield response curve when organic manures were used. This suggested a contribution to plant growth other than simple nutrient supply.

The entity and persistence of the effects largely depends on the durability of added organic material in the soil. Depending in turn on how much of the organic material is resistant to degradation and is incorporated into the native soil in relation to how much of the material is mineralized (23).

Senesi (23) stated that an important effect of the addition of easily decomposable organic residues to soils is the modification of the normal biological activity in soil equilibrium and broadening the spectrum of soil microbial activity. He stated that, the soil organic fertility of soil is unanimously attributed to the multiple and complex functions exerted by organic components in soil. Organic materials are universally recognized to highly contribute to equilibria and processes in the soil-plant system.

Organic matter, therefore, besides ensuring a balanced growth of plants and soil organisms, guarantees soil conservation and protection towards external factors of disturbance and contamination.

Natural sources of organic matter in soil are indigenous plant and animal debris, cropping wastes and animal manures. The latter have traditionally been used as the only means of maintaining and increasing soil fertility and crop production until they have been replaced almost completely by the introduction and extended use of chemical fertilizers in modern and intensive agriculture.

Natural sources of organic matter in soils are organic, plant residues which are subjected to decay in several, mainly microbially controlled stages of decomposition utilization and transformation leading to more refractory organic substances as stated by Senesi (23).

Organic Amendments

Important factors influencing the negative reproducibility in a soil are the extreme variability of soil composition and properties, crop requirements, and geoclimatic conditions. McCalla (14) has studied the relationships of manures as an organic amendment to soils, with utilization of the elements having the ability to provide nitrogen, phosphorous, and potassium. The incorporation of manures into the soil which are often classified as a waste may provide an alternate avenue to improve the soil resource.

The micronutrients within animal manures have been shown to correct zinc deficiencies in some cropland studies, and applications have shown to increase the organic matter content and improve the soils physical property. The problem with manure use is often related to cost of transportation, odors, hazards of runoff, metal toxicities, and nitrate pollution (14).

The nutrients in manures have been effective when used with high nitrogen requiring crops such as corn, sorghum, small grains, grasses, and other vegetable crops. Soils of eradicated areas have shown an improved revegetation status from the addition of manures supplying organic matter and nutrients to areas where the status of deficiency is unknown. Waterholding capacity and structural stability of the soil may be improved and in general the long term structure of the soil renewed (14).

Overall the fertility of a soil is attributed to the content of the organic material relation to the soil-plant system. Restoration of fertility in depleted soils may be accomplished by the mixing of organic materials, and may be used as a soil conservation and reclamation method (15).

In Italy, Sartori and others (20) detected noticeable changes in soil porosity and surface shrinkage in a remolded saline clay soil which was treated with compost. Widespread areas of Italy noticeably displayed deterioration of soil structure because of the severe shortage of farmyard manure causing a decrease of organic matter content within the soil structure.

For these reasons Sartori and others (20) expressed an increased interest in substances able to improve the physical properties of soil and in particular the soil structure, such as organic and inorganic soil conditioners and livestock effluents, sewage sludge, and composts. Interest in the agronomic use of these products has also increased because of the need for lower disposal costs and to recycle nutrient elements in the soil-crop system.

Sartori and others (20) experimented with wetting and drying cycles of soil aggregates treated with composts in a laboratory study. The variation of cracking patterns on the surface of the soil was higher in intraaggregate porosity concerning the treated samples than the control after the first wetting and drying cycle.

Sartori and others (20) noted that the addition of organic materials and the evolution of carbon dioxide indicated an increase in microbial activity regulating the decomposition rate of any such organic material in the soil. The first few weeks of incorporating the sewage sludge or compost into the soil indicated the CO2 evolution to be at its maximum potential in aiding the soil column.

In addition, the pore size distribution directly relates to plant growth because of the relation that pore size has to root penetration and storage of water and gases. Land may be left ultimately barren by the removal of top soil in a soil which is already saline, sodic, and low in organic matter.

CHAPTER III

MATERIALS AND METHODS

A saltwater injection plant in Dillard, Oklahoma near Ardmore (Figure 1) was selected as the site for a revegetation study. Knowledge from the revegetation of the oil field area can be applied at other sites where saltwater eradicated the soils.

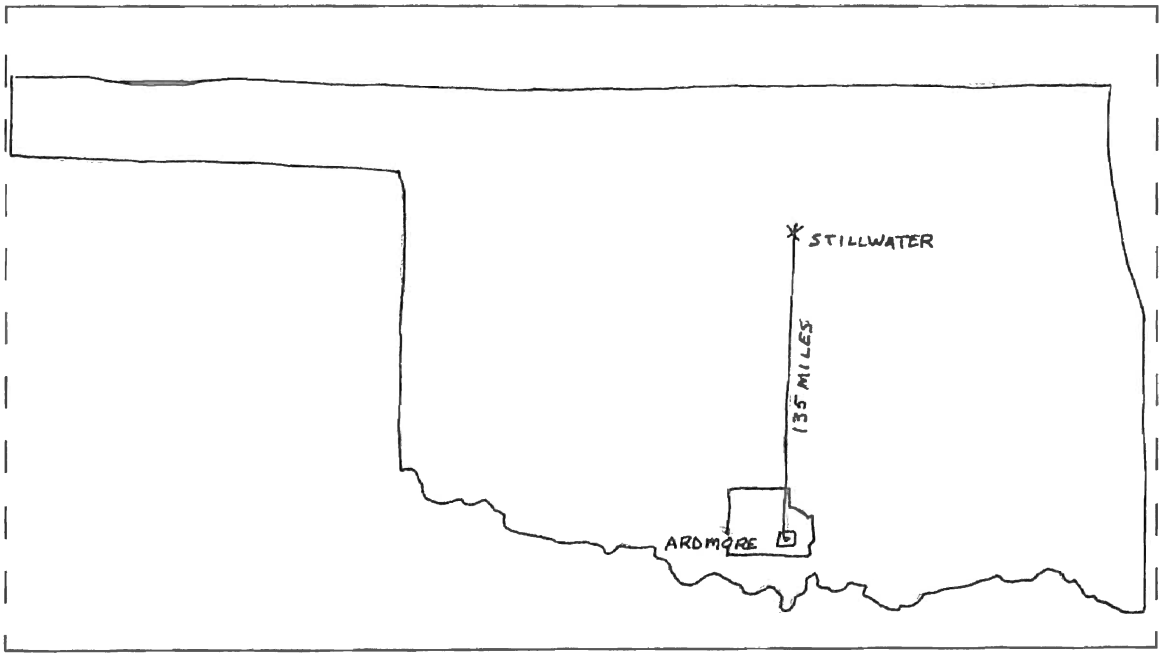

Figure 1. Location of Carter County in Oklahoma

Carter County is included in the 88.9 centimeter annual precipitation belt of southern Oklahoma. The mean annual temperature is 18.1 C. Carter County occupies approximately 535,680 acres, or 837 square miles. The county is largely rural with beef cattle and the oil and gas industry contributing to the majority of the economy. Carter County has a scarce supply of drinkable groundwater because of the presence of high levels of soluble salts making it unsuitable as a freshwater source (26).

Dominant plant species of Weatherford-Windthorst series are mostly bluestem, indian grass, switch grass, and a variety of forbs (ragweed, broomweed, thistle, and arrowleaf clover). The northern part of Carter County is rocky, sloping to slightly sloping limestone hills, with the southern half nearly level to sloping tree covered uplands (26).

The Weatherford-Windthorst soils formed are of deeply weathered soft sandstone, often referred to as packsand. The Soil Conservation Service, USDA mapping unit is depicted in the Appendix.

The area involved in this study is of the Weatherford-Windthorst mapping unit, with a representitve profile of the Weatherford soil depicted as having an A horizon 23 centimeters of pale brown, slightly acid fine sandy loam. The upper 41 centimeters of the B horizon is yellowish red, medium acid sandy clay loam, and the C horizon is 38 centimeters of reddish yellow, distinctly mottled, slightly acid sandy clay loam, with weakly consolidated sandstone below. Organic matter and fertility is extremely low, with surface layer medium acid to neutral, and shrink-swell capacity moderate. A representitive profile of the Windthorst soil depicts the A horizon as a grayish brown, medium acid fine sandy loam 8 centimeters thick. The B horizon is 8 centimeters of pale brown, medium acid fine sandy loam. The upper 66 centimeters of the C horizon is yellowish red and reddish yellow medium acid sandy clay. The lower 25 centimeters is reddish yellow, neutral sandy clay. The underlying layer is coarsely mottled, moderately alkaline soft shale. The mapping unit is predominantly 89 to 152 centimeters deep with available water capacity to a depth of 102 centimeters. The natural fertility is low, as well as organic matter, and shrink-swell potential is medium to high (26).

