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Gilbert C. Sigua

Louisiana State University and Agricultural & Mechanical College

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Sigua, Gilbert C., Ph.D.
The Louisiana State University and Agricultural and Mechanical Col., 1990
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SOIL- AND WATER-BASED MANAGEMENT STRATEGIES FOR REVEGETATION AND PRODUCTIVITY IMPROVEMENT OF BRACKISH MARSH SOIL

A Dissertation

Submitted to the Graduate Faculty of the Louisiana State University and Agricultural and Mechanical College in partial fulfillment of the requirements for the degree of Doctor of Philosophy in

The Department of Agronomy

by

Gilbert C. Sigua
B.S., Central Luzon State University, Philippines, 1978
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ABSTRACT

Laboratory, greenhouse, and field experiments were conducted on brackish marsh soil of Hackberry, LA. This study was aimed to obtain detailed information on some soil- and water-based management factors that were applicable to the revegetation and productivity improvement of the area. This area was inundated by brackish-saline water, and is now open water, almost totally void of vegetation.

The deteriorating productivity and continuous loss of vegetation in the study area can be related to the seasonal and temporal biochemical transformations. These transformations were significantly correlated to precipitation and minimum and maximum temperature in the area. Stochastic regression models were established to describe seasonal and temporal behavior of water and soil pH, electrical conductivity (EC), total dissolved solids (TDS), and ionic strength (IS) in brackish marsh.

The variability of individual soil properties in the study area as indicated by the coefficient of variations (CV) differed significantly (p=0.01). A uniform application of any soil amendments like fertilizer or gypsum in the area that possessed spatially variable soil would result in over application in some parts of the area and under application in others.

Soil drying significantly reduced urease activity in the area and was detrimental to the overall growth and yield of marsh vegetation. There was zero survival in the unflooded plots except that marsh hay cordgrass had survival rate of 32.8%.

The four species of marsh vegetation: Spartina patens Muhl. (marsh hay cordgrass), Distichlis spicata L. (salt grass), Paspalum vaginatum SW.
(joint grass), and *Scirpus americanus* Pers. (freshwater three-square) responded significantly to N and gypsum (G) applications. Their overall yield response was described as $\text{DMY} = 2.68 + 1.62N - 0.98N^2 + 0.37N^3 - 0.73G + 0.62G^2$. Plots receiving 7 Mg gypsum ha$^{-1}$ produced significantly more Dry matter yield than did the control. This treatment increased the DMY of joint grass (5.04 to 8.08 Mg ha$^{-1}$), marsh hay cordgrass (1.90 to 6.91 Mg ha$^{-1}$), salt grass (0.97 to 2.79 Mg ha$^{-1}$), and three-square (1.55 to 2.84 Mg ha$^{-1}$) in flooded plots. Significantly higher survival rates of plants were observed in flooded plots treated with gypsum than in the plots without gypsum or flooding.
INTRODUCTION

The coastal wetlands of Louisiana (LA) constitute 40 percent of all United States (U.S.) coastal wetlands and support a major portion of the U.S. fishing, hunting, and trapping industries. These coastal wetlands are reported to be among the most productive seafood grounds in the nation (Ho and Jane, 1973) and America's largest wetland community, is losing its marshes and swamps to the Gulf of Mexico at a rate of 167 km² per year (LA DNR, 1986). Saltwater damage and subsidence have caused most of this area to revert to open water, void of vegetation.

Aerial photographs of the marshes located in Hackberry, Cameron Parish, LA., covering the period between 1940 and 1983 provide a dramatic illustration of the changes that have occurred in this area. The 1940 photographs show the area to have a percentage ratio of emergent vegetation to open water of 99.0:1.0; 11.2:88.8 in 1968; 5.9:94.1 in 1978; and 1.8:98.2 in 1983 (Soil Survey Staff, 1985). The loss of the remaining vegetation will continue under present conditions. This will have a long-term detrimental effect on the productivity of associated fisheries, waterfowl, and other wildlife. The increased land use pressures on these areas have forced scientists to investigate them much more intensely. The nature and properties of soils of shoreland marshes and wetlands must be thoroughly understood before any rational decision can be made concerning their management and preservation. Marsh management is costly and the benefits gained depend on the amount of money invested and skill with which the program is planned. In planning a marsh management project, several factors should be carefully considered. One of the factors involved is to obtain detailed information on area environmental
conditions, such as water quality, water level fluctuation, soil characteristics, and climatic factors (Chabreck, 1988). Knowledge of these factors can be utilized to develop management strategies that are applicable to the revegetation and productivity improvement of brackish marsh.

Marshes, as part of our land and water regimes, are irreplaceable natural resources that must be preserved. One of the possible solutions for saving wetland from natural and accelerated losses is through restoration with suitable vegetation. Restoration of suitable vegetation usually requires some elaborate management practices that include water management, fertilization, chemical amelioration, and various other cultural practices. Irrigation methods and drainage practices could provide uniformity of application and downward movement of water through the soils which favor salinity control. Reclamation of soils that have been subjected to sea-water inundation is an agricultural problem of considerable economic importance that must be given a great deal of attention by soil and plant scientists. The problem is particularly more serious when it occurs on soils frequently inundated by sea-water in humid regions because of the lack of soluble Ca for replacing exchangeable Na.

Reclamation of soils in the southwest section of LA that have been subjected to sea-water inundation requires soluble Ca or gypsum application for replacing exchangeable Na and careful management combined with sound cultural practices for several years to reestablish the favorable physical and chemical status of the soil (Berg, 1950; Richards, 1954). Plant nutrients that are leached from the soil must be replaced. Fertilizer application following leaching should compensate for plant
nutrient losses, especially N. Early reports published elsewhere (Broome et al., 1975; Patrick and DeLaune, 1976; Mendellsson, 1979; Smart and Barko, 1980) indicated that marsh was most limited in N.

This study was proposed to obtain detailed information on some soil-and water-based management factors that were applicable to the revegetation and productivity improvement of brackish marsh in Hackberry, LA. This area was inundated by brackish-saline water, and is now open water. A comprehensive evaluation of plant-soil-water relationships designed to provide information on plant survival, plant-site relationships, and establishment of management techniques to improve plant adaptability in the brackish environment comprised the core of this investigation.

The specific objectives of this study were: 1) to determine the quantity, distribution, and spatial variability of some selected physicochemical properties of brackish marsh soil; 2) to compare and evaluate some chemical properties of water in the canal and marsh; 3) to determine the effect of gypsum addition on the seasonal variability of some selected properties of brackish marsh soils; 4) to determine the effect of soil drying, gypsum addition, and electrical conductivity on some soil properties that are related to urease activity; 5) to determine the influence of gypsum and N on plant survival and adaptability in brackish marsh soils; and 6) to determine the effect of gypsum and water management on the survival, yield, and protein content of selected species of marsh vegetation.
REVIEW OF LITERATURE


A. General Setting and Formation:

Marsh soils may be defined as soils that are more or less permanently saturated or submerged. This early definition was rather vague and broad. In 1966, Coleman advanced a more specific definition of marsh soils. He described them as regions bordered by a broad, flat coastal plain, and gently sloping continental offshore shelf. Marshes are formed along the shoreline when sediment deposited by rivers or sea that accrete from the sea bottom to elevations suitable for plant growth.

Marshes of the Chenier Plain of southwestern LA and southeastern Texas (TX) were developed from Mississippi River sediment discharged into the Gulf of Mexico. Later, sediments carried westward were deposited along the shoreline by Gulf currents, waves, and tides (Gould and McFarlan, 1959). The inland intrusion of sea water and seaward movement of freshwater govern the distribution of marsh plants and the boundaries of marsh types: salt, brackish, intermediate, and fresh occurring in bands paralleling the shoreline (Chabreck, 1988). Joffe (1949) also described freshwater marsh soils as occurring on the fringes of lakes and the networks of streams that feed them. Saltwater marshes are found in estuaries, deltas, and tidal flats. The outstanding features of these soils are the accumulation of plant residues in the surface horizon and the presence of a permanently reduced horizon below it (Pons and Van der Kevie, 1965).
B. Physical, Chemical, and Electrochemical Properties:

1. Physical and Mineralogical Properties

Chabreck (1988) described marsh soils as having mineral and organic components. He stressed that the amount of each varies with location, age of the marsh, and the environmental conditions prevailing in the area. The mineral component of marsh soils consists of silt and clay particles. Mineral soils with different particle size classes in different areas of marsh reflect the distributional pattern of marsh streams. Large soil particles are the first to settle out. As velocities continue to decrease, smaller particles settle to the bottom. Deposition of fine particles is enhanced by dense stands of marsh vegetation, which function to reduce water velocity and trap the sediment. Hudnall (1983) concluded that the sand content in the coastal wetland soils of Cameron Parish had generally increased along the major tributaries and decreased away from the natural levees. Freedman and Gavish (1970) reported that despite the heterogeneity of the coastal sediments, all soil samples were largely composed of "mud fraction". This later was described as muddy and silty sands or sandy and silty muds (Freedman and Gavish, 1970).

The mineralogy of the mineral and organic fractions of the coastal wetland soils in LA are dominated by smectite, with greater quantities of kaolinite in the soils that border the Calcasieu and Sabine Rivers. The increased kaolinitic concentrations was the result of local overflowing of sediments derived from the predominantly kaolinitic Coastal Plain soils within LA (Hudnall, 1983). Gibbs (1977) reported that samples taken from the mouth of the Amazon River had 27 to 40% montmorillonite while kaolinite ranged from 32 to 36%. Similar results on mineralogical
properties of the sediments of the Dublin River and its marsh soils were reported by Pomeroy and Imberger (1981).

Coultas (1980) found that Sulfihemists marshes predominated the delta of the Apalachicola River while Sulfaquents and Fluvaquents were found in the eastern portion of the estuary. Montmorillonite and mica were the dominant minerals of the clay-sand fraction. Coultas and Calhoun (1976) also found Psammaquents, Sulfihemists, and Sulfaquents in tidal marshes of Hernando (Gulf Coast) and Duval (Atlantic Coast) counties in Florida. Soil clays of the former were primarily montmorillonitic, micaceous, and kaolinitic. The soil clays of the latter were mostly vermiculite-chlorite and kaolinite-metahalloysite integrades.

2. Chemical Properties

The acidity of coastal marsh varies considerably as shown by early data reported elsewhere. Studies of Palmisano and Chabreck (1972) disclosed a pH ranging from 3 to 8. They reported that the soil acidity and the oxidation-reduction (redox) potentials are greatly affected by alternate drying and flooding of the marshes. Soil acidity is greater in organic soil than mineral soil. Brackish mucks with high levels of $SO_4^{2-}$ are usually the most acid. Ponnamperuma (1972) claimed that certain soil chemical properties markedly influence the pattern of pH change. The pH-buffering action of submerged soils is due to Fe and Mn redox system and $H_2CO_3$. If an acid soil is low in reducible Fe and has a high organic matter content, the pH may not attain a neutral value even after several weeks of submergence. The increased pH of acid soils after submergence depends not only on the release of $OH^-$ ions and consumption of $H^+$, but also on the ratio of $H^+$ consumed to electrons consumed (Bostrom, 1967). Moreover,
Ponnamperruma et al. (1966) reported that the decrease in pH of alkaline soils following submergence may be explained by several chemical and biological changes. Microbial decomposition of organic matter produces CO₂, which reacts with H₂O to form H₂CO₃, and later dissociates into H⁺ + HCO₃⁻ ions. The decreased in pH of alkali and calcareous soils upon submergence can be attributed to Na₂CO₃·H₂O·CO₂ and CaCO₃·H₂O·CO₂ systems, respectively.

The work of Brupbacher et al. (1973) on chemical properties of the soil materials from the coastal marshlands of LA showed that the concentration of water soluble Na, Mg, Ca, and K increased from fresh to salt water areas. The soil materials contained relatively high amounts of Cl⁻ and SO₄²⁻ with lesser amount of HCO₃⁻. The concentration of Cl⁻ and SO₄²⁻ increased from fresh to salt water areas. Soil reaction of the samples ranged from 3.7 to 7.5. Coultas and Calhoun (1976) reported that Psammaquents, Sulfihemists, and Sulfaquents in the tidal marshes of Florida were saline and neutral in pH except for Psammaquents that contained higher levels of S. A near neutral pH (7.4 to 7.8) for brackish marsh in LA was reported by Hudnall (1983).

Suerdrup et al. (1942) reported that seawater is rich in Na, K, and Mg. Sodium chloride is the major salt in seawater and contributes to the abundance of Na ions in salt marsh. Calcium is also abundant in seawater, but generally is higher in fresh marsh than in salt marsh (Palmisano, 1970). Calcium is higher in peat than in muck and clay soils, and much of this element is found in plant residues. Whitney et al. (1981) found that the amount of P in marshes is less than other nutrients, often held in dead plant tissue. This element is more abundant in salt marsh than fresh marsh. The work of Hudnall (1983) showed that in the brackish marsh, Mg
concentration was greater than or equal to the Na concentration which was greater than the Ca and K concentrations. He also reported that the salinity level in the fresh and brackish marshes ranged from 2.5 to 3.5 and 10 to 17 dS m\(^{-1}\), respectively.

DeLaune et al. (1976) reported that the marsh soils of LA contained 7,850 kg ha\(^{-1}\) of N in the *Spartina* root zone, and was mainly organic N. Approximately 250 kg ha\(^{-1}\) yr\(^{-1}\) of the soil organic N was mineralized to inorganic N, and is available to plants. The concentration of exchangeable Fe\(^{2+}\) in the streamside area of Barataria Bay was markedly higher than in the inland area. The former had a Fe\(^{2+}\) concentration ranging from 300 to 500 ug g\(^{-1}\) while the latter had 50 to 100 ug g\(^{-1}\). The extractable Mn levels of organic marsh soils were extremely low compared to those of mineral soils. Levels during the year ranged from a maximum of 5.3 ug g\(^{-1}\) in the streamside area to a maximum of 0.63 ug g\(^{-1}\) in the inland area. The levels of total S\(^{2-}\) (FeS, H\(_2\)S, etc) ranged seasonally between 100 and 500 ug g\(^{-1}\) for both streamside and inland areas of Barataria Bay. The levels of total S\(^{2-}\) at both locations were the same when considered on a dry weight basis. The extracted P of Barataria marsh soils ranged between 20 and 35 ug g\(^{-1}\) on a dry weight basis. On a volume basis, only 10.6 g m\(^{-3}\) and 4.8 g m\(^{-3}\) extractable P was found in streamside and inland areas, respectively. They reported further that no significant seasonal variation existed in the levels of extractable K in the sediments of the streamside and inland areas of Barataria Bay with the mean ranging from 1820 to 2140 ug g\(^{-1}\).

Aurand and Daiber (1973) studied the distribution of \(\text{NO}_3^-\) and \(\text{NO}_2^-\) in two Delaware salt marshes from July, 1966 through December, 1967. They
reported that Canary Creek Marsh located near the mouth of Delaware Bay, was characterized by high salinity and low level of NO$_3^-$ in the water. The Murderkill Marsh in central Delaware was characterized by low salinity and high NO$_3^-$ levels in the water. Summer NO$_3^-$ concentrations in the Canary Creek Marsh ranged from 2 ug L$^{-1}$ to 8 ug L$^{-1}$. Winter values were between 10 and 25 ug L$^{-1}$. At Murderkill Marsh, winter NO$_3^-$ concentrations ranged from 40 to 100 ug L$^{-1}$. The summer concentrations were generally in the range of 5 to 20 ug L$^{-1}$. Ho (1971) from her work on the seasonal changes in sediments and water chemistry in Barataria Bay (Airplane Lake, John the Fool Bayou and Lake Palourde) reported the seasonal variation in organic and S$^{2-}$ (6 N HCl decomposable) contents in sediments. The fresh water-dominated bayou sediment contained an average of 24% organic C whereas the southern areas had an average of less than 6%. Sulfide content was directly related to organic content, ranging from an average of 467 mg FeS 100 g$^{-1}$ in the bayou to 208 mg FeS 100 g$^{-1}$ in Airplane Lake and 51 mg FeS 100 g$^{-1}$ in Lake Palourde sediments. Salinity varied from 3 to 12% in the bayou and from 16 to 28% in the southern areas, depending on rainfall and direction of water interchange.

In 1979, DeLaune et al. reported that the percentage of organic C in LA marsh was 6 to 16% on a weight basis. Aerial standing crop was positively correlated with soil density, but negatively associated with soil C content and C/N ratio. According to Reimold (1972), Spartina alterniflora can serve as a nutrient pump and translocate measurable quantities of P from the salt marsh sediments to the leaves. With tidal inundation, an average of 9.84 mg P m$^{-2}$ was released in the marsh waters during each tidal cycle. His seasonal data indicate that the flux of P was
closely associated with the productivity of the plant material in the marsh.