In a preliminary survey of the Dillard oilfield area samples of the upper 25 centimeters of contaminated soils were collected from the two sites for physical and location characteristics, these are listed in Table I. Slope is interpreted for runoff concerns, and pH and parent material of the soil for present characteristics of the soil.

TABLE I

SELECTED SOIL AND SITE CHARACTERISTICS OF DILLARD, OKLAHOMA OILFIELD CONTAMINATED SOILS

SITE	LOCATION	SLOPE	PARENT MATERIAL	pH
1	S.22-T.4S-R.2W	1-12%	Sandstone	6.2
2	S.22-T.4S-R.2W	1-20%	Sandstone	5.3

Field Demonstration

Barley because it is a salt tolerant crop, was selected as the plant for demonstration purposes. Listed in Table II is a series of salt tolerant crops made available by the United States Salinity Laboratory (25). This is a best estimate of the threshold salinity level and yield decrease per unit salinity increase for a number of agricultural crops. Appropriate salinity and plant parameters measuring methods were used by the United States Salinity Laboratory to obtain meaningful salt tolerance data, along with many plant, soil, water, and environmental factors influencing the plant's ability to tolerate salt.

TABLE II

SALT TOLERANT CROPS

CROP		ECe (ds m-1)	
COMMON NAME	BOTANICAL NAME	50% EMERGENCE	50% YIELD
Barley	Hordeum vulgare	16-24	18
Cotton	Gossypium hirsutum	15	17
Sugarbeet	Beta vulgaris	6-12	15
Sorghum	Sorghum bicolor	13	15
Safflower	Carthamus tinctorius	12	14
Wheat	Triticum aestivum	14-16	13
Beetroot	Beta vulgaris	14	10
Cowpea	Vigna unguiculata	16	9
Lucerne	Medicago sativa	8-13	9
Tomato	Lycopersicon esculentum	8	8
Cabbage	Brassica oleracea	13	7
Maize	Zea mays	21-24	6
Lettuce	Latica sativa	11	5
Onion	Allium cepa	6-8	4
Rice	Oryza sativa	18	4
Bean	Phaseolus vulgaris	8	4

* Provided by the United States Salinity Laboratory (25).

The late summer-early August of 1992 lacked sufficient rainfall at the early part of the season for cool weather crops to germinate. It was at this time that a subsequent planting was made on Plot #2 which produced a significant enough stand that could be counted. Time intervals are reflected in Table III.

TABLE III

TIME INTERVALS OF FIELD STUDY

Tract #1	1st Planting	2nd Planting
Disked	8-27-92	
Seeded	8-30-92	
Fertilized	8-30-92	
Harvested	11-26-92	
Tract #2		
Disked	8-27-92	9-27-92
Seeded	8-30-92	9-27-92
Fertilized	8-30-92	9-27-92
Harvested		11-14-92

The plots chosen were sectioned off into three seperate areas (Figure 2). The experiment included a control, gypsum and 10-20-10, and gypsum and cow manure incorporated on plots three by nine meters. The only pretreatment conditions which were met were the initial flushing of the upper layers of the soil preceeding the saltwater spills, as a means of removing as much sodium chloride as possible through discharging and picking up the freshwater.

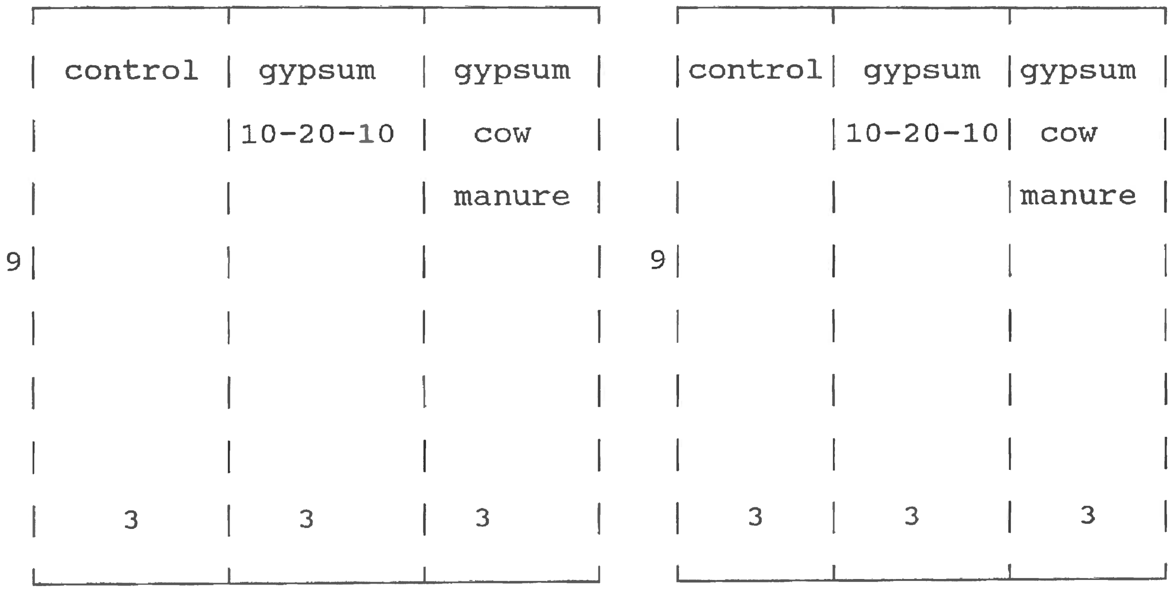

Figure 2. Schematic of Plots 1 & 2 Separated into 3 Sections.

The areas were initially disked six times with a tandem disk incorporating the gypsum, fertilizer, and manure to a sufficient depth. Because of the salinity of the soil the upper layer of the soil had a very hard, crusted appearance and required intense plowing. The subsequent planting required only two diskings because of the prior intense plowing making the soil a more porous and pliable material. After preparation of the soil, the seedbed was given double the amount of seed required for agricultural purposes (226 kg/ha), and lightly raked down for seed cover. The cow manure was incorporated with gypsum at a rate of 11.3 metric tons/ha through several series of disk plowing with a four meter tandem disk.

The overabundance of gypsum and manure created a much higher plot than the other two, standing 15 to 20 centimeters higher. Table IV depicts the rate of material applied in for each plot.

TABLE IV

MATERIAL RATES

	GYPSUM	10-20-10	* COW MANURE
Tract #1	11.3 metric t/ha	136 kg./ha	4.5 metric t/ha
Tract #2	11.3 metric t/ha	136 kg./ha	4.5 metric t/ha

* % Field moisture for the sample of fresh manure was 18.4.

Both plots recieved two heavy doses of saltwater, completely eradicating plant growth on both areas. Plot #1 had a difficult area of reclamation to be concerned with because of two saltwater leaks from pipeline breaks saturating the soil the first time with twenty barrels, and the second time with thirty. The hard encrustation on the upper part of the soil resulting from the number of saltwater spills that had occured over the years, made the area quite difficult to plow. This was a sandy loam soil with fragments of sandstone mixed, with no evidence of organic material visible.

Tract #2 was an embankment of soil with a slope of 5 to 10%. The land was within an area which had at one time had a a lot of organic matter, but because of a saltwater spill of a great magnitude contributing forty barrels of sodium chloride over an area of approxiamately four acres, had been completely eradicated, with no visible appearance of live vegetation. Three hundred and sixty barrels (42gallons/barrel) of freshwater was discharged at the upper side of the spill, and later picked up by vacuuum trucks, in an attempt to flush the chloride from the soil. The following week when soil moisture was at an acceptable dryness for plowing, the area was disked and seeded. However a rain of fifteen centimeters washed out the first seeded plots, and a diversion ditch had to be laid to move the water around the area to prevent any excess erosion and loss of material additions.

Following a two week wait for the soil to dry to an acceptable plowing consistency, the area was again plowed and seeded. The chemical analysis of the makeup of this saltwater is listed in Table V.

TABLE V

SALTWATER ANALYSIS IN COMPARISON TO A FRESHWATER SAMPLE FROM A SOURCE WITHIN THE AREA OF THE PLOTS

	Saltwater	Freshwater
pH	5.76	7.00
*Ca	6,000	2.50
*Mg	1,069	35
*Na and/or K	29,395	642
*S04	0	354
*Cl	59,301	660
*Fe	13.7	1.3
*Ba	647	0
*Total Solids Calculated	96,607	2,997
Resistivity ohms/m	.096	2.51

* Results reported in milligrams per liter.

CHAPTER IV

RESULTS AND DISCUSSION

Table VI reflects the percentages of dry moisture and organic carbon for the three sections of both plots. The per centage of air dry moisture is the same for the gypsum-manure plots and gypsum-10-20-10 plots, but easily distinguished from the control plots. However, the organic carbon percentages are vastly different, with the gypsum-manure plot far greater than the other two plots.