3. Electrochemical Properties

Ponnamperuma (1972) showed that submerging a soil could bring about a variety of electrochemical changes. These include: a) a decrease in redox potentials, b) changes in specific conductance and ionic strength, c) drastic shifts in mineral equilibrium, d) cation and anion exchange reaction, and e) sorption and desorption of ions. One of the most important soil physicochemical parameters used to characterize submerged soils is redox potentials. Submerged soils are characterized by negative redox potentials. Aerated soils have characteristics redox potentials in the range of +0.4 to +0.7 V while waterlogged soils exhibit potentials as low as −0.2 to −0.3 V (Ponnamperuma, 1972; Patrick and Reddy, 1978). The chemical changes are initiated by the biological redox processes that result from oxygen depletion. Changes in redox potential and pH are brought about by flooding. The oxidized forms of several redox systems serve as electron acceptors in microbial respiration. They undergo sequential reductions resulting in the reduction of O₂ to H₂O, NO₃⁻ to N₂, Mn⁴⁺ to Mn²⁺, Fe³⁺ to Fe²⁺, SO₄²⁻ to S⁻², CO₂ to CH₄, and H⁺ to H₂ gas (Patrick and Reddy, 1976). According to Montimer (1941), the critical potential for reduction of the soil-water interface is 0.2V. Lake and ocean muds have potentials of 0.3 to −0.3V, with occasional plunges to −0.4V (Bass–Becking et al., 1960).

Other important electrochemical changes associated with soil flooding and submergence are the changes in the specific conductance and ionic strength of soil solutions. Adams (1971) proposed the concept of
ionic strength as the foundation of electrolytic chemistry because it provides the means for calculating ionic activities. The ionic strength, $\mu$, of an electrolytic solution is a measure of the intensity of the electrical field in the solution and is defined as

$$\mu = 1/2 \sum (C_i Z_i^2)$$  \[1\]

where $C_i$ is the actual molar concentration of each ion in the solution and $Z_i$ is its valence. Ponnamperuma (1972) found that the specific conductance of the solution of most soil increases after submergence, attains a maximum, and declines to a fairly stable value that varies with the soil. The changes in conductance reflect the balance between reactions that produce ions and those that inactivate them or replace them with slower reacting ions. Ponnamperuma et al. (1966) developed a relationship between specific conductance ($k$) and ionic strength ($I$) described as:

$$I = 0.001 + 15.90k + 25.89k^2$$  \[2\]

where $k = \text{mmho cm}^{-1} \times 10^3$. Sato and Yamane (1973) also reported a similar relationship:

$$I = 19.6 - 13.6k$$  \[3\]

Ionic strength increases with the addition of increasing amount of sodium chloride to a submerged soil. Ponnamperuma (1972) proposed that the increase in cation concentrations in the aqueous phase may be attributed to displacement of cations from soil colloids by Na$^+$. The presence of extra electrolytes made a significant reduction in soil pH. Sato and Yamane (1973) formulated an equation to describe the relationship of specific conductance to the sum of cations. They found a relationship of specific conductance to the sum of cations ($R = 0.98$) and to the sum of anions ($R = 0.93$). They stressed that the sum of cations was far larger than sum of
anions. The equation that described the sum of cations was:

\[ Y = -3.76 + 2.31X \]

where \( Y \) is the specific conductance and \( X \) is the concentration of cations in soil solution.

II. Calcium:Sodium Interactions in the Soils and Plants.

A. Plant Responses:

Calcium ions play a crucial role in the regulation of the salt economy of the plants. It has an important function in the selective transport or exclusion of Na and other mineral ions by plant cell membranes (Hanson, 1960). Calcium also maintains the integrity of plant cell membranes that prevents the free diffusion of potentially toxic ions prevalent in saline environment (Rains, 1972 as cited by Ayoub, 1974). In 1974, Ayoub studied the efficiency of Ca in enhancing the tolerance of plants to Na. He found that the dry matter yield was positively correlated with increased Ca application. These yield parameters were negatively correlated with the Na content of irrigation water and plant tissue. The Na levels in both roots and tops declined significantly as levels of Ca added were increased. Calcium in the range of 2.0 to 8.0 mM L\(^{-1}\) caused competitive inhibition of Na uptake and Na translocation.

LaHaye and Epstein (1969) observed that plants exposed to 1 mM NaCl suffered great damage. At higher concentrations of gypsum, the plants grew well. They also observed that the Na concentration in the roots dropped by about one-third as gypsum concentration in the solution was increased from 0.1 to 10 mM. The Na concentration in the leaves decreased from 3.2 to 0.2 mg per 100 mg when the concentration of gypsum was increased from 0.1 mM to 3 mM. Their results show the efficacy of Ca in protecting plant
species against the deleterious effects of NaCl.

Ratner (1944) presented data to show that a given level of absorbed Ca in the soil is less exchangeable in the presence of adsorbed Na than when H, Mg, and K are the complementary adsorbed cations. His evidences indicated that the energy of Ca retention in soil colloids was sufficiently high in the presence of a relatively high level of adsorbed Na which prevented the Ca uptake by the plants, resulting in plant tissue death because of Ca starvation. One of the possible causes of poor plant growth on soils highly saturated with exchangeable Na is the inability of the plant to obtain an adequate supply of Ca (Ratner, 1935; Bower and Turk, 1946).

B. Calcium:Sodium Exchange In The Soil:

The deleterious effects of excess Na on soil structure and on plant growth have led to numerous studies on removal of Na from soils, usually by replacement with Ca. The emphasis in the reclamation of alkali soils is usually on reducing the Na to less than 15% of the exchange capacity (Chaudhry and Warkentin, 1968). Theoretical analyses have been applied to the displacement process to predict the final distribution of cations after exchange in soil columns (Bower et al., 1957; Dutt, 1964). Chaudhry and Warkentin (1968) reported that the curves for replacement of exchangeable Na by gypsum show rapid and efficient result until Na is less than 15% of the exchange capacity.

Bower (1959) proposed that a satisfactory expression of cation-exchange equilibrium was of considerable value in the study of soils affected by Na salts. The U. S. Salinity Laboratory Staff (1954) adopted an equation similar to that proposed by Gapon (1933) for relating the
ratio of adsorbed Na\textsuperscript+ to the Na\textsuperscript+ and Ca\textsuperscript{2+} + Mg\textsuperscript{2+} concentrations of an equilibrium water extract. Gapon's equation for the Na–Ca exchange was:

\[
\frac{\text{Na}_{\text{adsorbed}}}{\text{Ca}_{\text{adsorbed}}} = k \times \frac{[\text{Na}^+]/(\text{Ca}/2)^{1/2}}
\]

Bolt (1955) described the exchange equilibrium of Na and Ca on illite-rich soil by the following equation:

\[
\frac{D_1}{D} = \frac{(r/DB^{1/2})(\sinh^{-1})(DB^{1/2}/r + 4V_cD_1^{1/2})}{D_1/D}
\]

where \(D\) is the surface charge density of the medium in meq per sq cm, \(D_1/D\) is the fraction of the surface charge that is neutralized by the sum of the excess monovalent cations and the deficit of the monovalent anions near the surface, \(r = c_1/c_2^{1/2}\) where \(c_1\) and \(c_2\) are the bulk concentrations of the monovalent and divalent cations, respectively, \(B = 1.06 \times 10^{15}\) cm mmol\(^{-1}\) @ 25°C and \(V_c = 1\). Sheta et al. (1981) conducted a Na–Ca exchange measurements on 11 representative soils from the Nile Delta. Their experimental data were described either by a single Vanselow selectivity coefficient or by single Gaines–Thomas coefficient. The Vanselow's coefficient (Vanselow, 1932) was described as:

\[
K_v = X_{\text{Ca}}^* (\text{Na}^+)^2 / X_{\text{Na}}^* (\text{Ca}^{2+})
\]

The Gaines–Thomas coefficient (Gaines and Thomas, 1953):

\[
K_c = E_{\text{Ca}}^* (\text{Na}^+)^2 / E_{\text{Na}}^* (\text{Ca}^{2+})
\]

where \(X^*\) and \(E^*\) are the molar and equivalent fraction of cations in the exchange phase, respectively. Sheta et al (1981) concluded that the Vanselow coefficient, \(K_v\), and the Gaines–Thomas coefficient, \(K_c\), provided a simple equation of the Na–Ca exchange properties for the Nile Delta soils.

Levy and Hillel (1968) proposed that the exchange between ions was usually represented by their exchange isotherm, where quantities in
solution and on the soil complex were expressed as equivalent fractions. The thermodynamic equilibrium constant of Na-Ca exchange isotherms is:

\[ Ca_{soil} + 2NaCl \rightarrow Na_{2soil} + CaCl_2 \]  

[9]

and is represented by the equation:

\[ K = \frac{(MNa)^2 \cdot (CaCl_2)}{(MCa) \cdot (NaCl)^2} \]  

[10]

where all quantities are expressed as activities in solution, \( M \) was on molarity scale and as mole fractions:

\[ MNa = \frac{Na}{CEC} \]  

[11]

and

\[ MCa = \frac{Ca}{CEC} \]  

[12]

Babcock and Schulz (1963) also represented an exchange reaction for Na-Ca as:

\[ Ca^{2+}_{ad} + 2Na^+ \leftrightarrow 2Na^+_{ad} + Ca^{2+} \]  

[13]

Using thermodynamic methods, an equilibrium constant for the exchange reaction was written using the exchange reaction of Babcock (1963),

\[ \left(\frac{[Ca^{2+}]}{[Na^+]^2}\right) \left(\frac{[Na^+]^2}{[Ca^{2+}]_{ad}}\right) = K \]  

[14]

where \( K \) is the equilibrium constant and the brackets denote ionic activities.

Nakayama (1971) found that the solubility of gypsum (CaSO\(_4\).2H\(_2\)O), increased with increasing electrolyte concentration in a solution. Among Na salts having the same concentration, the order of solubility for CaSO\(_4\).2H\(_2\)O was: NaOAc > NaN\(_3\) > NaCl > NaClO\(_4\). The dissociation constants of 0.0575 for CaOAc\(^+\) and 0.526 for CaNO\(_3\)\(^+\) explained the solubility of gypsum in NaOAc and NaN\(_3\). Oster and Nalvorson (1978) indicated that the solubility of gypsum could be enhanced if the amendment was mixed with the soil. Upon mixing in the soil, gypsum reacts as follows:
\[
\text{CaSO}_4 \cdot 2\text{H}_2\text{O}_{\text{solid}} + \text{H}_2\text{O} \longrightarrow \text{Ca}^{2+} + \text{SO}_4^{2-} + 2\text{H}_2\text{O} \quad [15]
\]

\[
\text{Ca}^{2+} + 2\text{Na}_{(ex)} \leftrightarrow \text{Ca}_{(ex)} + 2\text{Na}^+ \quad [16]
\]

where \(\text{(ex)}\) represents the soil exchange complex. The soil exchange acts as a sink for \(\text{Ca}^{2+}\) until both reactions reach equilibrium. Hira and Singh (1980) claimed that the rate of gypsum dissolution depended upon: a) the activity of \(\text{Ca}^{2+}\) in solution which was governed by the exchangeable \(\text{Na}^+\) fraction, b) the size of the gypsum particles, and c) the rate of \(\text{Ca}^{2+}\) diffusion to the exchange site and the rate of \(\text{Na}\) diffusion away from the exchange site. The exchangeable \(\text{Na}^+\) acts as a sink for \(\text{Ca}^{2+}\) and lowers the activity of \(\text{Ca}^{2+}-\text{Na}^+\) exchange. The mobilization of solid phase gypsum was further enhanced during leaching due to the removal of the solution phase of \(\text{Na}^+\) from the site of exchange reaction. Oster and Frenkel (1980) also found that the effective solubility of gypsum was increased when mixed with sodic soil because the exchange phase acted as a sink for \(\text{Ca}^{2+}\) until both the gypsum dissolution and exchange reaction reach equilibrium. The amount of gypsum dissolved, expressed in moles of charge, was a linear function of the moles of the exchangeable \(\text{Na}^+\) replaced; \(R^2\) values typically exceeded 0.98. The slope of the regression line decreased with increasing final exchangeable \(\text{Na}^+\) (\(E_{\text{Na}}\)). Typical values of 1.40, 1.27, and 1.20 moles of charge gypsum dissolved per mole of exchangeable sodium replaced at final \(E_{\text{Na}}\)'s of 0.05, 0.10, and 0.15 were reported. Other researchers (Dutt et al., 1972; Tanji et al., 1972; Melamed et al., 1977) have described gypsum dissolution and Ca–Na exchange by a first-order rate equation in combination with the convective dispersion equation.
III. **Interrelationship of Salt Concentration and Soil Moisture to Plant Responses.**

**A. Growth and Yield Responses**

Salinity exerts a variety of effects on plant development and yield. The effect depends on several factors: a) nature of crops, b) differential tolerance to salinity during the various stages of development, and c) other related or interacting factors as soil moisture and salt concentration (Bernstein and Hayward, 1958). Ayoub et al. (1943) claimed that many factors undoubtedly play important roles in the effect of salts upon growth of plants. Special consideration should also be given to moisture stress within plants and the soil-root relationships affecting these stresses. These relationships are summarized in: a) increase work necessary to obtain water from the soil as the soil moisture tension increases, b) increased work necessary to obtain water from the soil solution as the osmotic concentration of the soil solution is increased, and c) the inability of the plant to produce new roots. Each of these factors may be affected directly or indirectly by the frequency of irrigation and may have a bearing upon irrigation practices in saline soils. There is much evidence to indicate that an increase in the osmotic pressure of the soil solution may result in a decrease in the water uptake by plant roots. Soil moisture tension increases as the soil becomes drier and the water films around the soil particles become thinner. This equivalent negative pressure is apparently additive to the osmotic pressure of the soil solution and limits the availability of water to plant roots. Ayoub (1943) termed the sum of soil moisture tension and the osmotic pressure of the soil solution as "total soil moisture stress".
Growth-moisture-salinity studies indicate that plant growth was a function of total soil moisture stress, regardless of whether this stress arises primarily from salinity or moisture tension (Magistad et al., 1943; Wadleigh and Ayers, 1945; Richard, 1954).

Plant roots absorb more water from dilute solutions than from concentrated solutions. More work was required to remove a gram of water from a concentrated solution. Plants growing in saline soils must then do more work to obtain a given amount of water than plants growing in a less concentrated soil solution (Eaton, 1941). Changes in the leaf area were found to be very sensitive to the changes in the salinity regime. The work of Lagerwerff and Eagle (1962) and Lunin (1965) have shown that transpiration expressed on a unit leaf area also decreased with increased salinity. The rate of water absorption by plant roots was conditioned to some degree by the osmotic concentration of the substrate as well as by the leaf surface area. The total leaf area and the number of leaves developing on a plant under saline conditions, were usually smaller than those on the control plants (Meiri and Mayber, 1970).

The increased levels of exchangeable Na result in decreased growth. Increasing levels of exchangeable Na in the soil were associated with increasing concentration of Na in the soil solution (Pearson and Berstein, 1958; Lunin et al., 1963). The progressive decrease in growth with increasing osmotic pressure of the external solution can be explained in terms of classical osmotic theory (Berstein and Hayward, 1958). Decreased cell growth was the most sensitive response of the plant to water stress, since cell growth was related to cell turgor and water potentials (Sands and Correl, 1976). The loss of cell turgor accompanied by stomatal closure
decreased photosynthesis. Complete stomatal closure lowered the actual rate of photosynthesis and respiration to zero (Sheikholes and Currier, 1977). Physiological changes resulting from long periods of stomatal closure and consequent starvation may predispose plants to infection, leading to dieback and decline (Tobiessen and Buchsbaum, 1976).

Yaron et al. (1972) formulated an estimation procedure for the response functions of crops to soil water content and salinity. Their model is described below as:

\[ Y = f(Q, X, S_0, K) \]  

where \( Y \) is the crop yield per unit area of the land, \( Q \) is the quantity of water applied per unit area of land, \( X \) is the measure of the salt concentration in the irrigation water, \( S_0 \) is the index of the initial salt concentration in soil solution, and \( K \) designates all other factors assumed constant for a given plant, soil, and climate. Equation 17 expresses crop yield as a function of man-controlled variables, \( Q \) and \( X \), and therefore have interest for economic analysis. However, it is convenient to analyze the functional relationship of equation 17 in two stages: a) the effect of \( Q \) and \( X \) on the water content of the soil and salinity of the soil solution, and b) the effect of the soil water content and the salinity of the soil solution on crop yield. The general functional form of the first relationship was described below as:

\[ S = g_1 (Q_1, X_1, S_0, K) \]  

\[ W = g_2 (Q, K) \]  

and the second relationship as

\[ Y = h' (W, S, K) \]  

where \( S \) is the index of the salt concentration in soil solution during the
crop growing season and \( W \) is the index of the water content of the soil during the crop growing season.

**B. Plant Uptake and Nutrient Composition**

The main cause of NaCl-induced growth inhibition was the difficulty in uptake of mineral nutrient due to competition with \( \text{Na}^+ \) (Solovev, 1969). He observed a \( \text{K}^+ \) deficiency in the lower parts of pumpkin and sweet clover plants subject to NaCl salinization. Nimbalkar and Joshi (1975) observed a two-fold effect of \( \text{Na}^+ \) on \( \text{K}^+ \) uptake. At low concentrations, \( \text{Na}^+ \) may actually increase \( \text{K}^+ \) uptake and decrease it at higher concentrations in the case of sugar cane and rice (Paricha et al., 1975). Calcium uptake and plant growth were also decreased at high \( \text{Na}^+ \) concentrations in both of these plants as well as in wheat (Poonia et al., 1972). Similarly, in spinach and lettuce, Na salts decreased dry matter production and leaf content of K, Mg, and Ca (Matar et al., 1975). Austenfeld (1974) also observed a decrease in the uptake of K, Mg, and Ca in *Salicornia europa*, though this plant is a halophyte. In Rhodesgrass, there was a progressive decrease in the amount of \( \text{K}^+ \) required for maximum growth as the level of Na salt application increased (Smith, 1974). Salinization impaired both growth and \( \text{N} \) uptake of young barley (Helal et al., 1975). In the halophyte, *Salicornia europa*, Austenfeld (1974) did not observe a significant effect of NaCl on growth and \( \text{NO}_3^- \) absorption.

Batchelder et al. (1963) have shown that plant composition represented the resultant of the interactive effects of the various cations and different concentrations. In a soil salinized with seawater, Na becomes a dominant cation. The increased uptake of this element by the plant with increasing level of salinization becomes the most consistent
relationship. Ayoub (1975) observed that plants growing on soils contained high amounts of K and Mg, especially in their leaves. In plants growing on saline soils, major changes in the proportion of the various cations occurred in different plant parts. Excessive amounts of Na and Ca were accumulated in the leaves, while the amount of K and Mg tended to decrease in the leaves. Gauch and Wadleigh (1951) reported that the content of K in Dallisgrass from the control cultures was much higher than that from the salinized cultures. The presence of any Na salts nearly doubled the concentration of Na in Rhodesgrass over that of the control plants. Bower and Wadleigh (1948) found a pronounced accumulation of Na in the roots of Dallisgrass and tops of Rhodesgrass. In 1968, Greenway observed increased Cl⁻ and Na⁺ as NaCl in the medium increased.

Ratner (1958) as cited by Bernstein and Hayward (1958) studied the influence of transpiration on the absorption of minerals by plants grown on saline soils and reported that high transpiration rates of plants grown on saline soil was damaging because of increased salt absorption. High transpiration simply increases the moisture deficit in the plants, thereby impairing growth. The increasing levels of exchangeable Na in the soil resulted in decreased absorption of Ca.

Waisel (1972) reviewed several aspects of the physiological ecology of marsh halophytes. He stressed the roles of salinity and aeration of the substrate as the two most important factors affecting species distribution in salt marshes. Reduced yield on the saline treatments were associated with large increases of Na in the shoot. Poorer uptake of K, Ca, and Mg on the waterlogged treatments in most of the marsh species could be interpreted as symptoms of stress on poorly aerated soils.
(Cooper, 1982). However, Parrondo et al. (1978) indicated the degree of drainage of the substrate between tides was more significant than soil salinity in governing species distribution in salt marshes of the eastern and gulf states of the U.S.

Early studies on the detrimental effect of salinity on protein synthesis were also reported in the literature. Wadleigh and Gauch (1942) showed a progressive diminution in the concentration of NO₃⁻—N in the tissues with increased osmotic pressure of the substrate in the presence of salt. Protein content, especially in the leaves, also decreased with increasing salt concentration. They also reported that the high concentrations of the Cl⁻ ion may have been somewhat inhibitory to carbohydrate synthesis. Excessive concentrations of Cl⁻ ion affect carbohydrate metabolism, possibly through reduced photosynthetic activity. Kahane and Mayber (1968) claimed that the effect of salinity on the incorporation of amino acid into root tip protein was apparently of dual nature. In the presence of salts, nutrient uptake was depressed and the normal metabolic pathways were disturbed. They concluded that higher salinity in the medium resulted in a lower incorporation of amino acid. Melander and Horvarth (1977) reported two antagonistic effects of salts on protein: a) they tended to break the electrostatic bonds of protein structure and b) increased the hydrophobic interactions which tend to block the synthesis of protein.

IV. Irrigation-Gypsum Interactions on Saline Marsh Soils.

One of the important management practices available to overcome problems of Na-rich irrigation water and soil salinity is the recharge interval. Research on this subject was begun at the U.S. Salinity
Laboratory in the late 1930's, yet the information available to date is still meager (Ayres and Westcot, 1976; Shainberg and Shalhevet, 1984). Bower (1969) reported that the sequence of steps in amelioration are: a) deepening of the water table, b) removal of adsorbed Na and salt, and c) improvement of soil permeability and tilth. Application of gypsum followed by leaching is the most common method employed to replace adsorbed Na. Leaching with successive dilutions of highly saline water having 30% or more Ca + Mg salts is an effective means of removing adsorbed Na while maintaining adequate soil permeability. Bridge and Kleinig (1968) found that gypsum application significantly increased soil moisture storage before and after irrigation at all irrigation frequencies. Laboratory measurements showed that gypsum application increased hydraulic conductivity of the subsoil, increased exchangeable Ca in the soil profile and decreased exchangeable Na and Mg.

Khosla et al. (1979) reported that field leaching studies in representative fine, mixed, hyperthermic, Salic Calciorthids required 0.4 cm leaching water for 80% reduction in profile salinity. Kanwar (1962) pointed out that 30 or 90 cm of leaching water with or without 2 ton ha⁻¹ of gypsum was possible to reclaim soil and bring it to normal production. He observed that for optimum production of rice, four irrigations in addition to 362 mm of rainfall were required during the growing period. Three irrigations plus 69 mm of rain were required for optimum production of barley.

Mendelssohn and Seneca (1980) reported that growth and survival of Spartina alterniflora was directly related to marsh soil drainage and aeration in a natural salt marsh in North Carolina. Linear regression
analysis indicated differential soil drainage accounted for 70% of the variation in plant height. Total biomass of tall and medium *Spartina* and the aerial standing crop of short *Spartina* were significantly reduced when soil drainage was experimentally impaired in the field. They also disclosed that biomass production of tall and medium *Spartina* was greatest when the soil-root system was undrained. Short *Spartina* was relatively unaffected by the soil drainage treatments. Linthurst and Seneca (1980) suggested that drainage and various depths of standing water affect growth of *Spartina alterniflora* in the salt marsh. They observed a decrease in both density and living biomass when the substrate surface was elevated 10 cm above the natural marsh surface.

From their work on aeration, N, and salinity as growth determinants of *Spartina alterniflora*, Linthurst and Seneca (1980) found aeration of non-catclay substrate in a greenhouse increased the growth of *S. alterniflora* to a degree equivalent to the addition of 168 kg N ha\(^{-1}\). They reported aeration and N as independent factors (additive factors). The addition of 168 kg N ha\(^{-1}\) and aeration via O\(_2\) saturation increased the biomass of *Spartina alterniflora* by 453% over the unfertilized, unaerated marsh substrate. The greenhouse experiment conducted by Linthurst (1979) on the correlations between waterlogging and aeration on the growth of *Spartina alterniflora* showed that both the aerial biomass and belowground biomass were enhanced by the aerated substrate treatments. Moreover, waterlogging alone did not appear to be responsible for the decreased growth, but rather the associated changes in pH and redox potentials.

Hess et al. (1975) concluded that high water levels (60 to 90 cm) for two weeks, killed 80 to 90% of the *Scirpus olneyi* after the second
planting. Optimum growth was obtained when water levels were maintained slightly below the soil surface. Each time after levels were lowered, the growth of *S. olneyi* was stimulated by soil aeration. Salinity levels of 20,000 mg kg$^{-1}$ reduced culm density, but 10,000 mg kg$^{-1}$ salinity combined with wet and dry treatments had little or no effect on plant growth. Ross and Chabreck (1972) also obtained an optimum growth for *S. olneyi* at 5,000 to 10,000 mg kg$^{-1}$ salinities. A 10,000 mg kg$^{-1}$ salt concentration was best for *S. olneyi* growth, while a 20,000 mg kg$^{-1}$ salt concentration was detrimental to plant growth. Palmasino (1972) as cited by Hess et al. (1975) has shown impoundments in brackish areas, with salinities of 5,000 to 10,000 mg kg$^{-1}$ and water depths from 0 to 10 cm to be the best environment to initiate *Scirpus olneyi* plantings on a large scale. Ross and Chabreck (1972) further stressed that management of the marshes for *Scirpus olneyi* whether naturally or artificially planted, appeared to depend primarily on maintenance of water and salinity levels. Maximum survival and growth occurred when water levels did not fall below a minimum yearly average of 5 to 10 cm above the soil surface while best water salinities for growth were 10,000 to 50,000 mg kg$^{-1}$. The best survival occurred from December and January plantings, each having a survival of 100%.

Phleger (1971) reported plants' growth and survival differed markedly in various salinities. He observed considerably less growth at higher salt concentrations. The greatest growth occurred during the 8-week period in nutrient solutions with 50% and 75% seawater and the least in the solutions with 100% and 125% sea water. Haller et al. (1974) from their work on the effects of salinity on growth of several aquatic macrophytes
also observed that growth rates of 10 aquatic macrophytes in various salinities under greenhouse conditions varied widely.

Other authors (Penfound and Hathaway, 1938; Adams, 1963; Good, 1965; Smart and Barko, 1978) reported decreased plant performance with increasing salinities. Parrondo et al. (1978) claimed that high salinity level restricted shoot growth more than root growth. Salt levels of 16 g NaCl L⁻¹ significantly reduced the dry weight of shoots but not the dry matter of roots of S. alterniflora.

V. Gypsum-NPK Interactions on Saline Marsh Soils.

The response of plants to fertilizers under saline conditions depends on three things: a) total salt concentrations; b) the ratios among the four cations: K, Na, Mg, and Ca; and c) anions, especially NO₃⁻ and Cl⁻¹ (Shalhevet, 1984).

Carter et al. (1977) applied NH₄NO₃ (449 kg ha⁻¹) and gypsum (4.48 ton ha⁻¹) for four years to bromegrass sod (Bromus inermis). There was a significant reduction in exchangeable Na, increased water infiltration, and increased depth of Ca penetration. In 1978, Carter et al. reported that heavy application of surface-applied gypsum in combination with NH₄NO₃ to the Ap and Btn horizons of a black solonetz under dry-land conditions favorably affected the chemical properties (pH, extractable cations, and tritratable acidity), increased water penetration, and yield of Bromus inermis.

The salinity-fertility studies of Bernstein et al. (1974) showed a marked interactive effect of salinity and P on corn plants. Salinity was more deleterious in combination with high concentration of P (2mM) than with low concentration of P (0.05 mM). The effect of N and P application
on yield and nutrient content of corn and cotton conducted by Khalil et al. (1967) disclosed poor response of corn and cotton to fertilizer application. This poor response was mainly attributed to decreased photosynthesis and poor utilization of photosynthate in the presence of high osmotic pressure in the root medium and disturbed inorganic nutrition. Nieman and Clark (1976) likewise reported the detrimental effects of salinity and the concentration of nutrient orthophosphate on corn plants. A general yield reduction was reported as P increased from 25 to 50 kg ha\(^{-1}\), because of reduced uptake of N in the presence of high P (Zahran et al., 1982).

Phosphogypsum, lime scum, lignite powder, and S increased yield of vetch, rye, Sudangrass, and hybrid grain sorghum on saline and alkaline soil. Phosphogypsum was the most efficient amendment (Stepanescu et al., 1966). Dragan and Ostap (1977) showed that the application of 18 ton ha\(^{-1}\) of phosphogypsum + 64 kg N ha\(^{-1}\) on Puccinellia distans produced an average fresh matter yield of 8.12 ton ha\(^{-1}\) while application of N alone produced 5.08 ton ha\(^{-1}\). Yield response with trace elements ranged from 8.11 ton ha\(^{-1}\) with N + phosphogypsum + Co to 9.64 ton ha\(^{-1}\) with N + phosphogypsum + Mn + Zn + Mo. In a study of Colibas and Colibas (1965), crops fertilized with phosphogypsum (20 ton ha\(^{-1}\)) + dung (30 ton ha\(^{-1}\)) + NP (40 and 50 kg ha\(^{-1}\)) produced the highest yield. Lowest yields were with phosphogypsum alone or NP fertilizers alone. Application of dung alone or in combination with fertilizers had no significant effect.

A favorable positive interactive effect of gypsum and NPK fertilization were reported by Rankov (1967) on saline soils. The application of gypsum + dung + NPK increased the number of Pseudomonas
sp., *Bacterium megaterium*, *Bacillus cereus*, and, to a lesser extent, *Bacillus myoides*. However, application of gypsum alone, particularly at the rate of 25 ton ha\(^{-1}\), reduced the number of these bacteria and inhibited ammonification and nitrification. Moreover, Rankov et al. (1967) reported that the application of gypsum with NPK or with NPK + organic matter to saline soils increased the total number of rhizosphere microorganisms per g of root and per g of dry soil.

Broome at al. (1975) reported the primary productivity of some *S. alterniflora* marshes was limited by availability of N. Application of N fertilizer doubled the yield of short *S. alterniflora* but there was no response to P and Fe additions. Applications of N and P fertilizers enhanced growth of seedlings and transplants that were artificially established on dredge spoil. Mendelssohn (1979) applied various levels of N to short and tall *S. alterniflora* in a North Carolina salt marsh. The aerial standing crop of short *Spartina* was increased by 172%. The yield of short *Spartina* increased significantly more from NH\(_4\) fertilization than from NO\(_3\), while there was no significant effect from the form of N on tall *Spartina*. Band application of NH\(_4\)-N fertilizer significantly increased the yield of short *Spartina*. Nitrate was of minor importance as a N source for *Spartina* as indicated by low soil interstitial water NO\(_3^-\) concentrations and low plant tissue NO\(_3^-\) reductase activities. Gallagher (1975) observed an increase in the aerial biomass and a sharp reduction in the C/N ratio of *S. alterniflora* when supplied with 200 kg N ha\(^{-1}\). He observed that the availability of N limited the growth of short *S. alterniflora* in the middle elevation of Georgia salt marsh, but not in the lower elevation for tall *S. alterniflora* and *J. roemerianus*. Similarly,
Patrick and DeLaune (1976) reported a yield increase of *Spartina alterniflora* of 15% when N at the rate of 200 kg ha\(^{-1}\) was applied. The total concentration of N in the plant was increased by one-fourth to one-half because of added N while the addition of inorganic PO\(_4\)^{-3} increased the concentration of P in the plant by 20%. They concluded the salt marsh in Barataria Bay, LA to be deficient in N but not in P for the growth of *S. alterniflora*.

Smart and Barko (1980) attempted to relate plant growth to both interstitial water salinity and NH\(_4\)–N using a multiple regression analysis. They found a negative interaction. Salinity alone was negatively correlated with aboveground biomass accrual (r = -0.65) while positive results was obtained from NH\(_4\)–N addition (r = 0.81). Other investigators also observed significant correlations of N and salinity to productivity of *Spartina* (Nixon and Oviatt 1973; Broome et al., 1975; Haines and Dunn, 1976; Valiela et al., 1976). Loveland and Ungar (1983) who studied the effect of N fertilization on plant production, soil and plant N content, and species distribution in Ohio salt marsh, showed that production of *Salicornia europaea* increased with N fertilization. They claimed that reduced soil N concentrations may be responsible for the different growth forms of *S. europaea*.

Jefferies (1977) and Jefferies and Perkins (1977) observed that regular additions of inorganic N over a period of three or four years had little or no change in the dominant species. This plant community, composed of less than a dozen herbaceous species, exhibited a strong degree of constancy towards nutritional perturbations. The level of primary productivity of this system was not limited by N shortage *per se*. 
but by deleterious effects of low water potentials and high salinities.

VI. Growth, Establishment, and Distribution of Salt Marsh Plant Habitats and Communities.

Various ecological studies on the growth, establishment and distribution of salt marsh plant habitats have been made on the Atlantic Coast of the U.S. Some of the earliest published reports were made by Johnson and York (1915), Conrad (1935), Taylor (1938), and Miller and Egler (1950). Adams (1963) concluded that the salt marsh vegetation in Southeastern North Carolina could be classified under two major types, high and low marsh. The high marsh was characterized by *Spartina patens*, *Distichlis spicata*, *Borrichia frustescens*, *Frimbistyles castanea* and *Aster tenvifolius*. The low marsh was further divided into those areas dominated by *Juncus roemirianus*, by a *Spartina alterniflora-Salicornia perennis-Limoneum carolinianum* association and by *Spartina alterniflora* alone. *Spartina alterniflora* was restricted to the low marsh because of its moderate salinity.

Blum (1968) made a rough approximation of the areal extent of plant communities in a 2.3 km transect in the western portion of high marsh in Barnstable Harbor, Wisconsin (WI). *Spartina alterniflora* constituted 32% of the total plant community. Approximately 12% was dominated by *Distichlis sp.*., while *Juncus gerardi* accounted for only 1%. The production of aboveground emergent grasses of a New England salt marsh was in the order: 840 g m$^{-2}$ for tall *Spartina alterniflora*, 432 g m$^{-2}$ for short *Spartina alterniflora* and 430 g m$^{-2}$ for *Spartina patens*. These values are similar to those for New York (NY) marshes, but substantially lower than the southern marsh types (Nixon and Oviatt (1973)).
In LA, Kirby and Gosselink (1976) reported *Spartina alterniflora* as the dominant vegetation in the saline marsh area of Brataria Bay. *Spartina patens*, *Distichlis spicata*, *Salicornia virginica*, and *Juncus roemerianus* constitute a small percentage of the total vegetation. White et al. (1978) from their study on the productivity and decomposition of the dominant salt marsh plants in LA observed that the peak standing crops in grams per square meter were: 1164 for *Distichlis spicata*; 2194 for *Spartina patens*; 1559 for *Juncus roemerianus* and 1473 for *Spartina alterniflora*. The net production estimates using the Weigert and Evans (1964) method in g m\(^{-2}\) yr\(^{-1}\) were: 1162 (*Distichlis spicata*); 1428 (*Spartina patens*); 1806 (*Juncus roemerianus*); and 2895 for *Spartina alterniflora*. These four species produce 14.6 million metric tons per year of plant material. Results of a 2-year evaluation of above ground production of seven plant species showed a higher level of production than other studies reported by Hopkinson et al. (1978).