TABLE VI

PERCENT DRY MOISTURE AND ORGANIC CARBON

SOIL SAMPLE	%AIR-DRY MOISTURE	%ORGANIC CARBON
Gypsum-Manure Plot 1	1.20	1.95
Gypsum-Manure Plot 2	1.14	2.26
Control Plot 1	0.63	0.34
Control Plot 2	0.71	0.93
Gypsum-10-20-10 Plot 1	1.22	0.51
Gypsum-10-20-10 Plot 2	1.27	0.71

Numerical results of the field study are reported in Tables VII and VIII. Two samples were taken from each of the three sections of both plots by randomly mixing samples from several different spots on each plot. Soil test reports were recorded in September of 1992 and April of 1993, establishing a mean and standard deviation for each plot. Plot #1 demonstrates the ability of the cow manure-gypsum mixture to raise the level of phosphorous, potassium, calcium and magnesium to the soil structure, however nitrates are relatively equal. Plot #2 reflects the potassium, phosphorous, and calcium extractable nutrient levels to be much higher, but nitrates and magnesium lower. The level of pH for both plots was raised considerably by the addition of gypsum-manure, but the gypsum-10-20-10 mixture in the first plot was much lower. An evident change occured over time from the dates of sampling for each section of both plots, with each one raising an appreciable number of pH units. Soluble salts declined in both control plots, but were significantly higher in the gypsum-manure plot, and were lower in the Plot #1 of the gypsum-10-20-10 than in Plot #2.

The unit of measurement used in analysis of the soil soluble salts and cation exchange capacity is reported in milligrams per liter. Nitrates, phosphorous, potassium, magnesium, calcium, and sodium are in kilograms per hectare.

TABLE VII

COMPARATIVE SOIL ANALYSIS TO DIFFERENCES IN TREATMENT FOR PLOT #1 AS NOTED FROM TWO SOIL SAMPLES

CONTROL

*	1st Sample	2nd Sample	Mean	Standard Deviation
pH	6.2	6.7	6.4	.3
NO3	24	42	33	12
P	11	9	10	1
K	159	120	139	27
Ca	2,000	1,800	1,900	141
Mg	270	230	250	28
Na	19,000	19,000	19,000	0
CEC	44	45	44	0
Soluble Salts Units	4,900	4,700	4,800	141

GYPSUM & 10-20-10

*	1st Sample	2nd Sample	Mean	Standard Deviation
pH	5.3	6.8	6.0	1
NO3	22	48	35	18
P	40	64	52	16
K	149	129	139	14
Ca	8,700	13,600	11,500	3,464
Mg	270	180	225	63
Na	17,000	16,000	16,500	707
CEC	56	64	60	5
Soluble Salt Units	8,400	6,700	7,550	1,202

GYPSUM & COW MANURE

*	1st Sample	2nd Sample	Mean	Standard Deviation
pH	6.6	7.3	6.9	.3
NO3	41	8	24	23
P	128	107	117	14
K	1,135	757	946	267
Ca	11,000	15,000	13,000	2,828
Mg	630	420	525	148
Na	17,000	16,000	16,500	707
CEC	52	89	71	26
Soluble Salt Units	6,300	7,900	7,100	1,131

Soluble salts are in parts per million extractable nutrient, and NO3, P, K, Mg, and Na are in kgs./ha.

TABLE VIII

COMPARATIVE SOIL ANALYSIS TO DIFFERENCES IN TREATMENT FOR PLOT #2 AS NOTED FROM TWO SOIL SAMPLES

CONTROL

*	1st Sample	2nd Sample	Mean	Standard Deviation
pH	6.2	6.7	6.4	.3
NO3	37	42	39.5	3
P	11	9	10	1
K	411	120	265	205
Ca	2,000	1,800	1,900	141
Mg	480	230	355	176
Na	24,000	19,000	21,500	3,535
CEC Units	50	44	47	5
Soluble Salts Units	23,000	19,000	21,000	2,828

GYPSUM & 10-20-10

*	1st Sample	2nd Sample	Mean	Standard Deviation
pH	6.2	6.9	6.5	.4
NO3	35	22	28.5	9
P	23	29	26	4
K	398	388	393	7
Ca	4,000	18,200	11,100	10,040
Mg	600	400	500	141
Na	23,400	17,000	20,200	4,525
CEC	62	77	70	11
Soluble Salts Units	7,840	8,260	8,050	296

GYPSUM & COW MANURE

*	1st Sample	2nd Sample	Mean	Standard Deviation
pH	6.3	7.0	6.6	.4
NO3	38	16	27	15
P	73	93	83	14
K	876	528	702	246
Ca	9,400	13,300	11,350	2,757
Mg	540	250	395	205
Na	23,000	22,000	22,500	707
CEC	52	76	64	17
Soluble Salts Units	19,600	21,200	20,400	1,131

Soluble salts are in parts per million extractable nutrient, and NO3, P, K, Mg, and Na are in kg./ha.

Mean dry weights of plant tops for each plot are recorded in Tables IX and X. Results are reported in kilograms per square meter, with a sixty one centimeter square used randomly for measurement of the plant tops.

Samples measured were higher in the gypsum-manure sections of each plot, and slightly higher in the gypsum-10-20-10 plots when compared to the control sections. It was at this time that numerous species of pillbugs, ants, and red worms were seen to be feeding upon the manure plot in great numbers.

TABLE IX

MEAN DRY WEIGHT OF PLANT TOPS (GRAMS/SQ.METER) GROWN IN SALT AFFECTED SOIL WITH THREE FERTILITY LEVELS AT RESEARCH PLOT #1

PLOT #1 SPECIES BARLEY	CONTROL	GYPSUM&10-20-10	GYPSUM&COW MANURE
SAMPLE #1	.95	1.40	2.94
SAMPLE #2	1.01	1.46	3.01
SAMPLE #3	.86	1.12	2.67
SAMPLE #4	.97	1.32	2.81
MEAN (ALL SAMPLES)	.94	1.36	2.86
STANDARD DEVIATION	.063	.148	.149

TABLE X

MEAN DRY WEIGHT OF PLANT TOPS (GRAMS/SQ.METER) GROWN IN SALT AFFECTED SOIL WITH THREE FERTILITY LEVELS AT RESEARCH PLOT #2

PLOT #2 SPECIES BARLEY	CONTROL	GYPSUM&10-20-10	GYPSUM&COW MANURE
SAMPLE #1	.86	1.13	2.43
SAMPLE #2	.83	1.46	2.36
SAMPLE #3	.78	1.67	2.67
SAMPLE #4	.42	1.11	2.34
MEAN	.72	1.34	2.45
STANDARD DEVIATION	.2043	.2709	.1516

Table XI depicts the actual number of plants counted for each section of both plots, with an increased number of plants evidenced in both the gypsum-manure plot, and the gypsum-10-20-10 plot, when compared to the control. Method of counting the plants was at random with a sixty one centimeter square.

TABLE XI

NUMBER OF BARLEY PLANTS GERMINATED AT BOTH PLOTS WITHIN A 61X61 CENTIMETER SAMPLE

	CONTROL	GYP./10-20-10	GYP./COW MANURE
PLOT #1	94	154	177
PLOT #2	60	111	133

The rapid accumulation of plant matter in the manure and gypsum plot conspicuously out produced the inorganic fertilizer and check treatments, as shown in figures 3 and 4.