Clarke and Hannon (1967, 1969, 1970) reported that the distribution of plant species in the Sydney mangrove swamps and salt marshes of Australia was sharply zoned. Species distribution was closely related to variations in physiography, pattern of tidal flooding, salinity of the soil solution, and water table fluctuations. King et al. (1982) concluded the gradient in plant production and the physiological response of *S. alterniflora* appear was a function of soil water movement. Both water movement and Fe input decrease from the productive creekbank regions to the less productive, more landward regions. Decreased water movement and Fe input resulted in an increasing gradient of S\(^{2-}\) and decreased plant production. Other studies showed that changes in plant production may be
a response to sulfide toxicity or to changes in redox caused by the sulfide gradient (Howes et al., 1981; Mendelssohn et al., 1981; and DeLaune et al., 1983). They speculated that sulfide may limit growth by preventing N uptake and root development. Goodman and Williams (1961) also found indirect evidence that Spartina alterniflora "die-back" in Britain was a result of $S^{2-}$ toxicity.
CHAPTER 1
QUANTITY, DISTRIBUTION, AND SPATIAL DEPENDENCE OF SOME
SELECTED PHYSICOCHEMICAL PROPERTIES OF
BRACKISH MARSH SOIL
The quantity, distribution, and spatial dependence of some selected physicochemical properties of brackish marsh soil were investigated by describing and analyzing samples from 40 profiles located at Hackberry, Louisiana.

Chemical and particle size data were used to develop a stochastic model that described the marsh characteristics in relation to the establishment of optimum and favorable soil conditions for revegetation and productivity improvement in the area. There was a significant difference (p=0.01) observed for all soil parameters tested. The variability of individual properties as indicated by coefficients of variation (CV) differed widely. Some soil properties in the lower horizons were more uniform than those at the surface because of less disturbances and effects of microtopography.

Spatial variability of soil properties can affect soil performance in many ways. A uniform application of any soil amendments like fertilizer or gypsum in the area that possessed spatially variable soil would result in over application in some parts of the area and under application in others. Knowledge of the existing soil variability in the area can be utilized to develop a stochastic model that describes the marsh soil's characteristics in relation to the patterns of vegetational degradation.

One aim of soil science is to establish the cause and effect relationship between soil properties and soil behavior so that users of soil resources can predict the performance and behavior of soils. The prediction is made by matching the requirements of specific use to the
characteristics of soils (Uehara et al., 1985). The matching process however, is very complex because of the existing soil variability in the field. Similarity and variability in soil properties have certainly been recognized for many years (Mader, 1963; Wilding et al., 1965; Bascomb and Jarvis, 1976; Campbell, 1978; Mausbach et al., 1980; Gajem et al., 1981; Warrick and Gardner, 1983). As described by Wilding (1985), spatial variability within landscape bodies is a continuum. Soils as landscape bodies contain wide ranges of physical, chemical, morphological, mineralogical properties, both laterally and vertically. Soils with similar properties and environments are expected to behave similarly. Limiting the range of soil variables permits more accurate predictions of expected response to alternative soil management inputs and land use. Statement of land use potential will depend in part on the precision and accuracy of the statements which can be made about the soils. This information has practical applications to marsh management.

In planning a marsh management project, several factors should be carefully considered. One of the factors involved is to obtain detailed information on area environmental conditions, such as water quality, water level fluctuation, soil characteristics, and climatic factors (Chabreck, 1988). Knowledge of the existing soil variability in the area can be utilized to develop a stochastic model that describes the marsh soil's characteristics in relation to the patterns of vegetational degradation (Hudnall et al., 1990). Spatial variability of soil properties affect soil performance as demonstrated by Warrick and Gardner (1983). An uniform application of any soil amendments, fertilizer or gypsum in spatially variable soil, results in over application in some parts of the field and
under application in others. Uehera et al. (1985) and Peck and Melsted (1967) discussed the desirability of accurate knowledge of soil variability in determining fertilizer requirements.

The objectives of the present study were: 1) to determine the quantity, distribution, and spatial variability of some selected physicochemical properties of brackish marsh soils; and 2) to develop a spatially-stochastic model describing the marsh soil's characteristics in relation to the revegetation and productivity improvement in the area.

GEOMORPHIC LOCATION OF THE STUDY AREA

The management unit or the study area consists of 716.80 ha bordered by Black Lake on the south, the alkali ditch on the east, a pastured marsh forced drainage area on the north, and levee on the west (Figure 1.1). It is generally located between 93°24'30" and 93°22'30" East and 30°21'30" and 30°2'30" North. The study area is specifically located in Sections 3, 4, 5, 8, 9, 10, 15, and 16; Townships 12 South, Range 10 West, Cameron Parish, LA. Approximately 98% of the area is open water. Saltwater damage, subsidence, and ponding have caused most of the area to revert to open water.

The soils of the study area are the Clovelly muck series. This soil is a very poorly drained, very slowly permeable organic soil that is moderately saline and very fluid. Clovelly soils formed in moderately thick accumulation of herbaceous plant material underlain by clayey alluvium. These soils were classified as clayey, montmorillonitic, euic, thermic Terric Medisaprists (SCS, 1988). Description of a typical profile follows:
<table>
<thead>
<tr>
<th>Horizon</th>
<th>Depth (cm)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oa1</td>
<td>0 - 20</td>
<td>Very dark grayish brown (10YR 3/2) muck, pressed and rubbed, very dark grayish brown (10YR 3/2); massive; very fluid; slightly acid; clear smooth boundary.</td>
</tr>
<tr>
<td>Oa2</td>
<td>20 - 50</td>
<td>Black (10YR 2/1) muck; very fluid; few medium and fine roots; neutral; gradual smooth boundary.</td>
</tr>
<tr>
<td>Abg</td>
<td>50 - 100</td>
<td>Black (10YR 2/1) mucky clay; few streaks of dark gray (N/4) clay; massive; very fluid; neutral; clear smooth boundary.</td>
</tr>
<tr>
<td>Cg</td>
<td>100 +</td>
<td>Gray (N/5) clay; massive; neutral.</td>
</tr>
</tbody>
</table>

**MATERIAL AND METHODS**

**Soil Sampling and Analyses:**

Figure 1.1 shows the sampling sites on the NS–EW transects of the study area. Surface and subsurface samples (profile sampling) were obtained across the 40 sampling sites. These samples were stored at 5–10°C until the different physical and chemical analyses were initiated.

Soil chemical analyses included electrical conductivity (Rhoades, 1982); pH (McLean, 1982); organic carbon (SCS, 1981); and water-soluble Na, Mg, Ca, K, S, Fe, Al, and Mn by inductively coupled plasma spectroscopy (ICP). Soil extraction was performed via an automatic soil extractor. Distilled water was the extracting solution for the water-soluble cations. A 1:2 soil to extracting solution ratio was used for all the extractions. The cation exchange capacity (CEC) of the soil was analyzed following the procedures outlined by Chapman (1965).

The concentration of Cl\(^-\) in the soil sample was determined using a chloride electrode (Model 94-17B). Each 50-mL water extract was treated with 2-mL ionic strength adjustor (ISA = 5 M NaNO_3) to maintain similar
Figure 1.1. Location of study area and sampling sites.
ionic strength of each sample. The concentration of Cl\(^-\) for each sample corresponding to the measured potential (mV) was determined from the calibration curve. The calibration curve in Figure 2a.2 has an incremental standard concentration of NaCl (Chapter 2a). This standard curve was established by pipetting incremental amount of NaCl equivalent to 0, 0.02, 0.05, 0.10, 0.15, 0.20, 0.30, 0.40, 0.50, 0.60, 0.80, and 1.0 M to a 50-mL volumetric flask. Deionized distilled water was added to each standard solution. The mV potential of each standard solution was determined and the mV–chloride concentration relationship was plotted (Figure 2a.2).

Particle size analyses were completed on all mineral horizons to determine the sand, silt, and clay content using hydrometer and sieve procedures outlined by Day (1965).

**Statistical Analyses:**

Analysis of variance and mean separation. The principles of univariate and multivariate techniques of variance analyses were followed to evaluate the spatial dependence of selected physicochemical properties of soil in brackish marsh (SAS, 1985). Mean separation was based on the principles of Least Significant Difference (LSD) using the SAS User's Guide: Statistics (SAS, 1985).

**Geostatistical Analyses: (KRIGING TECHNIQUE)**

Selected physicochemical properties were interpolated by kriging using the SURFER program (Golden Software Inc., 1987). The east–west (EW) or the east–west transects (EWT) and north–south (NS) or north–south transects (NST) coordinates of control point with the corresponding observed values of the different physicochemical properties of soil in the study area were the main input variables. The computer algorithm of SURFER
was to generate 3-D and contour representations based on kriging and inverse distance interpolations. Kriging was performed following the procedures described by Journel and Huijbregts (1978) and Burgess and Webster (1980). Each estimated value $z^*(x_0)$ is a weighted average of the observed values, $z(x_i)$ within the neighborhood of the kriging location $x_0$; i.e.,

$$z^*(x_0) = \sum_{i=1}^{N} r_i z(x_i)$$  \hspace{1cm} [1.1]

where $r_i$ are the weights of each sample location. The theory and principles of kriging are described below.

**KRIGING TECHNIQUE: Application, Theory and Principles:**

*Uses and Applications.* Kriging is a means of spatial prediction that can be used for soil properties. It is a form of weighted local averaging. It is optimal in the sense that it provides estimates of values at unrecorded places without bias and with minimum and known variance (Burgess and Webster, 1980a, 1980b). It has also been used to make regional estimates with substantial gains in precision over traditional practice (Webster and Burgess, 1983).

Geostatistical methods have been used to describe the structure of spatial dependence both for isotropically varying soil properties (Burgess and Webster, 1980; Vieira et al., 1981) and for anisotropic properties that vary in different locations (Burgess and Webster, 1980; McBratney and Webster, 1981; Trangmar et al., 1986). Kriging of soil properties in the presence of isotropic has been widely practiced (Burgess and Webster, 1980; Vieira et al., 1981), but few authors have quantitatively analyzed anisotropic spatial dependence and applied it in kriging (Burgess and Webster, 1980; Webster and Burgess, 1980).
Theory and Principles. Matheron (1963) developed a theory he called "Theory of Regionalized Variables" that describes the fundamentals of geostatistics. The kriging method of interpolation, which is based on the theory of regionalized variables while using the degree of autocorrelation between adjacent samples, estimates values for any coordinate position within the domain without bias and with minimum variance (Journel and Huijbregts, 1978; Vieira et al., 1983).

The aims of statistical spatial analyses are two fold. The first is to describe the observed variations by a particular spatially-stochastic process. Once a suitable model has been procured, it leads to the second aim, which is to be able to map or predict the value of soil property at unvisited sites with a given level of confidence (Burrough, 1983). To reach these aims, certain assumptions must be made. The most common assumptions for spatial and time series analyses are:

1. Second order stationarity. The mean does not depend on location \( x \), i.e.,

\[
E[Z(x)] = \mu \tag{1.2}
\]

and that the covariance exists, and for any two places, location \( x \) and \( (x + h) \) depends only on the separation distance \( h \)

\[
c(h) = E[Z(x+h)*Z(x)] - \mu^2 \tag{1.3}
\]

2. The mean does not depend on location \( x \), but the second order stationarity is limited to the first differences on the series. The variance of the difference is finite and constant throughout locality

\[
\text{Var}[Z(x+h) - Z(x)] = E[(Z(x+h) - Z(x))^2] = 2\gamma(h) \tag{1.4}
\]

where \( \gamma(h) \) is known as the semivariance.

3. The residual (\( \epsilon \)) are normally distributed as Gaussian's "noises".
Suppose that one want to estimate values $z^*$ for all the location, $x_0$. The values have not been measured and the estimation is to be linear combination of measured values. Then,

$$z^*(x_0) = \Sigma r_i z(x_i) \quad i=1 \text{ to } N \quad [1.5]$$

in which $N$ is the number of measured values $z(x_i)$ involved in the estimation and $r_i$ are the weights attached to each measured value, $z(x_i)$. By taking $z(x_i)$ as a realization of the random function $Z(x_i)$ and assuming stationarity of order 2, the estimator becomes

$$z^*(x_0) = \Sigma r_i Z(x_i) \quad [1.6]$$

The best estimator must be unbiased and must have a minimum variance. This is mathematically written as

$$E(z^*(x_0) - Z(x_0)) = 0 \quad [1.7]$$

and

$$E([z^*(x_0) - Z(x_0)]^2) = \text{minimum} \quad [1.8]$$

If stationarity of order 2 can be assumed, then the kriging system can be written in terms of either covariance $c(h)$ or semivariogram $\gamma(h)$ as shown in equation 1.9 and 1.10

$$\Sigma r_j \gamma(x_i, x_j) + \mu = \Gamma(x_i, x_0) \quad i=1 \text{ to } N \quad [1.9]$$

The estimation variance $\delta_k^2(x_0)$

$$\delta_k^2(x_0) = \mu + \Sigma r_i \Gamma(x_i, x_0) \quad [1.10]$$

The kriging system can be written in matrix notation as

$$[c][\tau] = [b] \quad [1.11]$$

whose solution is of the form

$$[\tau] = [c]^{-1}[b] \quad [1.12]$$

in which $[c]$ is the covariance matrix, or the kriging matrix in terms of covariance, $[c]^{-1}$ is the inverse of $[c]$, $[\tau]$ is the matrix of unknown
weighting factors $r_i$.

In matrix notation, equation 1.10 becomes

$$\delta^2_k(x_o) = c(0) - [r]^t [b]$$

[1.13]

where $[r]^t$ is the transpose of the matrix $[r]$.

RESULTS AND DISCUSSION

Distribution and Spatial Variability:

Sodium, Mg, Ca, K, and S. The mean, skewness, and coefficient of variations (CV) are shown in Table 1.1 while Table 1.2 shows the minimum and maximum value, and standard deviation (SD) for Na, Mg, Ca, K, and S concentrations on the EWT and NST of brackish soil. Distribution of spatial dependence of these elements were significantly affected by sampling direction, sampling location, and sampling depth (Table 1.3). The mean concentration of Na(0.25%), Mg(0.02%), Ca(0.01%), K(0.02%), and S(0.05%) on the EWT were relatively comparable to the mean concentration of Na(0.26%), Mg(0.02%), Ca(0.01%), K(0.02%), and S(0.04%) for soil samples from the NST. The maximum concentration of Na(0.61%), Mg(0.007%), Ca(0.05%), K(0.06%), and S(0.13%) on the EWT as opposed to 0.59%(Na), 0.07%(Mg), 0.03%(K), and 0.11%(S) on the NST are shown in Table 1.2.

The maximum spatial dependence of Na and S were observed on similar locations (between latitude 30.032°N and longitude 93.390°E). Except for two secondary peak locations, the spatial variability of Na was evenly spatially distributed while S dependence was characterized by complex primary and secondary peaks. These peaks were observed at latitude 30.021°N and 30.031°N and longitude 93.381°W and 93.403°W, respectively (Figures 1.2 to 1.5).
TABLE 1.1. SKEWENESS, COEFFICIENT OF VARIABILITY, AND MEAN OF SOME PHYSICOCHEMICAL PROPERTIES OF SOIL IN BRACKISH MARSH.