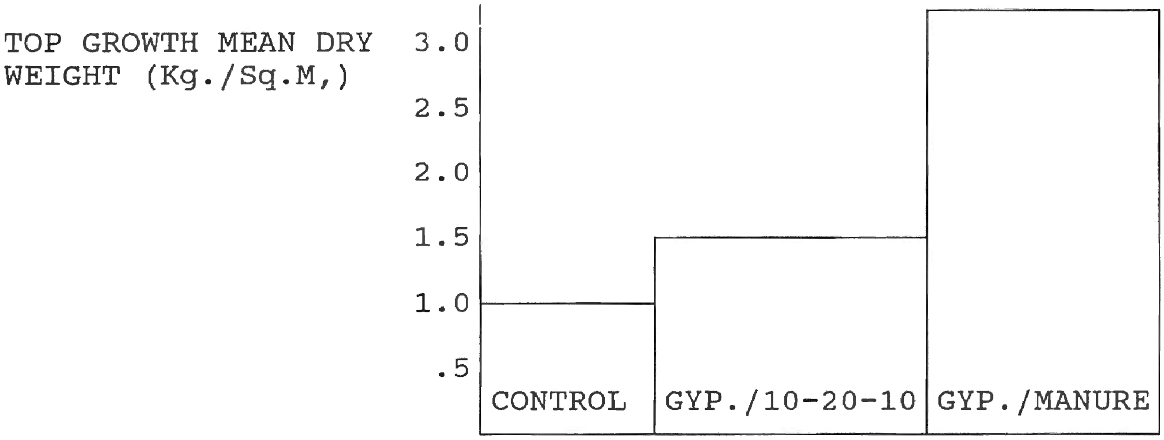

Figure 3. Plant Response to Inorganic and Organic Amendments to Plot #1

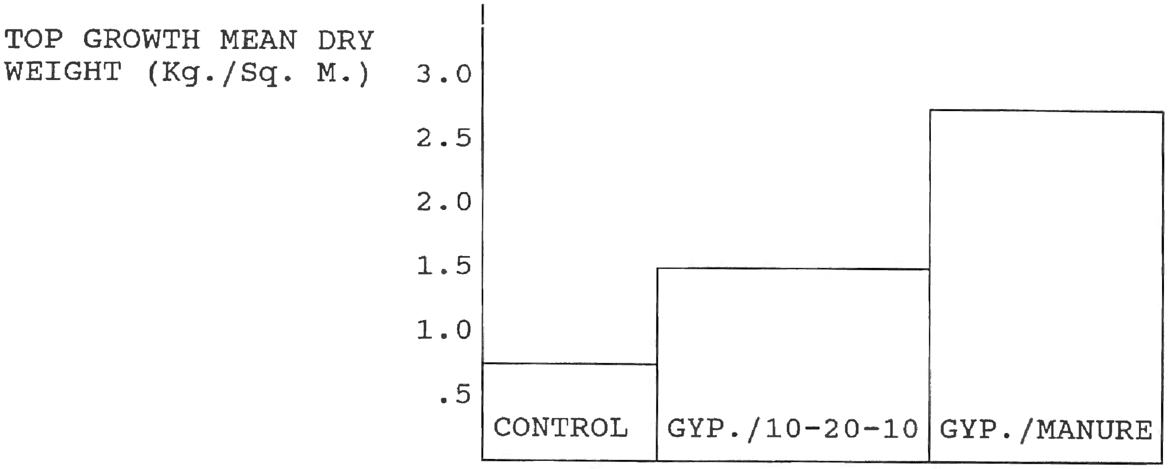

Figure 4. Plant Response to Inorganic and Organic Amendments to Plot #2

The comparison of treatments from the two plots over three treatments in regards to nitrates are noted in Figures 5 & 6. The means for nitrate nutrients were higher in both plots of the gypsum-10-20-10 section than in the other two sections. Plot #1 was significantly lower than the other two in the gypsum-manure section, and the other two were almost the same. On each of the gypsum-manure plots a very substantial drop in nitrate nutrients occured from the time the first soil sample was taken to the second sample, possibly because of the greater number of plants utilizing the nutrient during rapid germination and growth. A nitrogen ionalyzer probe was used as the type test for nitrates.

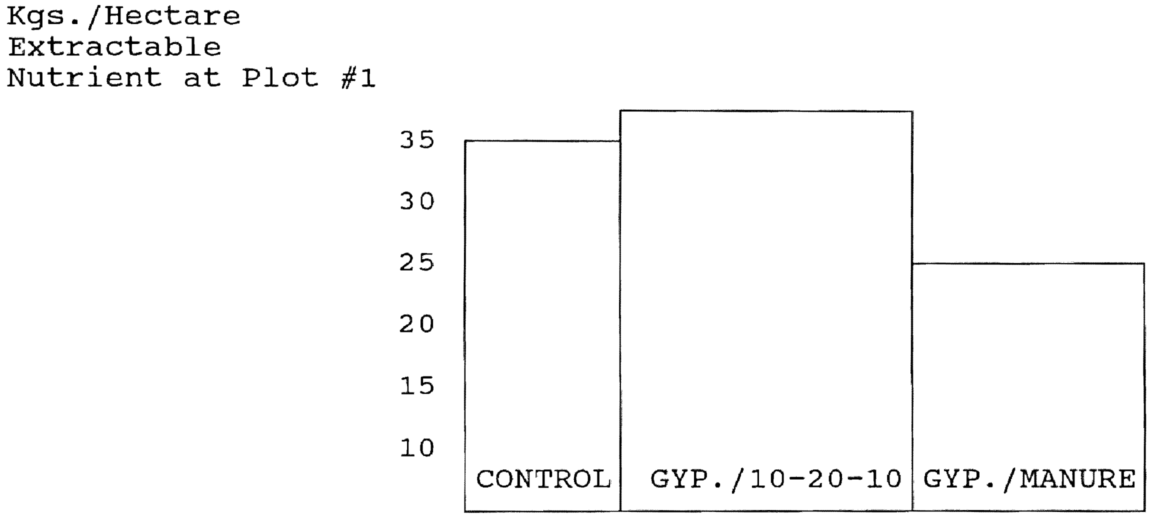

Figure 5. Mean Comparison of Nitrate Amounts at All Three Sections of Plot #1

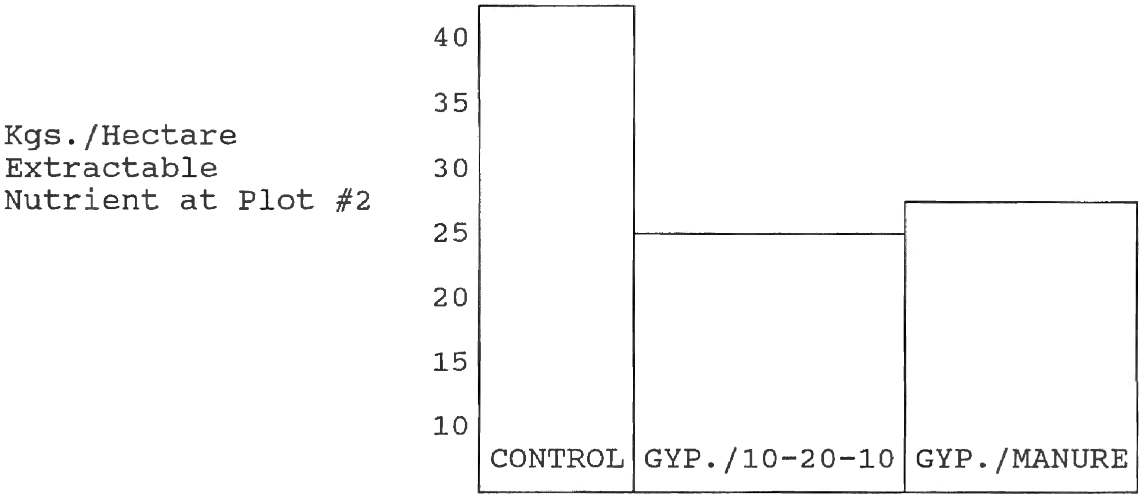

Figure 6. Mean Comparison of Nitrate Amounts at All Three Sections of Plot #2

Figures 7 and 8 exemplify the phosphorous nutrient accumulation for each plot in parts per million, with the gypsum-cow manure plots having several units more than the control and gypsum-10-20-10 plots, increasing the chances for a successfull germination and initial growth to be established for the plants. The Bray #1 extractant color test was used in measuring the levels of phosphorous for the samples, the number of plants which became established were clearly a measure of the phosphorous content in the gypsum-manure plots.