<table>
<thead>
<tr>
<th>PROPERTY</th>
<th>EW TRANSECTS (EWT)</th>
<th></th>
<th></th>
<th>NS TRANSECTS (NST)</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MEAN</td>
<td>CV(%)</td>
<td>SKEWNESS</td>
<td>MEAN</td>
<td>CV(%)</td>
<td>SKEWNESS</td>
</tr>
<tr>
<td>pH</td>
<td>6.3b</td>
<td>10.9</td>
<td>0.17</td>
<td>6.5a</td>
<td>10.16</td>
<td>0.37</td>
</tr>
<tr>
<td>EC (dS/m)</td>
<td>7.2a</td>
<td>117.1</td>
<td>1.14</td>
<td>7.0b</td>
<td>37.54</td>
<td>0.62</td>
</tr>
<tr>
<td>OM (%)</td>
<td>24.9b</td>
<td>120.7</td>
<td>11.14</td>
<td>29.6a</td>
<td>104.17</td>
<td>0.83</td>
</tr>
<tr>
<td>CEC(me/100)</td>
<td>104.0a</td>
<td>114.0</td>
<td>1.79</td>
<td>102.1a</td>
<td>100.06</td>
<td>1.51</td>
</tr>
<tr>
<td>Na (%)</td>
<td>0.2a</td>
<td>45.0</td>
<td>0.91</td>
<td>0.26a</td>
<td>38.60</td>
<td>0.41</td>
</tr>
<tr>
<td>Mg (%)</td>
<td>0.02a</td>
<td>57.3</td>
<td>0.91</td>
<td>0.02a</td>
<td>46.69</td>
<td>1.33</td>
</tr>
<tr>
<td>Ca (%)</td>
<td>0.01a</td>
<td>48.1</td>
<td>1.46</td>
<td>0.01a</td>
<td>35.86</td>
<td>1.56</td>
</tr>
<tr>
<td>K (%)</td>
<td>0.02a</td>
<td>50.4</td>
<td>1.40</td>
<td>0.02a</td>
<td>50.33</td>
<td>1.49</td>
</tr>
<tr>
<td>Si (%)</td>
<td>0.06a</td>
<td>233.3</td>
<td>3.63</td>
<td>0.03b</td>
<td>204.32</td>
<td>5.01</td>
</tr>
<tr>
<td>S (%)</td>
<td>0.1a</td>
<td>50.9</td>
<td>0.82</td>
<td>0.04b</td>
<td>45.45</td>
<td>1.42</td>
</tr>
<tr>
<td>Mg/Ca Ratio</td>
<td>1.69b</td>
<td>28.5</td>
<td>0.47</td>
<td>1.72a</td>
<td>22.54</td>
<td>–0.38</td>
</tr>
<tr>
<td>Na/Ca Ratio</td>
<td>18.6b</td>
<td>34.0</td>
<td>0.76</td>
<td>19.81a</td>
<td>27.39</td>
<td>–0.39</td>
</tr>
<tr>
<td>Fe (mg/kg)</td>
<td>105.0a</td>
<td>211.1</td>
<td>3.26</td>
<td>77.58b</td>
<td>204.0</td>
<td>3.85</td>
</tr>
<tr>
<td>Al (mg/kg)</td>
<td>295.0a</td>
<td>259.2</td>
<td>4.55</td>
<td>193.0b</td>
<td>239.0</td>
<td>4.46</td>
</tr>
<tr>
<td>Mn (mg/kg)</td>
<td>1.37a</td>
<td>114.5</td>
<td>2.91</td>
<td>1.11b</td>
<td>100.0</td>
<td>2.06</td>
</tr>
<tr>
<td>Cl (mg/kg)</td>
<td>484.0b</td>
<td>56.9</td>
<td>0.33</td>
<td>487.31a</td>
<td>47.17</td>
<td>–0.04</td>
</tr>
<tr>
<td>SO₄ (mg/kg)</td>
<td>1466.0a</td>
<td>50.9</td>
<td>0.82</td>
<td>1226.0a</td>
<td>45.45</td>
<td>1.42</td>
</tr>
<tr>
<td>Clay (%)</td>
<td>28.3a</td>
<td>41.8</td>
<td>0.59</td>
<td>28.9a</td>
<td>37.14</td>
<td>0.61</td>
</tr>
<tr>
<td>Sand (%)</td>
<td>26.4a</td>
<td>39.2</td>
<td>0.01</td>
<td>26.4a</td>
<td>36.78</td>
<td>0.12</td>
</tr>
<tr>
<td>Silt (%)</td>
<td>45.3a</td>
<td>18.0</td>
<td>–0.04</td>
<td>44.7a</td>
<td>17.08</td>
<td>–0.04</td>
</tr>
</tbody>
</table>

*Means in row followed by the same letter(s) are not significantly different at p=0.05.*
Table 1.2. MINIMUM VALUE, MAXIMUM VALUE, AND STANDARD DEVIATION OF SOME PHYSICOCHEMICAL PROPERTIES OF SOIL IN BRACKISH MARSH.

<table>
<thead>
<tr>
<th>PROPERTY</th>
<th>EW TRANSECTS (EWT)</th>
<th>NS TRANSECTS (NST)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MINIMUM VALUE</td>
<td>MAXIMUM VALUE</td>
</tr>
<tr>
<td>pH</td>
<td>4.5</td>
<td>8.0</td>
</tr>
<tr>
<td>EC (dS/m)</td>
<td>0.8</td>
<td>14.4</td>
</tr>
<tr>
<td>OM (%)</td>
<td>0.9</td>
<td>98.8</td>
</tr>
<tr>
<td>CEC (me/100)</td>
<td>10.1</td>
<td>565.0</td>
</tr>
<tr>
<td>Na (%)</td>
<td>0.07</td>
<td>0.61</td>
</tr>
<tr>
<td>Mg (%)</td>
<td>0.002</td>
<td>0.07</td>
</tr>
<tr>
<td>Ca (%)</td>
<td>0.002</td>
<td>0.05</td>
</tr>
<tr>
<td>K (%)</td>
<td>0.001</td>
<td>0.06</td>
</tr>
<tr>
<td>Si (%)</td>
<td>0.001</td>
<td>0.79</td>
</tr>
<tr>
<td>S (%)</td>
<td>0.008</td>
<td>0.13</td>
</tr>
<tr>
<td>Mg/Ca Ratio</td>
<td>0.5</td>
<td>3.42</td>
</tr>
<tr>
<td>Na/Ca Ratio</td>
<td>7.5</td>
<td>38.43</td>
</tr>
<tr>
<td>Fe (mg/kg)</td>
<td>0.0</td>
<td>989.2</td>
</tr>
<tr>
<td>Al (mg/kg)</td>
<td>1.3</td>
<td>4534.0</td>
</tr>
<tr>
<td>Mn (mg/kg)</td>
<td>0.1</td>
<td>9.5</td>
</tr>
<tr>
<td>Cl (mg/kg)</td>
<td>53.2</td>
<td>1029.5</td>
</tr>
<tr>
<td>SO₄ (mg/kg)</td>
<td>244.8</td>
<td>3918.0</td>
</tr>
<tr>
<td>Clay (%)</td>
<td>10.5</td>
<td>57.9</td>
</tr>
<tr>
<td>Sand (%)</td>
<td>4.1</td>
<td>50.5</td>
</tr>
<tr>
<td>Silt (%)</td>
<td>23.5</td>
<td>60.3</td>
</tr>
</tbody>
</table>
Table 1.3. OBSERVED F-VALUES (AOV) FOR SOME SELECTED PHYSICOCHEMICAL PROPERTIES OF BRACKISH SOIL.

<table>
<thead>
<tr>
<th>PROPERTY</th>
<th>TD&lt;sup&gt;a&lt;/sup&gt;</th>
<th>SL&lt;sup&gt;b&lt;/sup&gt;</th>
<th>SD&lt;sup&gt;c&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>87.57**</td>
<td>45.98**</td>
<td>272.61**</td>
</tr>
<tr>
<td>EC (dS/m)</td>
<td>1.44ns</td>
<td>2.00**</td>
<td>2.33*</td>
</tr>
<tr>
<td>OM (%)</td>
<td>83.21**</td>
<td>131.39**</td>
<td>1497.71**</td>
</tr>
<tr>
<td>CEC (me/100g)</td>
<td>0.22ns</td>
<td>36.58**</td>
<td>169.74**</td>
</tr>
<tr>
<td>Na (%)</td>
<td>3.83*</td>
<td>100.00**</td>
<td>208.16**</td>
</tr>
<tr>
<td>Mg (%)</td>
<td>98.46**</td>
<td>215.51**</td>
<td>330.50**</td>
</tr>
<tr>
<td>Ca (%)</td>
<td>298.82**</td>
<td>309.45**</td>
<td>552.15**</td>
</tr>
<tr>
<td>K (%)</td>
<td>29.27**</td>
<td>167.56**</td>
<td>257.81**</td>
</tr>
<tr>
<td>Si (%)</td>
<td>2812.60**</td>
<td>2575.89**</td>
<td>2429.07**</td>
</tr>
<tr>
<td>S (%)</td>
<td>751.34**</td>
<td>240.37**</td>
<td>861.98**</td>
</tr>
<tr>
<td>Mg/Ca Ratio</td>
<td>13.20**</td>
<td>107.91**</td>
<td>115.76**</td>
</tr>
<tr>
<td>Na/Ca Ratio</td>
<td>41.24**</td>
<td>43.80**</td>
<td>22.13**</td>
</tr>
<tr>
<td>Fe (mg/kg)</td>
<td>1731.82**</td>
<td>3898.34**</td>
<td>9337.37**</td>
</tr>
<tr>
<td>Al (mg/kg)</td>
<td>1344.18**</td>
<td>2160.76**</td>
<td>4108.58**</td>
</tr>
<tr>
<td>Mn (mg/kg)</td>
<td>92.73**</td>
<td>118.07**</td>
<td>142.54**</td>
</tr>
<tr>
<td>Cl (mg/kg)</td>
<td>175.01**</td>
<td>1428.19**</td>
<td>1274.24**</td>
</tr>
<tr>
<td>SO₄²⁻ (mg/kg)</td>
<td>751.34**</td>
<td>240.37**</td>
<td>861.98**</td>
</tr>
<tr>
<td>Clay (%)</td>
<td>4.97*</td>
<td>86.97**</td>
<td>156.14**</td>
</tr>
<tr>
<td>Sand (%)</td>
<td>0.01ns</td>
<td>81.39**</td>
<td>21.19**</td>
</tr>
<tr>
<td>Silt (%)</td>
<td>2.74ns</td>
<td>38.78**</td>
<td>53.64**</td>
</tr>
</tbody>
</table>

<sup>a</sup>TD - Transect Direction (EW vs. NS)
<sup>b</sup>SL - Sampling Sites
<sup>c</sup>SD - Soil Depth (Horizon)
** - Significant at p=0.01
* - Significant at p=0.05
ns - Not significant
Figure 1.2. 3-D and contour representation of krigged concentration of Na.
Figure 1.3. 3-D and contour representation of krigged concentration of S.
Figure 1.4. 3-D and contour representation of krigged concentration of Ca.
Figure 1.5. 3-D and contour representation of krigged concentration of Mg.
The spatial variability of Ca and Mg concentrations were very similar (Figures 1.4 and 1.5). Three primary peaks were identified and very conspicuous between latitude 30.021°N and 30.042°N, and longitude 93.360°E and 93.401°W. These locations were a part of the micro-relief that was observed during the field review and field sampling. As a result of this micro-relief that was running parallel to the EWT, significantly higher CV's were observed from the EWT than the NST. The CV's for Na, Mg, Ca, K, and S were 45.05%, 57.29%, 48.11%, 50.33%, and 50.89%, respectively (Table 1.1). The presence of micro-relief (lows and highs) along the EWT provides some buffering effect (buffer zone) on the deposition of nutrients and sediments. Water that carries these nutrients and sediments tend to slow down after entering the buffer zone. Slow water movement then, stimulate deposition, and over time build up significant amount of sediments and different nutrients in situ. If several high micro-relief are scattered over the whole area, a more variable spatial dependence could be expected. The variability seen in Figures 1.2 to 1.5 may be due to a number of factors including: 1) the total cations adsorbing capacity of the exchange complex; 2) differential adsorption schemes of the sediments for each cation; 3) the selectivity of different soil types for different cations; 4) the degree of fixation of the cations by the sediments; 5) the amount of time for thorough mixing between the sediments that contained the dissolved cation and the interstitial water; and 6) man's activities in the marsh.

**Electrical conductivity and pH.** The spatial dependence (3-D and contour) of EC and pH values in brackish soil are shown in Figures 1.6 and 1.7. The spatial dependence of EC and pH was significantly higher in the
Figure 1.6. 3-D and contour representation of krigged concentration of EC.
Figure 1.7. 3-D and contour representation of krigged values of soil pH.
EWT than in the NST (Tables 1.1 and 1.3). The EWT had pH values ranging from 4.50 to 8.00 and averaged of 6.29. The EC ranged from 0.80 to 14.40 dS m\(^{-1}\) and averaged of 7.21 dS m\(^{-1}\). The NST had an average pH of 6.48 (4.70 to 8.20) and EC of 7.04 dS m\(^{-1}\) (0.90 to 16.70 dS m\(^{-1}\)). These values were statistically different at \(p=0.05\) (Table 1.3).

Overall, soil pH in the EWT and NST had low spatial dependence because of low SD of 0.69 and 0.66, respectively. The EC, on the other hand, possessed high degree of dependency because of high SD; 2.76 for EWT and 30.34 for NST.

Iron, Al, and Mn. The average concentration of Fe in the EWT was 105.44 mg kg\(^{-1}\), 295.32 mg kg\(^{-1}\) for Al, and 1.37 mg kg\(^{-1}\) for Mn, while the NST had 77.58 mg kg\(^{-1}\) for Fe, 192.84 mg kg\(^{-1}\) for Al, and 1.11 mg kg\(^{-1}\) for Mn. The analysis of variance (ANOVA) presented in Table 1.3 was a clear indication of highly significant dependence of Fe, Al, and Mn on transect direction, sampling location, and sampling depth. Significantly higher CV's were noted among Fe, Al, and Mn on the EWT and NST than most other elements. In the EWT, the CV's for Fe was 211%, 259% for Al, and 114% for Mn versus the CV's in the NST of 204% for Fe, 239% for Al, and 114% for Mn (Table 1.1).

The spatial dependence of Fe and Al concentration in the study area are shown in Figures 1.8 and 1.9. They depict a similar surface responses except for a peak in the Al concentration between latitude 30.051°N and longitude 93.370°E. The maximum peak concentration of 120 mg kg\(^{-1}\) for Fe and 380 mg kg\(^{-1}\) for Al were both observed between latitude 30.04°N and longitude 93.39°W. These coordinates are a topographic high. If the surface responses are superimposed, a much clearer position of micro-high would
Figure 1.8. 3-D and contour representation of krigged concentration of Fe.
Figure 1.9. 3-D and contour representation of krigged concentration of Al.
become visible and easier interpretation of spatial variability in the area can be expected.

**Na/Ca and Mg/Ca Ratios and Cl⁻.** The ratios of Na to Ca and Mg to Ca as well as the Cl⁻ concentrations on the NST were significantly higher than the EWT (Table 1.1) The average Na/Ca ratio on the NST was 1.72 (4.36 to 33.96) while the mean Mg/Ca ratio was 1.72 (0.68 to 2.72 as opposed to 7.52 to 38.43 for Na/Ca ratio, and 0.52 to 3.42 for the Mg/Ca ratio in the EWT. The EWT had an average Na/Ca ratio of 18.59 and Mg/Ca ratio of 1.69. The Cl⁻ concentration between the EWT and NST was rather close but significantly different, yielding a range of 53 to 1030 mg kg⁻¹, with an average of 484 on the EWT and ranged from 35 to 1030 mg kg⁻¹ with an average of 487 for the NST (Tables 1.2 and 1.3). Further, the overall CV's for Na/Ca and Mg/Ca ratios and Cl⁻ on the EWT were significantly higher than those the NST by 6.63%, 5.95%, and 9.72%, respectively (Table 1.1).

The spatial dependence of Na/Ca ratio and Cl⁻ concentration of surface soil in brackish marsh are shown in Figures 1.10 and 1.11. The surface response of Na/Ca ratio and Cl⁻ content in the study area disclosed significant spatial variability on the EWT-NST. Variable surface trends were noted. However, the peak concentration of Cl⁻ and Na/Ca ratio were observed from similar coordinates (between latitude 30.041°N and longitude 93.391°W).

**Organic Matter and CEC.** The spatial dependence of OM and CEC in the surface soil of brackish marsh are shown in Figures 1.12 and 1.13. There was a negligible OM distribution variability while the CEC values were more variable. The EWT had a very high CV of 121% for OM and 114% for CEC while the NST had CV value of 104% and 100%, respectively (Table 1.1).
Figure 1.10. 3-D and contour representation of krigged concentration of Na/Ca ratio.
Figure 1.11. 3-D and contour representation of krigged concentration of Cl⁻.
Figure 1.12. 3-D and contour representation of krigged values of OM.
Figure 1.13. 3-D and contour representation of krigged values of CEC.
Particle size. The average clay, silt, and sand content of the mineral horizons (Cg) on the EWT and NST were statistically comparable (Table 1.1). The clay content ranged from 10.5 to 57.8%, silt content ranged from 23.5 to 60.3%, and sand content ranged from 4.1 to 50.5% on the EWT while NST had clay content that ranged from 11.2 to 57.0%, silt content of 30.0 to 59.9%, and sand content that ranged from 4.2 to 52.2%.

The CV data in Table 1.1 revealed significant variability of clay, silt, and sand content on the EWT and NST. The spatial distribution of clay, silt and sand are shown in Figures 1.14 to 1.16. Clay and silt particles were evenly distributed except for the highest peak observed between latitude 30.031° to 30.042°N and longitude 93.360° to 93.370°E. The highest peak for sand distribution was observed between latitude 30.03° and 30.04°N and longitude 93.36° to 93.40°E.

The results show spatial dependence of some selected physicochemical properties in the study area. The variability of individual properties as indicated by CV differed widely. Generally, physical properties (particle size) were more uniform than chemical properties. The spatial dependence observed in the area are related to and explained by the interactive effect of local relief (micro-relief) and hydrologic pattern.

The most readily observable influence of relief and hydrologic pattern on soil spatial dependence can be summed up briefly in the statement "water runs downhill". Moving surface water almost always carries some solid particles, salts, and suspended particles that produces sequential deposition and erosion. Local relief serves to alter the influence of parent material by depositional changes, as a result of toposequential variability, runoff, and water table regime. The undersides
Figure 1.14. 3-D and contour representation of krigged values of clay content in the mineral horizon.
Figure 1.15. 3-D and contour representation of krigged values of silt content in the mineral horizon.
Figure 1.16. 3-D and contour representation of krigged values of sand content in the mineral horizon.
of the local relief are favored sites initially because moving water would collect there. This area collects various kinds of chemical compounds and organic and mineral particles. Until the area becomes a micro-high, it will continue to be a sink for sediments and soluble compounds. The rate at which deposition takes place varies with time and space, thus creating a very complex time- and space-dependent soil variability. As claimed by Burrough (1983), soil is a complex phenomenon whose properties are controlled by differences in parent material, topography, biological and anthropogenic activity, and the inherent properties of the soil material itself. Each cause of soil variation may not only operate independently or in combination with other factors, but also over a wide range of scales. The spatial variation of soil may be gradual or abrupt, depending on the predominant cause.

Microtopography or local relief, controls much of the distribution of soils in the landscape. Soils develop markedly contrasting morphologies and properties that vary laterally and vertically and yet are in equilibrium under existing local conditions (Birkeland, 1984). Many of the differences and spatial dependence that vary with topography are due to some combination of microclimate, pedogenesis, geological surficial processes, and the sorting effects of water movement. Mader (1963) also stressed the significant effect of microtopography on the uniformity of soil properties. He observed that some soil properties in the lower horizons were more uniform than those at the surface because of less disturbance and effects of microtopography.

The hydrology of wetland creates unique physicochemical conditions that make such ecosystems different from both well-drained terrestrial
systems and deep-water aquatic systems (Mitsch and Gossenlink, 1986). Hydrologic pathways such as surface runoff, tides, and flooding rivers transport energy and nutrients to and from wetlands. Hydrologic conditions can directly modify or change chemical and physical properties such as nutrient availability, soil salinity, sediment properties, and pH. When hydrologic conditions in wetlands change even slightly, the whole system may respond with massive changes, but when the pattern remains similar from year to year, wetland's structural and functional integrity may persist for many years. Although the latter may be true, the former may not happen all the time because of the inherent microtopographic variability just below the water surface. The succession of high and low micro-relief in the area would determine the final structure and characteristics of a wetland system. If one end of the area was exposed and the other end was under water because of topographic setting, differential physical and chemical mixing would be expected. Time allows tremendous impact on the spatial and temporal variability in the water and sediments properties.

The study of Rainey (1979) on the factors affecting nutrient chemistry distribution in LA coastal marshes showed that 40% of the variability of nutrient concentrations may be explained by the hydrologic unit. Chabreck (1970) delineated nine different hydrologic units and recognized the impetus of these drainage systems to the drainage pattern of LA wetlands. Ho and Jane (1973) stressed that the diffusion of interstitial nutrients causing spatial and temporal variability were primarily due to the tidal and wind actions. These two factors played important role in the vertical and lateral mixing processes.
Variability within Soil Profile:

Sodium, Mg, Ca, and K. The comparative average profile distribution on the EWT and NST of Na, Mg, Ca, and K are shown in Figure 1.17. Generally, the concentration of these nutrients decreased with soil depth. These trends are best described by the correlation and regression analyses data in Tables 1.4, 1.5, and 1.6.

The comparative concentration of Na, Mg, Ca, and K between the organic and mineral horizons are shown in Figure 1.18. Except for K, the average concentration of Na, Mg, and Ca in the organic horizon were significantly higher than in the mineral horizon by 0.03%, 0.02%, and 0.01%, respectively. The average concentration of K between the organic and mineral horizon was 0.01%.

pH and EC. The average profile distribution of pH and EC are shown in Figure 1.19. The soil pH on the NST showed significant increase between 0 and 50 cm followed by slight decrease at 60 cm. A similar pH trend was observed for the EWT. The EC, generally showed significant reduction with soil depth except for a slight increase between 0 and 20 cm for the EWT. Correlation and regression analyses data in Tables 1.4, 1.5, and 1.6 described the distribution of pH and EC within the soil profile. Figure 1.18 also shows the variation of soil pH and EC between the organic and mineral horizons.

The EC of the soil in the study area was significantly and positively related to Na, Mg, Cl⁻, and SO₄²⁻ content by multiple regression analysis (stepwise technique) shown in Equation 1.14.

\[
\text{EC} = 1.06 + 15.52\text{Na} + 13.28\text{Mg} + 0.001\text{Cl} + 0.0007\text{SO}_4
\]

\[ R^2 = 0.76** \]  

[1.14]
Figure 1.17. Profile distribution of Na, Mg, Ca, and K concentrations in the EWT and NST.
Table 1.4. CROSS-CORRELATION MATRIX OF SOME SELECTED PHYSICOCHEMICAL PROPERTIES FOR THE EWT AND NST.

<table>
<thead>
<tr>
<th>PROPERTY</th>
<th>SD\textsuperscript{a}</th>
<th>CLAY</th>
<th>OM</th>
<th>EC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>r-value</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Na</td>
<td>-0.34**</td>
<td>0.48**</td>
<td>0.57**</td>
<td>0.85**</td>
</tr>
<tr>
<td>Mg</td>
<td>-0.15**</td>
<td>0.08\textsuperscript{ns}</td>
<td>0.41**</td>
<td>0.69**</td>
</tr>
<tr>
<td>Ca</td>
<td>-0.22**</td>
<td>0.04\textsuperscript{ns}</td>
<td>0.43**</td>
<td>0.70**</td>
</tr>
<tr>
<td>Fe</td>
<td>0.30**</td>
<td>-0.09\textsuperscript{ns}</td>
<td>-0.30**</td>
<td>-0.33**</td>
</tr>
<tr>
<td>Al</td>
<td>0.25**</td>
<td>-0.02\textsuperscript{ns}</td>
<td>-0.24**</td>
<td>-0.31**</td>
</tr>
<tr>
<td>Mn</td>
<td>0.02\textsuperscript{ns}</td>
<td>-0.08\textsuperscript{ns}</td>
<td>-0.06\textsuperscript{ns}</td>
<td>-0.01\textsuperscript{ns}</td>
</tr>
<tr>
<td>CEC</td>
<td>-0.38**</td>
<td>0.39**</td>
<td>0.66**</td>
<td>0.48**</td>
</tr>
<tr>
<td>Cl</td>
<td>-0.29**</td>
<td>0.38**</td>
<td>0.48**</td>
<td>0.68**</td>
</tr>
<tr>
<td>SO\textsubscript{4}</td>
<td>-0.23**</td>
<td>0.19*</td>
<td>0.32**</td>
<td>0.68**</td>
</tr>
<tr>
<td>pH</td>
<td>0.46**</td>
<td>0.16*</td>
<td>-0.37**</td>
<td>-0.20**</td>
</tr>
<tr>
<td>Clay</td>
<td>-0.16*</td>
<td>1.00</td>
<td>0.57**</td>
<td>0.38**</td>
</tr>
<tr>
<td>OM</td>
<td>-0.65**</td>
<td>0.52**</td>
<td>1.00</td>
<td>0.48**</td>
</tr>
<tr>
<td>EC</td>
<td>-0.27**</td>
<td>0.37**</td>
<td>0.48**</td>
<td>1.00</td>
</tr>
</tbody>
</table>

\textsuperscript{a}SD - Soil Depth (Horizon)  
** - Significant at p=0.01  
* - Significant at p=0.05  
ns - Not significant
Table 1.5. REGRESSION ANALYSES ON THE RELATIONSHIP OF SOME SELECTED PHYSICOCHEMICAL PROPERTIES AND SOIL AND SOIL DEPTH (SD) FOR THE EWT.

<table>
<thead>
<tr>
<th>REGRESSION EQUATION</th>
<th>R²</th>
</tr>
</thead>
</table>

I. EAST–WEST TRANSECTS (EWT):

SO₄ (mg/kg) = 2074.20 - 167.85 * SD  
OM (%) = 99.90 - 27.60 * SD  
Cl (mg/kg) = 887.50 - 127.80 * SD  
Na/Ca Ratio = 21.48 - 2.37 * SD  
Mg/Ca Ratio = 2.03 - 0.05 * SD  
Fe (mg/kg) = -38.42 + 31.59 * SD  
Mn (mg/kg) = 0.38 + 0.29 * SD  
TDS (mg/kg) = 8192.00 - 1120.00 * SD  
CEC (meq/100g) = 459.95 - 127.02 * SD  
EC (dS/m) = 12.80 - 1.75 * SD  
pH = 5.87 + 0.06 * SD  
Mg (%) = 0.04 - 0.005 * SD  
Ca (%) = 0.02 - 0.002 * SD  
Na (%) = 0.43 - 0.07 * SD  
K (%) = 0.02 + 0.0004 * SD  
Clay (%) = -3.02 + 8.25 * SD  
Silt (%) = 20.46 + 9.35 * SD  
Sand (%) = 82.59 - 17.62 * SD  

ns = Not significant  
* = Significant at p=0.05  
** = Significant at p=0.01
Table 1.6. REGRESSION ANALYSES ON THE RELATIONSHIP OF SOME SELECTED PHYSICOCHEMICAL PROPERTIES SOIL AND SOIL DEPTH (SD) FOR THE NST.

<table>
<thead>
<tr>
<th>REGRESSION EQUATION</th>
<th>R²</th>
</tr>
</thead>
</table>

**II. NORTH-SOUTH TRANSECTS (NST):**

- SO\(_4\) (mg/kg) = 2394.68 - 560.42 * SD
- OM (%) = 53.50 - 15.16 * SD
- Cl (mg/kg) = 816.75 - 198.95 * SD
- Na/Ca Ratio = 19.20 - 2.07 * SD
- Mg/Ca Ratio = 1.57 - 0.07 * SD
- Fe (mg/kg) = -167.02 + 118.26 * SD
- Mn (mg/kg) = 1.55 - 0.03 * SD
- TDS (mg/kg) = 6848.00 - 1235.20 * SD
- CEC (meq/100g) = 142.60 - 35.62 * SD
- EC (dS/m) = 10.70 - 1.93 * SD
- pH = 5.52 + 0.39 * SD
- Mg (%) = 0.04 - 0.006 * SD
- Ca (%) = 0.02 - 0.003 * SD
- Na (%) = 0.38 - 0.07 * SD
- K (%) = 0.02 + 0.003 * SD
- Clay (%) = 9.00 + 5.62 * SD
- Silt (%) = 44.29 + 2.28 * SD
- Sand (%) = 46.64 - 7.85 * SD

ns = Not significant  
* = Significant at p=0.05  
** = Significant at p=0.01
Figure 1.18. Comparative concentrations of Na, Mg, Ca, K, and values of pH, EC, Mg/Ca and Na/Ca ratios between organic and mineral horizons.
Figure 1.19. Profile distribution of pH and EC values in the EWT and NST.
Chloride and $\text{SO}_4^{2-}$. The profile distribution of $\text{Cl}^-$ and $\text{SO}_4^{2-}$ are shown in Figure 1.20. The $\text{Cl}^-$ content of soil in the organic horizon was 520 mg kg$^{-1}$ as opposed to 250 mg kg$^{-1}$ in the mineral horizon while the $\text{SO}_4^{2-}$ content was slightly reduced from 1320 to 1029 mg kg$^{-1}$ or a difference of 291 mg kg$^{-1}$ between the organic and mineral horizons (Figure 1.21). These decreasing trend were further described by the regression analyses data in Tables 1.5 and 1.6.

Iron, Al, and Mn. The average profile distribution of Fe, Al, and Mn increased with soil depth (Figure 1.22). These increasing trends were best described by the correlation and regression analyses data in Table 1.4, 1.5, and 1.6. Manganese distribution varied slightly with soil depth.

The concentrations of Fe and Al were significantly higher in the mineral horizons than the organic horizon. The concentration of Fe increased from 22 to 201 mg kg$^{-1}$ while the increase in Al was from 70 to 580 mg kg$^{-1}$. The concentration of Mn decreased from 1.08 (organic) to 0.58 mg kg$^{-1}$ (mineral).

Na/Ca and Mg/Ca ratios. The Na/Ca and Mg/Ca ratios on the EWT and NST are shown in Figure 1.23. There was a slight decrease in Mg/Ca ratio with soil depth while a significant decrease in the Na/Ca ratio with soil depth were observed for the EWT and NST (Tables 1.5 and 1.6). The Na/Ca ratio within the soil profile of the NST ranged from 10 to 15 while the Na/Ca ratio in the EWT ranged from 10 to 19.

CEC and OM. The average profile distribution of CEC and OM with soil depth in brackish marsh are shown in Tables 1.5 and 1.6. The CEC of the soil was significantly correlated to OM ($r=0.66^{**}$) and clay content ($r=0.39^{**}$). This relationship is shown in Table 1.4.
A. NORTH-SOUTH TRANSECTS

Cl & SO₄ (mg/kg)

0 1000 2000 3000

DEPTH (cm)

Cg1

Cg2

■■ Chloride
●● Sulfate

B. EAST-WEST TRANSECTS

Cl & SO₄ (mg/kg)

0 1000 2000 3000

DEPTH (cm)

Oa1

Oa2

Cg1

Cg2

■■ Chloride
●● Sulfate

Figure 1.20. Profile distribution of Cl⁻ and SO₄²⁻ in the EWT and NST.
Figure 1.21. Comparative concentration of TDS, \( \text{SO}_4^{2-} \), \( \text{Cl}^- \), Fe, Al, and Mn between organic and mineral horizons.
Figure 1.22. Profile distribution of Fe, Al, and Mn in the EWT and NST.
Figure 1.23. Profile distribution of Mg/Ca and Na/Ca ratios in the EWT and NST.
A linear regression equation shown in Equation 1.15 described the relationship of CEC to OM content.

\[ \text{CEC} = -2.09 + 4.68 \text{OM} \quad R^2 = 0.98^{**} \quad [1.15] \]

The relationship of CEC to clay content, OM, and soil depth (SD) is shown in Equation 1.16.

\[ \text{CEC} = 19.58 + 0.37 \text{Clay} + 4.18 \text{OM} - 3.99 \text{SD} \quad R^2 = 0.72^{**} \quad [1.16] \]

Generally, CEC and OM decreased with soil depth (Figure 1.24). The CEC of the organic horizon was approximately 354% more than in the mineral horizon. The OM content of the organic horizon had an average value of 59% while the average OM in the mineral surface horizon was 2.16% (Figure 1.25) The high organic matter content in the surface horizon was sufficient to classify this soil into the subgroup "Medisaprist".

The amount of organic matter has the greatest influence on the CEC (Brady, 1974), and, indeed, the amounts of the available cations in the LA marsh increase with increases in organic matter in the soil materials (Brupbacher et al., 1973).

**SUMMARY AND CONCLUSIONS**

The objectives of this study were: 1) to determine the quantity, distribution, and spatial variability of some selected physicochemical properties of brackish marsh soils; and 2) to develop a spatial model describing the marsh soil's characteristics in relation to the revegetation and productivity improvement in the area. Surface and subsurface samples were obtained across the 40 sampling sites on an x and y grid (transect sampling).
Figure 1.24. Profile distribution of CEC and OM between the EWT and NST.
Figure 1.25. Comparative values of CEC and OM between organic and mineral horizons.
Results of this study are summarized as follows:

1. The variability of individual physicochemical properties of soil as indicated by coefficients of variation (CV) differed widely. There was a significant difference (p=0.01) observed for all soil parameters tested.

2. Some soil properties in the lower horizons were more uniform than those at the surface because of less disturbance and effects of microtopography.

3. Most of the physicochemical properties of the soils were highly correlated to the organic matter content of the soil. This is exhibited by higher concentration of nutrients in the organic fraction than the mineral horizon.

4. Highly significant variability of some soil properties within soil profile distribution were observed (p=0.1).

5. The majority of the spatial variability in the area was attributed to interactive effect of microtopography and hydrologic pattern.

Spatial variability of soil properties will therefore affect soil performance. A uniform application of any soil amendments like fertilizer or gypsum in the area that possessed spatially variable soil would result in over application in some parts of the area and under application in others.

LITERATURE CITED


CHAPTER 2
TEMPORAL AND SEASONAL VARIATIONS OF SOME SELECTED
PHYSICOCHEMICAL PROPERTIES OF SOIL AND
WATER IN THE BRACKISH MARSH OF
HACKBERRY, LOUISIANA
INTRODUCTION

The coastal wetlands of Louisiana (LA) are reported to be among the most productive seafood grounds in the nation (Ho and Jane, 1973). These wetlands support a major portion (40%) of the U.S. fishing, hunting, and trapping industries. To sustain the continuous growth of these biotic populations, available food source must be effectively maintained. The nutrient dynamics and transformations underlying the richness of LA coastal wetlands must be known. The seasonal and temporal variations of nutrient dynamics in the marsh must be understood. These variations are very crucial factors that should not be overlooked during the planning and management operations because they are likely to affect the overall productivity of coastal marshes. Yet the mechanism of generation, transformation, and availability of nutrients are not clear.

Very limited and specific studies are available for consultation. Earlier studies conducted by Ho and Jane (1973), Brannon (1976), and DeLaune et al. (1976) were very specific to the seasonal and temporal nutrient dynamics of salt marsh in Barataria Bay, LA. The extrapolation of their findings to the humid southwest section of LA marshes is not practical because of the existing geographical and environmental differences between these locations.

This study was subdivided into two experiments (Chapters 2a and 2b) in order to show in detail the temporal and seasonal variability of nutrient dynamics in a brackish marsh near Hackberry, LA. The objectives of Experiment I were: 1) to determine the temporal variations of some selected chemical properties of brackish marsh water; and 2) to compare and evaluate some chemical properties of water in the canal and
marsh. Experiment II was aimed to determine the seasonal variations of some selected chemical properties of brackish marsh soils near Hackberry, LA and to evaluate the effect of gypsum addition on the seasonal variability of some selected properties of brackish soils.