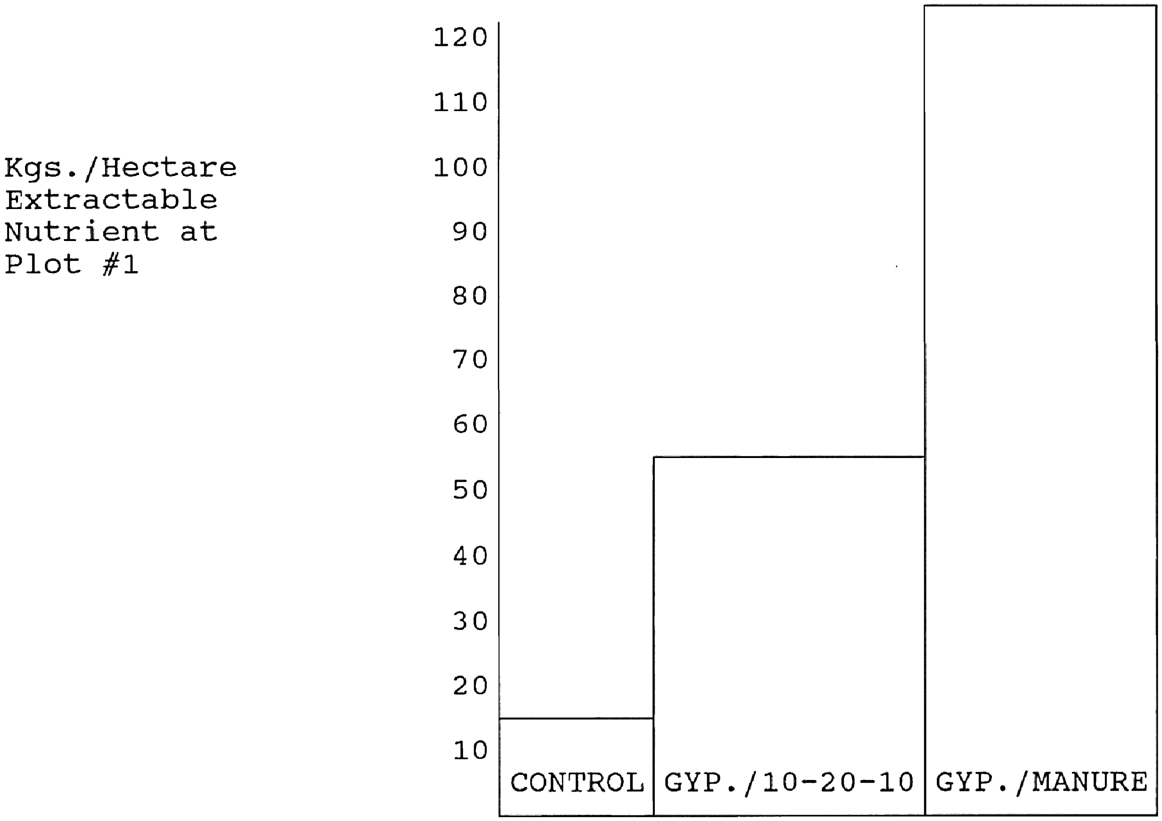

Figure 7. Mean Comparison of Phosphorous Amounts at All Three Sections of Plot #1

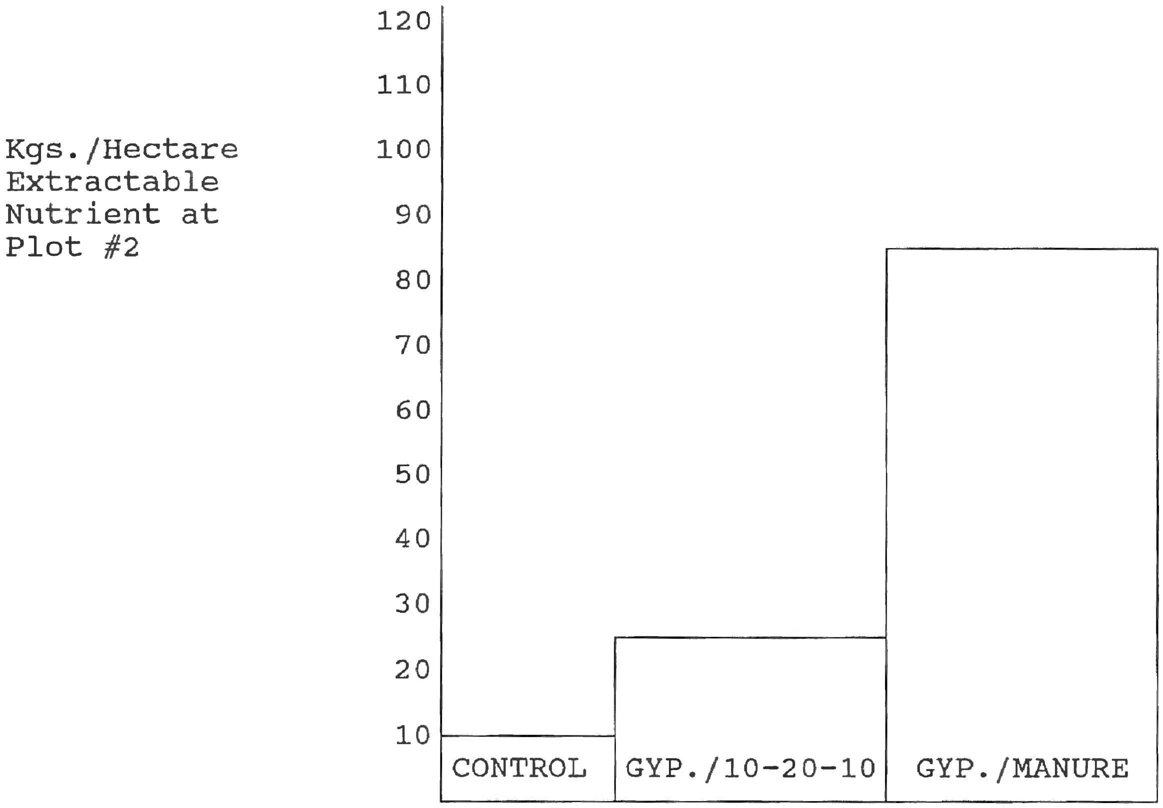

Figure 8. Mean Comparison of Phosphorous Amounts at All Three Sections of Plot #2

Potassium levels on Plot #1 were very high in the gypsum-manure section and the control and gypsum-10-20-10 sections were the same, as illustrated in Figure 9. Plot #2 samples showed the control which was much higher than in Plot #1, but still low in comparison to the gypsum-manure plot, and the gypsum-10-20-10, as illustrated in Figure 10. The type test used for measuring the units of potassium was ammonium acetate extraction.