CHAPTER 2A: TEMPORAL VARIABILITY OF SOME SELECTED CHEMICAL PROPERTIES OF WATER IN THE BRACKISH MARSH OF HACKBERRY, LOUISIANA

ABSTRACT

The objectives of this study were: 1) to determine the temporal variations of selected chemical properties of brackish marsh water and 2) to compare and evaluate some chemical properties of water in the canal and marsh. Samples of surface water were collected periodically (October 1, 1988 to October 1, 1989) from the drainage canal and brackish marsh near Hackberry, LA.

Results disclosed highly significant temporal variations of water pH, electrical conductivity (EC), total dissolved solids (TDS), ionic strength (IS), osmotic pressure (OP), and concentration of Na, Ca, Mg, K, S, Cl\(^-\), NO\(_3^-\), Br\(^-\), and F\(^-\). These temporal variations were significantly correlated to precipitation and maximum and minimum temperatures in the area. The marsh water samples had higher pH, EC, Na, Mg, S, TDS, IS, OP, Cl\(^-\), NO\(_3^-\), and F\(^-\) than water samples from the canal.

MATERIALS AND METHODS

Water sampling and sampling time:

Surface water samples were periodically collected from the canal and marshland of a brackish marsh in Hackberry, LA. Samples were
obtained on a weekly basis for the first six months of sampling period, followed by a bi-weekly sampling for the last six months of the study period. These samples were kept inside an ice cooler while being transported to the laboratory. Water samples in air-tight bottle were stored at 5-10°C until the chemical analyses were initiated. Sampling locations are shown in Figure 2a.1.

Analytical Procedures:

Each water sample was carefully filtered using a Whatman # 42 filter paper. Chemical analyses of each sample included pH, electrical conductivity (EC), and concentrations of Na, Mg, Ca, K, S, Fe, Al, Mn, NO₃⁻, Cl⁻, Br⁻, and F⁻.

Water pH was measured directly from a 20 mL freshly filtered sample using the expandomatic pH meter (McLean, 1982). Electrical conductivity (EC) was determined using an electrical conductivity bridge (Rhoades, 1982). The concentrations of Na, Mg, Ca, K, and S were determined by inductively coupled plasma spectroscopy (ICP) while the concentration of NO₃⁻, Br⁻, and F⁻ were determined from a sample of 1:100 water sample to deionized water ratio using the ion chromatograph (IC).

The concentration of Cl⁻ in the water sample was determined using a chloride electrode (Model 94-17B). Each 50-mL water sample was treated with 2 mL ionic strength adjustor (ISA = 5 M NaNO₃) to maintain similar ionic strength of each sample. The concentration of Cl⁻ for each sample corresponding to the measured potential (mV) was determined from the calibration curve (Figure 2a.2).

The values of total dissolved solids (TDS) and osmotic pressure (OP) were derived and calculated from the value of the electrical conductivity
Figure 2a.1. Location of study area and sampling sites.
Figure 2a.2. Relationship of Cl⁻ concentration and millivolts (standard curve).

\[ \text{Cl} = 1.18 - 0.020mV + 0.000097mV^{2} \]

\[ R^{2} = 0.940 \]
following the equations of Richard (1954) while the ionic strength
(IS) values were from the equation of Ponnamperuma et al., (1966).

Statistical Analyses:

Analysis of variance and mean separation. The principles of
univariate and multivariate techniques of variance analysis were followed
to evaluate the temporal variations of selected chemical properties of
brackish water (SAS, 1985). Mean separation was based on the principles of
(SAS, 1985).

Regression analyses. The principles of the regression and stepwise
regression techniques as outlined in SAS Statistics Guide (SAS, 1985) were
followed to determine the best-fit in describing the effect of temperature
and precipitation on some selected chemical properties of brackish marsh
water. The different regression models describing the behavior of water
pH, EC, TDS, and IS in brackish water were also evaluated.

RESULTS AND DISCUSSION

Temporal Variability:

pH and EC. The comparative temporal variability of pH and EC of
water samples collected from the canal and marshland of a brackish marsh
are shown in Figure 2a.3. The analysis of variance (ANOVA) shown in Table
2a.1 has significant F-values for water pH and EC.

The pH of water samples from the marsh ranged from 7.2 to 8.6 while
the pH of water samples in the canal ranged from 6.8 to 7.8. Both pH
values of water samples from the canal and marsh increased from 7.4 and
7.5 to 7.8 and 8.6 between October 1, 1988 and November 23, 1988. This
increasing trend was followed by a remarkable decrease until September 1,
Figure 2a.3. Temporal distribution of pH and EC in the canal and marsh water sample.
Table 2a.1. ANALYSIS OF VARIANCE (ANOVA) ON THE EFFECT OF TIME\textsuperscript{a} AND LOCATION\textsuperscript{b} OF SAMPLING ON SOME SELECTED CHEMICAL PROPERTIES (QUALITY) OF BRACKISH WATER AT HACKBERRY, LA.

<table>
<thead>
<tr>
<th>Property</th>
<th>Sources of variation</th>
<th>Time(T)</th>
<th>Location(L)</th>
<th>TxL</th>
<th>R\textsuperscript{2}model</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>F-value</td>
<td></td>
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<tr>
<td>Na (%)</td>
<td></td>
<td>6518.83**</td>
<td>61.21**</td>
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<td>0.99**\textsuperscript{f}</td>
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<td>Mg (%)</td>
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<td>3689.32**</td>
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<td>87.02**</td>
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<td>1474.31**</td>
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</tr>
<tr>
<td>K (%)</td>
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<td>542.66**</td>
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<td>S (%)</td>
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<tr>
<td>EC (dS/m)</td>
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<td>62.19**</td>
<td>30.21**</td>
<td>0.97**</td>
</tr>
<tr>
<td>Mg/Ca Ratio</td>
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<td>14.68**</td>
<td>0.95**</td>
</tr>
<tr>
<td>Na/K Ratio</td>
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<td>52.55**</td>
<td>23.10**</td>
<td>7.30**</td>
<td>0.91**</td>
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<tr>
<td>Na/Ca Ratio</td>
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<td>18.25**</td>
<td>1265.46**</td>
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<tr>
<td>TDS\textsubscript{c}/(mg/L)</td>
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<td>184.82**</td>
<td>62.19**</td>
<td>30.21**</td>
<td>0.97**</td>
</tr>
<tr>
<td>IS\textsubscript{d}/(moles/L)</td>
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<td>146.96**</td>
<td>26.29**</td>
<td>20.52**</td>
<td>0.96**</td>
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<tr>
<td>OP\textsubscript{e}/(bar)</td>
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<td>184.82**</td>
<td>62.19**</td>
<td>30.21**</td>
<td>0.97**</td>
</tr>
<tr>
<td>Nitrate (mg/L)</td>
<td></td>
<td>82.27**</td>
<td>105.77**</td>
<td>67.00**</td>
<td>0.96**</td>
</tr>
<tr>
<td>Cl (mg/L)</td>
<td></td>
<td>1029.11**</td>
<td>399.44**</td>
<td>257.00**</td>
<td>0.96**</td>
</tr>
<tr>
<td>Br (mg/L)</td>
<td></td>
<td>758.35**</td>
<td>188.70**</td>
<td>90.14**</td>
<td>0.99**</td>
</tr>
<tr>
<td>F (mg/L)</td>
<td></td>
<td>2294.32**</td>
<td>161.07**</td>
<td>07.02**</td>
<td>0.99**</td>
</tr>
</tbody>
</table>

\textsuperscript{a}Sampling Time: 10-01-88 to 09-01-1989
\textsuperscript{b}Canal vs. Marsh (Plot)
\textsuperscript{c}TDS (Total Dissolved Solids) = EC x 640
\textsuperscript{d}IS (Ionic Strength) = 0.001 + 15.90EC + 25.89EC\textsuperscript{2}
\textsuperscript{e}OP (Osmotic Pressure) = EC x 0.38
\textsuperscript{f}Significant at p = 0.01
\textsuperscript{ns}Not Significant
1989 sampling. The pH of water samples from the marsh was lowered from 7.6 to 6.8 while the pH value of water samples from the canal sample was reduced from 8.4 to 7.2 between December 26, 1988 and September 1, 1989.

The temporal variability of EC of water samples from the marsh and canal showed bi-modal distribution (Figure 2a.3). The highest water EC reading of 8.4 dS m\(^{-1}\) from the marsh was observed on November 23, 1988 while the second highest of 7.1 dS m\(^{-1}\) was observed on May 13, 1989. A high of 7.6 and second high of 7.8 dS m\(^{-1}\) from the canal were obtained on November 11, 1988 and April 30, 1989, respectively. These highs were observed during low to zero precipitation in the area. The initial EC reading in the marsh was 3.0 dS m\(^{-1}\) and 2.1 dS m\(^{-1}\) for the canal samples. The ending EC of 2.3 dS m\(^{-1}\) was observed in the marsh while the canal samples had an ending EC of 2.0 dS m\(^{-1}\). The different factors that contributed to the above-mention temporal variability will be discussed in a later portion of this section.

Calcium and Mg concentrations. Results disclosed a highly significant time factor on the variability of Ca and Mg concentrations in brackish water (Table 2a.1). The concentration of Mg was higher than Ca concentration at any given time, but their temporal distribution from October 1, 1988 to September 1, 1989 were very similar (Figure 2a.4).

Calcium concentration between the October 1, 1988 and the November 22, 1988 sampling from the canal and marsh were increased from 0.012 to 0.024% and 0.004 to 0.009%, respectively. These increasing trends were immediately followed by a significant reduction in Ca concentration until February 27, 1989 for the canal and marsh samples.
Figure 2a.4. Temporal variations of Ca and Mg concentrations in the canal and marsh water sample.
The temporal distribution of Mg concentration from the canal and marsh were very similar to the trend of Ca distribution. The highest Mg concentration of 0.036 and 0.025% for marsh and canal samples were observed in the November 22, 1988 and May 13, 1989 sampling, respectively. The lowest Mg content of 0.005% was observed on September 1, 1989 for both canal and marsh samples.

Sodium and K concentrations. The temporal distribution of Na and K are shown in Figure 2a.5. A very significant temporal variability on Na and K concentration was observed in brackish water (Table 2a.1). The highest Na concentration of 0.21% and the lowest Na concentration of 0.02% were observed from marsh samples and canal samples during the November 23, 1988 and August 15, 1989 sampling, respectively. The distribution of Na in canal and marsh samples were characterized by alternate increase-decrease-increase trend during the whole sampling time.

The K concentration over time in Figure 2a.5 shows a Gaussian normal distribution. The highest K content of 0.034% was observed from the canal samples on January 20, 1989 while a high K value of 0.015% was obtained from the marsh on February 27, 1989. The concentration of K before and after this peak date were relatively low, but uniformly distributed.

Sulfur and OP. The temporal distribution of S and osmotic potentials (OP) were very similar to the other preceding chemical properties (Figure 2a.6). The time factor of S and OP distribution were very significant as shown in Table 2a.1. The highest S concentration of 0.05 and 0.02% for water samples in the marsh and canal were both observed during the November 23, 1988 sampling. The concentration of S after the November 23,
Figure 2a.5. Temporal variations of Na and K concentrations in the canal and marsh water sample.
Figure 2a.6. Temporal variations of S and OP concentrations in the canal and marsh water sample.
1988 was a combination of decrease-increase cycle.

The osmotic pressure (OP) of water samples from the canal and marsh showed bi-modal distribution over time (Figure 2a.6). The two peaks of OP for canal and marsh water samples were observed on November 23, 1988 and April 30, 1989 and on December 11, 1988 and May 13, 1989, respectively. Distribution of OP was very much related to the precipitation and temperature in the area. Discussion of these relationships are in a later part of this section.

Chloride and NO₃⁻ concentrations. The time distribution of Cl⁻ and NO₃⁻ show highly significant variability (Table 2a.1). Data given in Figure 2a.7 depict the temporal variability of Cl⁻ and NO₃⁻ in brackish water.

The highest Cl⁻ concentration of 15000 and 14000 mg L⁻¹ were obtained from the marsh and canal samples on November 23, 1988 and April 30, 1989, respectively. Between October 1, 1988 and November 23, 1988 sampling, the Cl⁻ concentration increased from 6000 to 15000 and 3000 to 11000 mg L⁻¹ for canal water and marsh samples, respectively. Significant decrease in Cl⁻ concentration were observed at two separate sampling times. The first significant reduction was on December 16, 1988 and the second major reduction was on May 13, 1989. After the May 13, 1989 sampling, no significant increase in the Cl⁻ concentration was observed.

The NO₃⁻ content of water sample showed different temporal variations because of the significant decrease in its concentration even after the initial sampling date. The NO₃⁻ concentration, after the major drop, does not show any dramatic changes. The distribution was fairly uniform throughout except for a minor increase in the canal NO₃⁻ on June 24, 1989. Between October 15, 1988 and September 1, 1989, the concentration of NO₃⁻
Figure 2a.7. Temporal variations of Cl\textsuperscript{-} and NO\textsubscript{3}\textsuperscript{-} concentrations of water sample in the canal and marsh.
in samples from the canal and marsh have a narrow range of 25 to 50 and 50 to 55 mg L\(^{-1}\), respectively.

**Bromide and F\(^{-}\) concentrations.** The temporal variability of Br\(^{-}\) and F\(^{-}\) are shown in Figure 2a.8 while the analysis of variance on time factor is shown in Table 2a.1.

The distribution of Br\(^{-}\) in the water sample from the marsh has an alternate increase-decrease cycle until May 13, 1989 (Figure 2a.8). Water from the marsh had Br\(^{-}\) content ranging from 0 to 118 mg L\(^{-1}\) compared to 0 to 106 mg L\(^{-1}\) in the canal samples.

The F\(^{-}\) distribution over time in Figure 2a.8 shows a bi-modal trend. Similar pattern of F\(^{-}\) concentration were observed between water samples from the marsh and canal. The first F\(^{-}\) peak of 96 mg L\(^{-1}\) was observed on October 30, 1988 and 68 mg L\(^{-1}\) on October 22, 1988 while the second peak of 66 mg L\(^{-1}\) on March 18, 1989 and June 24, 1989 were obtained from the marsh sample.

**Total dissolved solids and IS.** The temporal variability of total dissolved solids (TDS) and ionic strength (IS) of water samples from the canal and marsh are shown in Figure 2a.9. The result of the ANOVA for TDS and IS distribution are shown in Table 2a.1.

Data given in Figure 2a.9 show a very similar distribution pattern between TDS and IS over time. A bi-modal distribution was very prominent. The two highest peak for TDS of 5250 and 4750 mg L\(^{-1}\) and 5000 and 5250 mg L\(^{-1}\) in the canal and marshland water samples were observed on November 11, 1988 and April 30, 1989, respectively. The two highest peaks for IS of 1900 and 1600 moles L\(^{-1}\) and 1650 and 1800 moles L\(^{-1}\) in the canal and marshland water samples were obtained on similar dates as the TDS.
Figure 2a.8. Temporal variations of Br⁻ and F⁻ concentrations of water sample in the canal and marsh.
Figure 2a.9. Temporal variations of TDS and IS content of water sample in the canal and marsh.
**Mg/Ca and Na/Ca Ratios.** The temporal variability of Mg/Ca and Na/Ca ratios are shown in Figure 2a.10. Highly significant temporal variability on these ratios are shown in Table 2a.1.

The temporal distribution of Mg/Ca and Na/Ca ratios follow similar pattern. Between October 1, 1988 and July 21, 1989, both the Mg/Ca and Na/Ca ratios of the marsh and canal water samples had an increasing trend. The ratio of Mg to Ca in the canal increased from 1.6 to 2.1 while the water sample in marsh increased from 1.0 to 1.9. The Na/Ca ratio in the canal sample increased from 13.0 to 16.0 and the marsh sample was increased from 6.0 to 11.0.

Evidences presented in the preceding section show the remarkable temporal variability of all the chemical properties of brackish water that were considered in this study. Further, the ANOVA exhibited strong support to the temporal variations of selected chemical properties that were mentioned above such as pH, EC, TDS, IS, Na, Mg, Ca, K, Cl\(^{-}\), NO\(_3\)^{-}, Br\(^{-}\), F\(^{-}\), and ratios of Mg/Ca and Na/Ca. Earlier studies conducted by Brannon (1973), Ho and Jane (1973), DeLaune et al., (1976), and Mitsch and Gosselink (1986) attributed seasonal and temporal variability of sediments and water parameters to some factors that include tidal and wind actions, hydrologic activity, precipitation, temperature, and microbial activity. Ho and Jane (1973) stressed that the diffusion of interstitial nutrients causing nutrient variability in water were primarily due to the tidal and wind actions. These two factors played important role in the vertical mixing process. Brannon (1973) and DeLaune et al. (1976) suggested similar factors. They reported that the tidal action and the southerly and
Figure 2a.10. Temporal variations of Ma/Ca and Na/Ca ratios in the water sample from the canal and marsh.
northerly wind action were the two factors contributing to the seasonal variations of sediments and water parameters in Barataria Bay, LA. Mitsch and Gosselink (1986) stressed water depth, flow patterns, and duration and frequency of flooding, which are the result of all the hydrologic inputs and outputs, influence the biochemistry of sediments and interstitial water in the marsh. The effect of temperature and precipitation was reported by Cho and Ponnampemuma (1971).