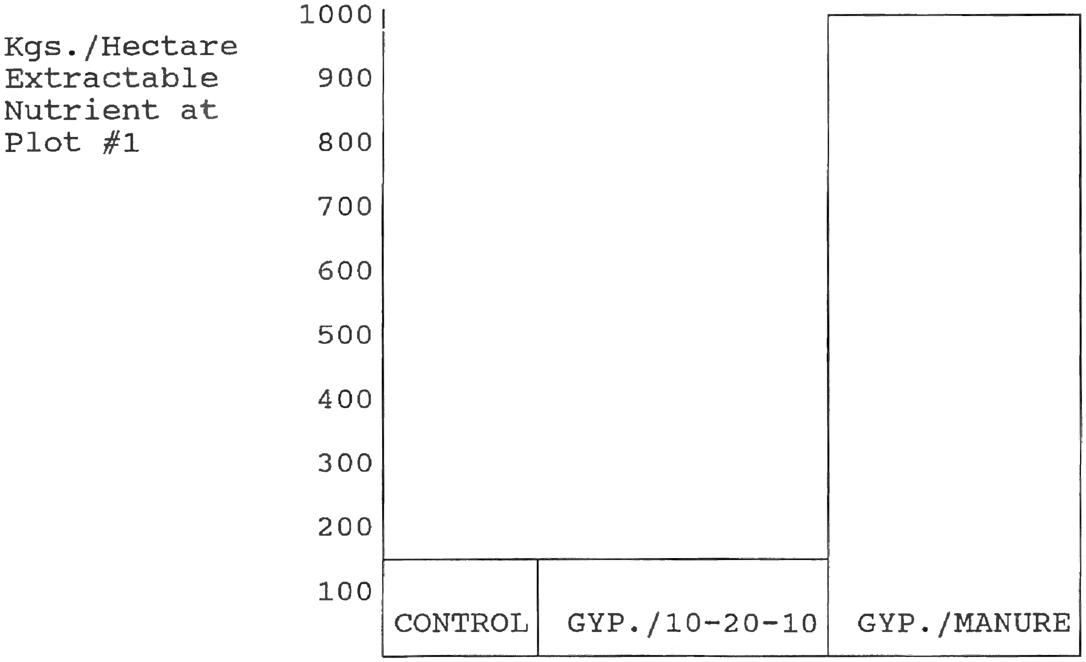

Figure 9. Mean Comparison of Potassium Amounts at All Three Sections of Plot #1

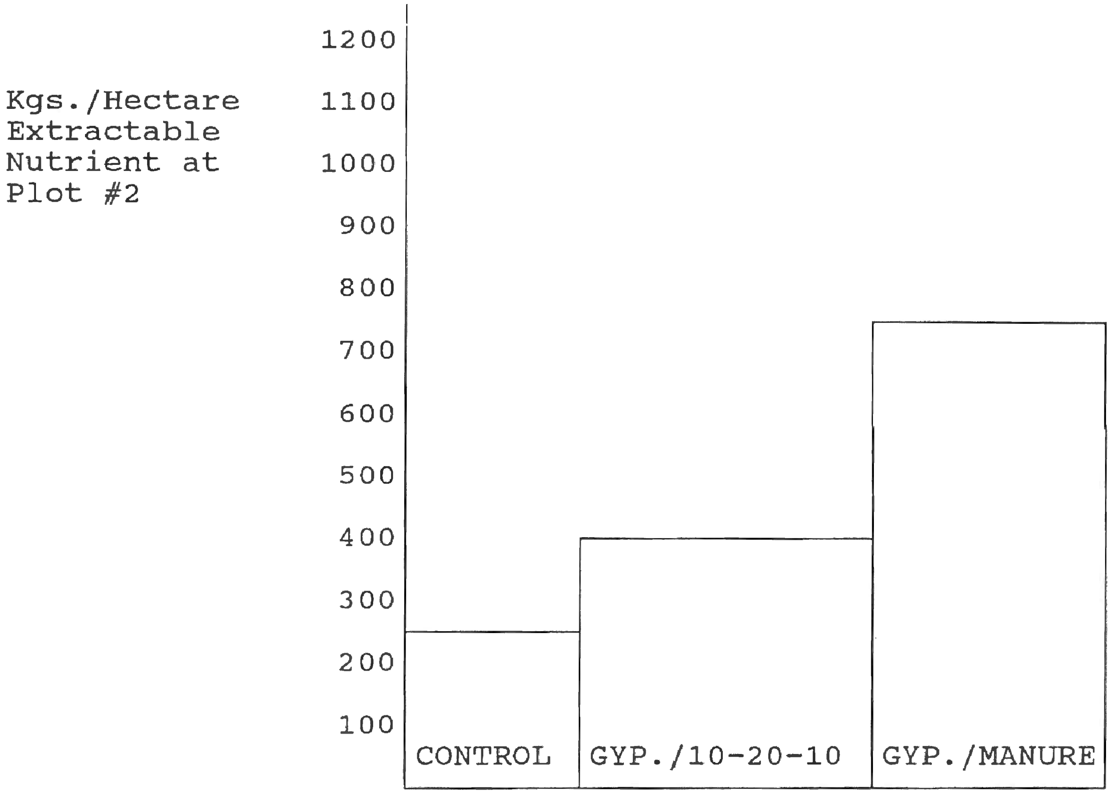

Figure 10. Mean Comparison of Potassium Amounts at All Three Sections of Plot #2

Figures 11 and 12 exemplify the Cation Exchange Capacity units in relation to soluble salts and calcium measurements. Plot #1 reflects a lower value, with the gypsum-10-20-10 section slightly higher, and the gypsum-manure section still higher. Plot #2 in the control section was the lowest, the gypsum-10-20-10 was the highest, and the gypsum-manure was relatively in the middle of the two.

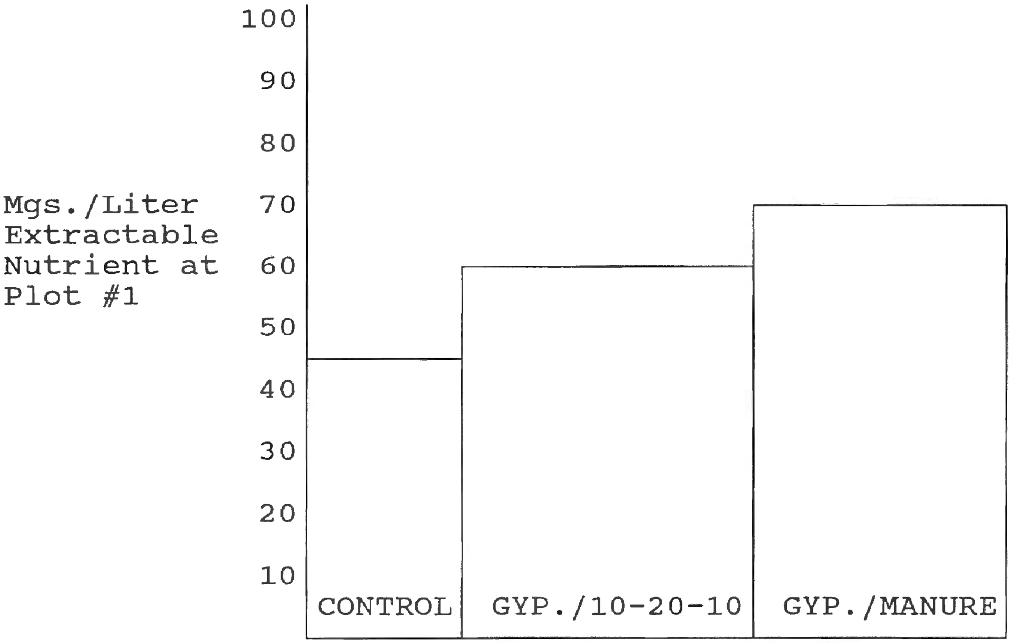

Figure 11. Mean Comparisons at All Three Sections of Plot #1 of Cation Exchange Capacity

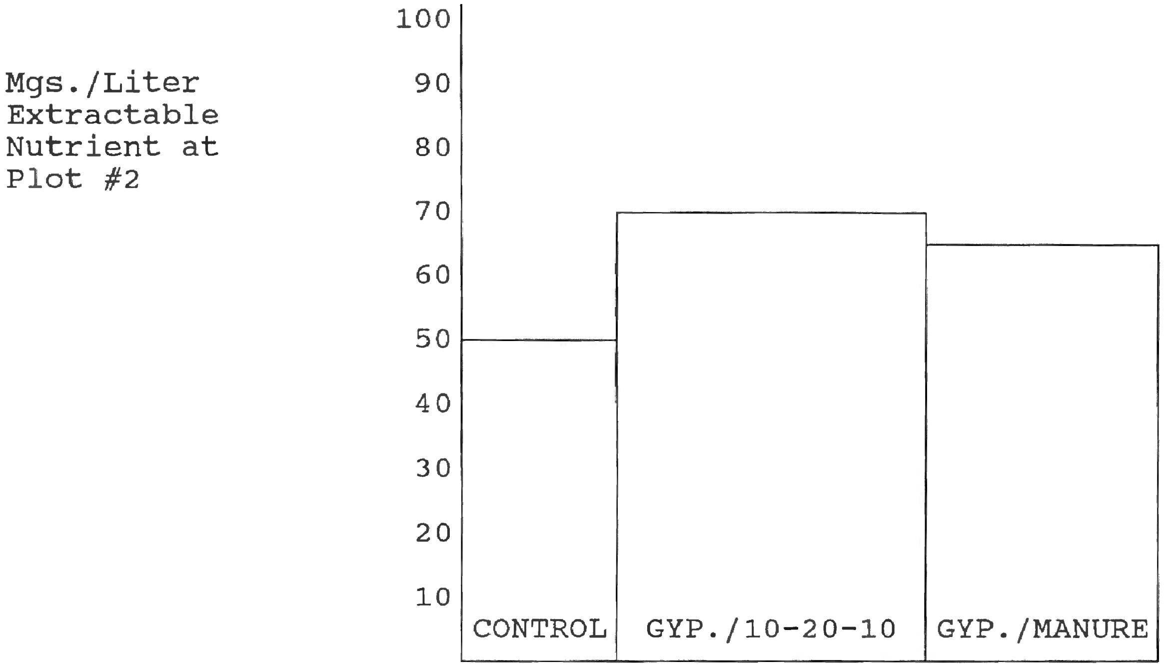

Figure 12. Mean Comparisons at All Three Sections of Plot #2 of Cation Exchange Capacity

Soluble salts for the two plots are characterized in Figures 13 and 14, and were measured on a one to one water to soil test. On both plots the measurement of salts in the control section lowered over time. However, in each of the other sections the level of soluble salts was raised from the addition of both the inorganic fertilizer, and the manure. On the manure plot, initially after several rains, salt encrustation occured on top of the soil. However, the salts had no apparent harmful affect on the plants to be seen.

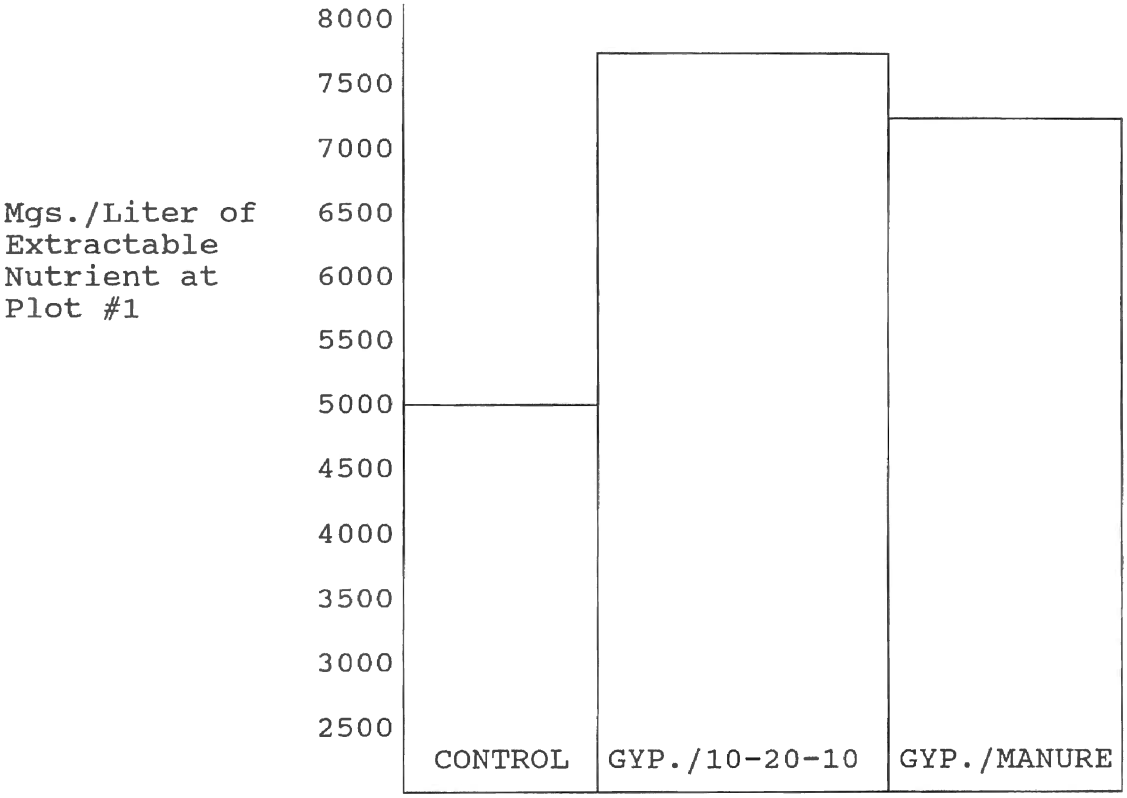

Figure 13. Mean Comparisons of Soluble Salts at All Three Sections of Plot #1

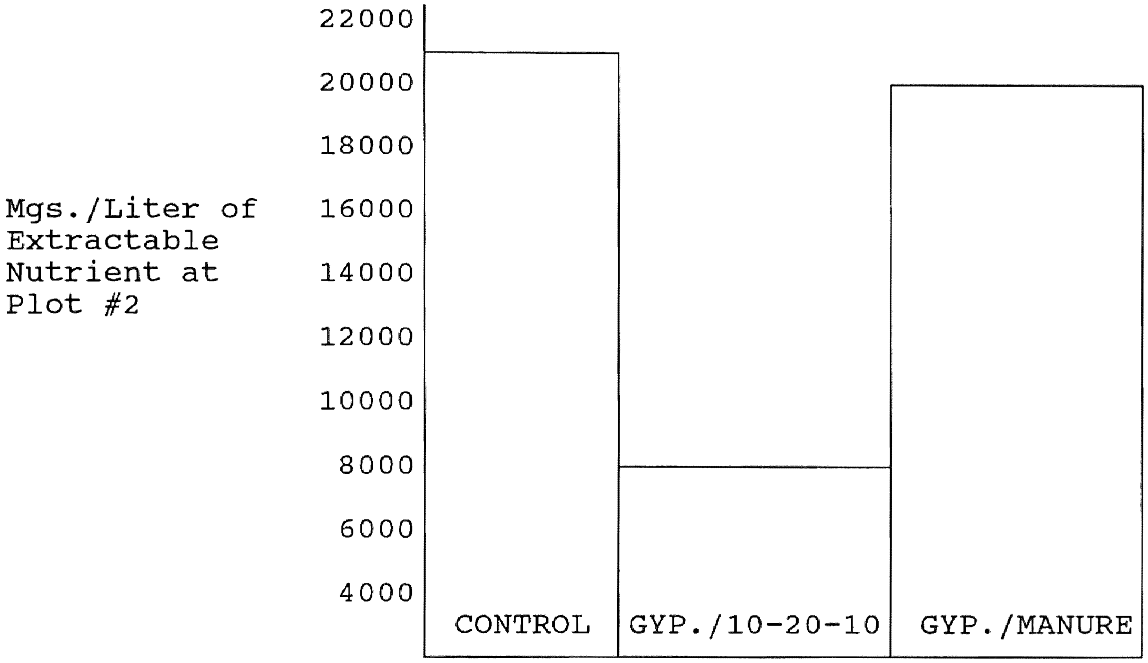

Figure 14. Mean Comparisons of Soluble Salts at All Three Sections of Plot #2

Some of the conditions considered unfavorable for plant establishment and growth on the salt affected soils included:

1) A inadequate supply of nutrients (unfertilized plots).

2) A deficiency of moisture at the soil surface.

3) A hard encrustation from the accumulation of salts, and loss of organic matter.

4) A below average amount of precipitation during germination.

Plant performance in relation to the salt affected soils was greatly enhanced by the addition of the cow manure on each plot studied. The plants showed a vast difference from a visual standpoint in: vigor, persistence, immediate germination and seed establishment,and resistance to further salt accumulation from further leaching by rain. The control and 10-20-10 plots had scattered and few plants because of the inability to germinate, plants which did not germinate quickly yellowed and withered making each plot barren of vegetation.

Barley as a potential salt tolerant grass for any reestablishment purposes demonstrated a great deal of positive qualities when used under adverse conditions. Any soil which comes in contact with negligible amounts of salt water has little potential for plant reestablishment, without the aid of nutrients and a healthy, vigorous plant with the persistence and ability shown by barley.

Specifically the addition of cow manure and gypsum to the barren areas could be considered an enhancement to plant and soil remediation because of nutrients are necessary to produce more plants. The visual appearance of the gypsum and manure plots portrayed one of a much more vigorous and tolerant establishment because of the number of plants, size, and coloration.

CHAPTER V

SUMMARY AND CONCLUSIONS

The environment encountered by plants in saltwater eradicated areas varies tremendously, from trees, shrubs, native grasses and forbs to aquatic plants in ponds and streams. Chemical, physical,and biological characteristics of the soil and climatic conditions of the particular area affect revegetation efforts.

The oil field areas of Carter County are derived from sandstone parent materials. The oil field area which was the site of this study has been subjected to operations since the 1920's.

Soil material collected for sampling purposes labelled as a "control" were extremely low in available phosphorous and medium in potassium. Available nitrogen was medium to low, and in general the saltwater eradicated areas had absolutely no visible sign of vegetative life or organic matter.

The cow manure and gypsum mixture exhibited a "very good" suitability factor for reclamation purposes, with available natural organic materials exhibiting a very quick soil rejuvenation after application. The phosphorous availability with the manure quickly germinated the seeds and got them off to a healthy start.

An advisable revegetation treatment for saltwater eradicated areas would be the incorporation of manure and gypsum into the soil and planting a salt resistant variety of vegetation.

Basic treatments for seed establishment include:

1) Preparation of a seedbed.
2) Dependant upon the area and its availability of living organic matter make additions of manures and gypsum suitable to the soil test results for each individual site.
3) Broadcast a salt resistant seed at a higher than normal seeding rate.
4) Lightly cover seeds with soil.
5) Arrange for protection of plants until seed establishment (terracing, adequate water, water diversion ditches, and any other feasible activity).

A SELECTED BIBLIOGRAPHY

(1) Amundson, R. G., and L. J. Lund. (1985). "Changes in the Chemical and Physical Properties of a Saline-Sodic Soil in the San Joaquin Valley of California." Soil Science Vol. 140, No.3, pp. 213-222.

(2) Bernstein, L., L. E. Francois. and R. A. Clark. (1974). "Interactive Effects of Salinity and Fertility on Yields of Grains and Vegetables." Agronomy Journal Vol. 66, pp. 412-421.

(3) Bossert, I., and R. Bartha. (1985). "Plant Growth in Soils With a History of Oily Sludge Disposal." Soil Science Vol. 140, No. 1, pp. 75-77.

(4) Brady, N. C. (1990). The Nature and Properties of Soils. New York: MacMillan Publishing Company.

(5) DeJong, E. (1982). "The Reclamation of Soil Contaminated with Sodium Chloride." Canada Journal of Soil Science Vol. 62, pp. 351-364.

(6) Elkins, N. Z., L. Parker, E. Aldon, and W. G. Whitford. (1984). "Responses of Soil Biota to Organic Amendments in Stripmine Spoils in Northwestern New Mexico." Journal of Environmental Quality Vol. 13, No. 2, pp. 215-219.

(7) Elshout, S. V., and A. Kamphorst. (1990). "Suitability of Coarse Grade Gypsum for Sodic Soil Reclamation: A Laboratory Experiment." Soil Science Vol. 149 No. 4, pp. 229-234.

(8) Guttay, J. R., R. L. Cook, and A. E. Erikson. (1956). "The Effect of Green and Stable Manure on the Yield of Crops and on the Physical Condition of a Tappan Parkhill Loam Soil." Soil Science Society Proceedings Vol. 20, pp. 526-528.

(9) Halvorsan, G. A., and K. Lang. (1990). "Revegetation of a Saltwater Blowout Site." Journal of Range Management Vol. 42, No. 1, pp. 61-65.

(10) Hira, G. S., M. S. Bajwa, and N. T. Singh. (1981). "Prediction of Water Requirement for Gypsum Dissolution in Sodic Soils." Soil Science Vol. 131, No. 6, pp. 353-358.

(11) Hoffman, G. J., and M. C. Shannon. (1986). "Relating Plant Performance and Soil Salinity." Reclamation and Revegetation Research Vol. 5, pp.211-225.

(12) Keller, E. A. (1988). Environmental Geology. Ohio: Merrill Publishing Company. 5th Edition.

(13) Maas, E. V. and G. J. Hoffman. (1977). "Crop Salt Tolerance-Current Assessment." Journal of Irrigation and Drainage Division, American Society of Civil Engineers Vol. 103, pp.115-133.

(14) McCalla, T. M. (1974). "Use of Animal Wastes as a Soil Amendment." Journal of Soil and Water Conservation Vol. 29, No. 5, pp. 213-216.

(15) Meek, B., L. Graham, and T. Donovan. (1982). "Long Term Effects of Manure on Soil NItrogen, Phosphorous, Pottasium, Sodium, Organic Matter, and Water Infiltration Rate." Soil Science Society of America Journal Vol. 46, pp. 1014-1019.

(16) Merril, S. D., K. Lang, and E. C. Doll. (1990). "Contamination of Soil with Oilfield Brine and Reclamation with Calcium Chloride." Soil Science Vol. 150, No. 1, pp. 469-475.

(17) Olsen, R. J., R. F. Hensler, and O. J. Attoe. (1970). "Effect of Manure Application, Aeration, and Soil pH on Soil Nitrogen Transformations and on Certain Soil Test Values." Soil Science Society of America Proceedings Vol. 34, pp. 222-224.

(18) Plice, M. J. (1949). "Some Effects of Saltwater on Soil Fertility." Soil Science Society of America Proceedings Vol. 42, pp. 782-786.

(19) Prather, R. J., J. O. Goertzen, and H. Frenkel. (1978). "Efficient Amendment Use in Sodic Soil Reclamation." Soil Science Society of America Journal Vol. 42, pp. 782-786.

(20) Sartori, G., G. A. Ferrari, and M. Pagliai. (1985). "Changes in Soil Porosity and Surface Shrinkage in a Remolded Saline Clay Soil Treated With Compost." Soil Science Vol. 139, No. 6, pp. 523-529.

(21) Schmerbauch, R. P. (1974). "Restoring Salt Damaged Soil." Society of Petroleum Engineers AIME SPE 4874.

(22) Scholl, D. G., and C. P. Pase. (1984). "Wheatgrass Response to Organic Amendments and Contour Furrowing on Coal Mine Spoil." Journal of Environmental Quality Vol. 13, No. 3, pp. 479-482.

(23) Senesi, N. (1989). "Composted Materials as Organic Fertilizers." The Science of the Total Environment Vol. 81, pp. 521-542.

(24) Tank, R. W. (1983). Environmental Geology. New York: Oxford University Press.

(25) United States Department of Agriculture. (1954). Diagnosis and Improvement of Saline and Alkaline Soils. Handbook No. 60.

(26) United States Department of Agriculture. (1979). Soil Survey of Carter County, Oklahoma.

(27) Vitosh, M. L., J. F. Davis, and B. D. Knezek. (1973). "Long Term Effects of Manure, Fertilizer, and Plow Depth on Chemical Properties of Soils and Nutrient Movement in a Monoculture Corn System." Journal of Environmental Quality Vol. 2, No. 2, pp. 296-299.

(28) Walters, R. S., and R. L. Auchmoody. (1989). "Vegetation Re-establishment on a Hardwood Forest Site Denuded by Brine." Landscape and Urban Planning Vol. 17, pp. 127-133.

APPENDIX

DESCRIPTION AND CHARACTERIZATION OF WEATHERFORD-WINDTHORST SOILS

WEATHERFORD SOILS

The dominant soils of this mapping unit typically have grayish brown to pale brown fine sandy loam in A horizons that are about 20 centimeters thick. Parent material of the soil is weathered sandstone, with the B horizon primarily sandy clay loam to patchy clay films, with the C horizon soft sandstone and sandy clay loam.

(Colors are for dry soil)

A	0-8"	Grayish brown (10 yr. 5/2) fine sandy loam, very dark grayish brown (10 yr. 3/2) moist; weak fine granular structure; hard very friable; slightly acid; clear very smooth boundary.
	6-8"	Pale brown (10 yr. 6/3) fine sandy loam, brown (10 yr. 6/3) fine sandy loam, brown (10 yr. 4/3) moist; weak fine granular structure; hard very friable.
B	8-50"	Yellowish red, reddish yellow sandy clay loam weak coarse prismatic structure parting to moderate and weak subangular blocky; very hard firm patchy clay that has gradular to films on faces of peds; medium acid; clear wavy boundary.
C	50-60"	Reddish yellow (7.5 yr. 6/6) and reddish brown soft sandstone; few thin interbedded layers of reddish yellow sandy clay loam;

slightly acid.

Type Location: Carter County, Oklahoma; About 17 miles west of Ardmore; 582 meters south and 122 meters east of the northwest corner of Section 22, T. 4 S., R. 2 W.

Range in Characteristics: All horizons are sandy clay loam or patchy clay films. Depth to sandstone is 102 to 152 centimeters. The A, or Ap horizon is pale brown, brown, light brownish gray, grayish brown, or reddish brown. The A2 has similar colors but includes very pale brown or yellowish brown. A horizon is medium acid to neutral.

The B2t horizon is reddish yellow, yellowish red, or red. Brownish or reddish mottles occurs in some pedons. The soil is neutral through strongly acid. The B3 horizon has colors similar to those of the B2t and has none to common brownish to reddish mottles. It is medium acid through neutral, less than 10% is fragments of sandstone that are less than 8 centimeters in diameter. Some pedons lack a B3 horizon.

The C horizon is weakly cemented sandstone.

Setting: Weatherford soils are on hillsides or ridgetops, with slopes very gentle to strongly sloping, and range from 1 to 12%.

Principal Associated Soils: The Weatherford soils are similar to Konsil, Konawa, and Stephenville soils, of which the Konsil and Konawa soils are more than 152 centimeters deep, and the Stephenville is 50 to 100 centimeters deep.

Drainage and Permeability: These are deep, well drained soils, moderately permeable, with eroded areas on ridgetops and hillsides.

Use and Vegetation: Briars, blackjack oak, and post oaks are the principal vegetation species along creek banks, with an understory of native grasses.

WINDTHORST SOILS

The typical soil color of the Windthorst soils are grayish brown to brown to reddish brown to yellowish brown, from a fine sandy loam to an extremely hard firm clay film on the faces of peds. Parent material of the soil is weathered mostly from clays or shaley clays under a cover of trees and native grasses. The A horizon is primarily fine sandy loam with the B horizon made up of distinct, hard firm clays, and the C horizon a sandy clay yellowish brown with softly gravelly sandstone fragments.

A 0-11" Grayish brown (10 yr. 5/2) fine to pale brown (10 yr. 3/2) sandy loam with a weak fine granular structure, slightly hard. Very friable, slightly to medium acid, with a clear to abrupt smooth border.

B 11-54" Reddish brown (5 yr.5/4) to light yellowish brown to brownish yellow medium blocky structure, extremely hard, patchy to distinct clay films on faces of peds with gravelly fragments, and mildly alkaline.

C 54-65" Brownish yellow (10 yr. 6/6) sandy clay with mottling medium distinct gray, extremely hard and firm, with

10% by volume of soft gravelly sandstone fragments, moderately alkaline.

Type Location: Carter County, Oklahoma; about 17 miles west of Ardmore; 667 meters south and 79 meters east of the northwest corner of Section 22, Tract 4 South, and Range 2 West.

Range in Characteristics: Horizons are fine sandy loam to medium acid clay to mildly alkaline clay with a few brownish yellow mottles.

A1 is grayish brown to A2 which is very pale brown.

B21t is 28 to 64 centimeters of reddish brown clay.

B22t is 64 to 86 centimeters of light yellowish brown clay with extremely hard firm clay.

B3t is 86 to 137 centimeters brownish yellow with distinct mottles of pale brown.

C is 137 to 165 centimeters of brownish yellow sandy clay with common medium to distinct gray mottles, and 10% by volume of soft gravelly sandstone fragments.

Setting: Very gently to moderately steep soils on uplands with slopes ranging from 1 to 20 per cent.

Principal Associated Soils: The Windthorst soils are associated with Darnell, Stephenville, and Weatherford soils, and are similar to Chigley soils which are gravelly and formed in Cherty conglomerates with interbedded layers of hard shale or sandstone.

Drainage and Permeability: Deep and moderately well drained.

Use and Vegetation: Tame pasture of native grass with blackjack oak, red oak, and willow trees along creek and pond banks.

VITA

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