In this study, an attempt was made to relate temporal variability of some selected chemical properties of brackish water to precipitation and temperature in the area. Temporal variability was also defined on the basis of their interactions and interrelationship. Several regression models were generated to retain the best-fit model through stepwise regression technique. Results of the correlation and multiple regression analyses are shown in Tables 2a.2 to 2a.4.

High correlations were observed between the different chemical properties of brackish water and precipitation and maximum and minimum temperatures (Tables 2a.2 and 2a.3). The concentrations of Na, Mg, and Ca were negatively correlated with increasing precipitation, but negatively related to increasing temperature in the area. The EC, IS, and TDS of the water samples in the study area were also negatively related to precipitation. Further, significant correlations between EC, OP, TDS, and IS and some selected chemical properties of brackish water were observed. Multiple regression analyses shown in Table 2a.4 suggested that the temporal variability of some selected chemical properties of water can be attributed to any variation of precipitation and maximum and minimum temperatures. Distribution and variations of these environmental factors
Table 2a.2. CORRELATION MATRIX DESCRIBING THE RELATIONSHIP OF SOME CHEMICAL PROPERTIES (QUALITY) OF BRACKISH WATER TO PRECIPITATION (PPT), MAXIMUM TEMPERATURE (MAXT), AND MINIMUM TEMPERATURE (MINT) AT TWO DIFFERENT SAMPLING LOCATION.

<table>
<thead>
<tr>
<th>Property</th>
<th>PPT</th>
<th>MAXT</th>
<th>MINT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(mm)</td>
<td>(°C)</td>
<td>(°C)</td>
</tr>
<tr>
<td>I. Location: Canal</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Na (%)</td>
<td>-0.28*</td>
<td>0.18ns</td>
<td>0.23**a</td>
</tr>
<tr>
<td>Mg (%)</td>
<td>-0.23*</td>
<td>0.17ns</td>
<td>0.28ns</td>
</tr>
<tr>
<td>Ca (%)</td>
<td>-0.24*</td>
<td>0.16ns</td>
<td>0.27**</td>
</tr>
<tr>
<td>pH</td>
<td>-0.21*</td>
<td>-0.52**</td>
<td>-0.60**</td>
</tr>
<tr>
<td>EC (dS/m)</td>
<td>-0.49**</td>
<td>-0.21*</td>
<td>-0.12ns</td>
</tr>
<tr>
<td>Na/Ca Ratio</td>
<td>0.43**</td>
<td>0.32**</td>
<td>0.43**</td>
</tr>
<tr>
<td>TDS (mg/L)</td>
<td>-0.49**</td>
<td>-0.22*</td>
<td>-0.12ns</td>
</tr>
<tr>
<td>OP (bar)</td>
<td>-0.49**</td>
<td>-0.21*</td>
<td>-0.12ns</td>
</tr>
<tr>
<td>Nitrate (mg/L)</td>
<td>-0.04ns</td>
<td>-0.26*</td>
<td>-0.25*</td>
</tr>
<tr>
<td>Chloride (mg/L)</td>
<td>-0.28**</td>
<td>-0.55**</td>
<td>-0.47**</td>
</tr>
<tr>
<td>Bromide (mg/L)</td>
<td>-0.30**</td>
<td>-0.64**</td>
<td>-0.60**</td>
</tr>
<tr>
<td>Flouride (mg/L)</td>
<td>-0.29**</td>
<td>0.13ns</td>
<td>0.09ns</td>
</tr>
<tr>
<td>II. Location: Marsh (Plot)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Na (%)</td>
<td>-0.26*</td>
<td>-0.18ns</td>
<td>0.27**</td>
</tr>
<tr>
<td>Mg (%)</td>
<td>-0.26*</td>
<td>0.16ns</td>
<td>0.27*</td>
</tr>
<tr>
<td>Ca (%)</td>
<td>-0.29**</td>
<td>0.18ns</td>
<td>0.25*</td>
</tr>
<tr>
<td>pH</td>
<td>-0.20*</td>
<td>-0.38**</td>
<td>-0.54**</td>
</tr>
<tr>
<td>EC (dS/m)</td>
<td>-0.66**</td>
<td>-0.11ns</td>
<td>-0.14ns</td>
</tr>
<tr>
<td>Na/Ca Ratio</td>
<td>0.19ns</td>
<td>0.04ns</td>
<td>0.18ns</td>
</tr>
<tr>
<td>TDS (mg/L)</td>
<td>-0.65**</td>
<td>-0.11ns</td>
<td>-0.15ns</td>
</tr>
<tr>
<td>OP (bar)</td>
<td>-0.65**</td>
<td>-0.12ns</td>
<td>-0.16ns</td>
</tr>
<tr>
<td>Nitrate (mg/L)</td>
<td>-0.19ns</td>
<td>-0.19ns</td>
<td>-0.21*</td>
</tr>
<tr>
<td>Chloride (mg/L)</td>
<td>-0.33**</td>
<td>-0.47**</td>
<td>-0.52**</td>
</tr>
<tr>
<td>Bromide (mg/L)</td>
<td>-0.41**</td>
<td>-0.48**</td>
<td>-0.32**</td>
</tr>
<tr>
<td>Flouride (mg/L)</td>
<td>-0.39**</td>
<td>0.06ns</td>
<td>-0.18ns</td>
</tr>
</tbody>
</table>

aPearson Correlation Coefficient
** - Significant at p=0.01
* - Significant at p=0.05
ns - Not significant
Table 2a.3. CORRELATION MATRIX DESCRIBING THE RELATIONSHIP OF ELECTRICAL CONDUCTIVITY (EC), OSMOTIC POTENTIAL (OP), TOTAL DISSOLVED SOLIDS (TDS), AND IONIC STRENGTH (IS) TO SOME SELECTED CHEMICAL PROPERTIES OF BRACKISH WATER AT HACKBERRY, LA.

<table>
<thead>
<tr>
<th>Property</th>
<th>EC</th>
<th>OP</th>
<th>TDS</th>
<th>IS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(dS/m)</td>
<td>(MPa)</td>
<td>(mg/L)</td>
<td>(moles/L)</td>
</tr>
<tr>
<td>I. Location: Canal</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Na (%)</td>
<td>0.46**</td>
<td>0.48**</td>
<td>0.48**</td>
<td>0.51a**</td>
</tr>
<tr>
<td>Mg (%)</td>
<td>0.47**</td>
<td>0.47**</td>
<td>0.47**</td>
<td>0.52**</td>
</tr>
<tr>
<td>Ca (%)</td>
<td>0.47**</td>
<td>0.47**</td>
<td>0.48**</td>
<td>0.52**</td>
</tr>
<tr>
<td>K (%)</td>
<td>0.40**</td>
<td>0.40**</td>
<td>0.40**</td>
<td>0.43**</td>
</tr>
<tr>
<td>S (%)</td>
<td>0.49**</td>
<td>0.48**</td>
<td>0.48**</td>
<td>0.53**</td>
</tr>
<tr>
<td>Mg/Ca Ratio</td>
<td>0.71**</td>
<td>0.70**</td>
<td>0.71**</td>
<td>0.67**</td>
</tr>
<tr>
<td>Na/K Ratio</td>
<td>0.18ns</td>
<td>0.17ns</td>
<td>0.17ns</td>
<td>0.20*</td>
</tr>
<tr>
<td>Na/Ca Ratio</td>
<td>0.30**</td>
<td>0.29**</td>
<td>0.30**</td>
<td>0.32**</td>
</tr>
<tr>
<td>Chloride</td>
<td>0.53**</td>
<td>0.52**</td>
<td>0.53**</td>
<td>0.53**</td>
</tr>
<tr>
<td>MaxT (°C)</td>
<td>-0.22*</td>
<td>-0.22*</td>
<td>-0.21*</td>
<td>-0.09ns</td>
</tr>
<tr>
<td>Ppt (mm)</td>
<td>-0.50**</td>
<td>-0.49**</td>
<td>-0.49**</td>
<td>-0.49**</td>
</tr>
<tr>
<td>II. Location: Marsh (Plot)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Na (%)</td>
<td>0.50**</td>
<td>0.50**</td>
<td>0.50**</td>
<td>0.56**</td>
</tr>
<tr>
<td>Mg (%)</td>
<td>0.49**</td>
<td>0.49**</td>
<td>0.49**</td>
<td>0.55**</td>
</tr>
<tr>
<td>Ca (%)</td>
<td>0.52**</td>
<td>0.52**</td>
<td>0.52**</td>
<td>0.57**</td>
</tr>
<tr>
<td>K (%)</td>
<td>0.48**</td>
<td>0.47**</td>
<td>0.47**</td>
<td>0.52**</td>
</tr>
<tr>
<td>S (%)</td>
<td>0.54**</td>
<td>0.54**</td>
<td>0.54**</td>
<td>0.59**</td>
</tr>
<tr>
<td>Mg/Ca Ratio</td>
<td>0.42**</td>
<td>0.41**</td>
<td>0.41**</td>
<td>0.45**</td>
</tr>
<tr>
<td>Na/K Ratio</td>
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<td>-0.02ns</td>
<td>-0.09ns</td>
<td>-0.06ns</td>
</tr>
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<td>-0.04ns</td>
<td>-0.04ns</td>
<td>-0.10ns</td>
</tr>
<tr>
<td>Chloride</td>
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<td>0.23ns</td>
<td>0.24ns</td>
<td>0.24ns</td>
</tr>
<tr>
<td>MaxT (°C)</td>
<td>-0.12ns</td>
<td>-0.11ns</td>
<td>-0.11ns</td>
<td>-0.04ns</td>
</tr>
<tr>
<td>Ppt (mm)</td>
<td>-0.65**</td>
<td>-0.66**</td>
<td>-0.66**</td>
<td>-0.61**</td>
</tr>
</tbody>
</table>

*Pearson Correlation Coefficient
** — Significant at p<0.01
* — Significant at p<0.05.
ns — Not significant
Table 2a.4. MULTIPLE REGRESSION ANALYSES ON THE EFFECT OF PRECIPITATION (PPT), MINIMUM TEMPERATURE (MINT), AND MAXIMUM TEMPERATURE (MAXT) ON SOME SELECTED CHEMICAL PROPERTIES OF BRACKISH WATER AT HACKBERRY, LA.

<table>
<thead>
<tr>
<th>Property</th>
<th>(b_0^a)</th>
<th>(b_1^b)</th>
<th>(b_2^c)</th>
<th>(b_3^d)</th>
<th>(R^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>I. Location: Canal</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Na (%)</td>
<td>0.906</td>
<td>-0.005</td>
<td>-0.084</td>
<td>0.091</td>
<td>0.32**</td>
</tr>
<tr>
<td>Mg (%)</td>
<td>0.123</td>
<td>-0.001</td>
<td>-0.110</td>
<td>0.120</td>
<td>0.32**</td>
</tr>
<tr>
<td>Ca (%)</td>
<td>0.056</td>
<td>-0.0003</td>
<td>-0.005</td>
<td>0.005</td>
<td>0.31**</td>
</tr>
<tr>
<td>K (%)</td>
<td>0.051</td>
<td>-0.0001</td>
<td>-0.004</td>
<td>0.004</td>
<td>0.24**</td>
</tr>
<tr>
<td>pH</td>
<td>7.527</td>
<td>-0.0004</td>
<td>0.038</td>
<td>-0.059</td>
<td>0.42**</td>
</tr>
<tr>
<td>EC (dS/m)</td>
<td>12.034</td>
<td>-0.043</td>
<td>-0.059</td>
<td>0.424</td>
<td>0.41**</td>
</tr>
<tr>
<td>Mg/Ca Ratio</td>
<td>2.550</td>
<td>-0.003</td>
<td>-0.059</td>
<td>0.051</td>
<td>0.39**</td>
</tr>
<tr>
<td>Na/Ca Ratio</td>
<td>15.854</td>
<td>-0.005</td>
<td>-0.278</td>
<td>0.332</td>
<td>2.28**</td>
</tr>
<tr>
<td>Na/K Ratio</td>
<td>20.413</td>
<td>-0.010</td>
<td>-0.612</td>
<td>0.973</td>
<td>0.15**</td>
</tr>
<tr>
<td>TDS</td>
<td>7062.103</td>
<td>-27.896</td>
<td>-324.327</td>
<td>271.731</td>
<td>0.41**</td>
</tr>
<tr>
<td>IS</td>
<td>2203.166</td>
<td>-11.888</td>
<td>-125.394</td>
<td>114.987</td>
<td>0.39**</td>
</tr>
<tr>
<td>Nitrate</td>
<td>70.022</td>
<td>0.009</td>
<td>-0.772</td>
<td>-0.277</td>
<td>0.07ns</td>
</tr>
<tr>
<td>Chloride</td>
<td>20531.437</td>
<td>-32.367</td>
<td>-792.850</td>
<td>430.515</td>
<td>0.40**</td>
</tr>
<tr>
<td>Bromide</td>
<td>148.791</td>
<td>-0.248</td>
<td>-4.719</td>
<td>1.208</td>
<td>0.07ns</td>
</tr>
<tr>
<td>Flouride</td>
<td>24.294</td>
<td>-0.508</td>
<td>1.867</td>
<td>-0.411</td>
<td>0.12**</td>
</tr>
</tbody>
</table>

| **II. Location: Marsh (Plot)** |           |           |           |           |        |
| Na (%)           | 0.767     | -0.006    | -0.068    | 0.076     | 0.28** |
| Mg (%)           | 0.134     | -0.001    | -0.012    | 0.013     | 0.28** |
| Ca (%)           | 0.061     | -0.001    | -0.005    | 0.006     | 0.27** |
| K (%)            | 0.034     | -0.0002   | -0.003    | 0.003     | 0.25** |
| pH               | 6.925     | -0.0001   | 0.125     | -0.142    | 0.48** |
| EC (dS/m)        | 5.980     | -0.046    | -0.017    | 0.017     | 0.43** |
| Mg/Ca Ratio     | 2.098     | -0.001    | -0.017    | 0.017     | 0.43** |
| Na/Ca Ratio     | 14.095    | 0.006     | -0.499    | 0.461     | 0.24** |
| Na/K Ratio      | 12.214    | 0.043     | -0.138    | 0.388     | 0.18** |
| TDS              | 3832.645  | -29.786   | 10.732    | 11.169    | 0.43** |
| IS               | 1075.819  | -12.896   | -12.668   | 18.946    | 0.39** |
| Nitrate          | 62.117    | -0.648    | -2.169    | 4.538     | 0.11*  |
| Chloride         | 11728.702 | -29.657   | 118.339   | -370.032  | 0.32** |
| Bromide          | 100.247   | -0.383    | -0.116    | -2.201    | 0.36** |
| Flouride         | 16.914    | -0.222    | 3.637     | -3.333    | 0.27** |

\(^a\)Intercept of the multiple regression line
\(^b\)value for the effect of precipitation
\(^c\)value for the effect of maximum temperature
\(^d\)value for the effect of minimum temperature

** - Significant at \(p=0.01\)
* - Significant at \(p=0.05\)
are shown in Figure 2a.11.

**Effect of sampling location:**

**pH and EC.** The effect of sampling location on the pH and EC of brackish water are shown in Figure 2a.12. The pH values of water sample from marsh were significantly higher than the pH of canal water. Similarly, the EC value of the marsh was significantly higher than the EC of the canal (Table 2a.5).

**Sodium, Mg, Ca, K, and S.** Generally, higher concentrations of Na, Mg, Ca, and S were obtained from marsh water than in the canal sample. The concentration of Na, Mg, Ca, and S in the marsh were 0.18, 0.031, 0.018, and 0.031% against the concentration of 0.17, 0.022, 0.011, and 0.020% in the canal (Figure 2a.13). Potassium has similar concentration in both locations with a mean of 0.008% (Table 2a.5).

**Total dissolved solids, IS, and OP.** The comparative TDS, IS, and OP of water sample at the two sampling locations are shown in Figure 2a.14. Marsh samples have significantly higher TDS, IS, and OP than the canal samples (Table 2a.5). Water samples from the marsh have 3002 mg L\(^{-1}\) of TDS, 748 moles L\(^{-1}\) IS, and 1.78 bar of OP while canal samples contained 2701 mg L\(^{-1}\) of TDS, 654 moles L\(^{-1}\) of IS, and 1.60 bar of OP.

**Chloride, NO\(_3^-\), Br\(^-\), and F\(^-\).** The effect of sampling location on the concentrations of Cl\(^-\), NO\(_3^-\), Br\(^-\), and F\(^-\) in brackish water are shown in Figure 2a.15. Significant difference existed between the marsh and canal samples (Table 2a.5). Chloride was the dominant anion for both marsh and canal samples with mean of 7967 and 7011 mg L\(^{-1}\), respectively. Significantly higher NO\(_3^-\) and F\(^-\) were observed from marsh water samples than the canal sample. However, canal sample had higher Br\(^-\) content than
Figure 2a.11. Distribution of total precipitation, maximum and minimum temperature in the study area (Hackberry, LA).
Figure 2a.12. Comparative analyses of pH and EC of water samples in the canal and the marsh.
Table 2a.5. COMPARATIVE ANALYSIS ON SOME SELECTED CHEMICAL PROPERTIES (QUALITY) OF BRACKISH WATER AT TWO DIFFERENT SAMPLING SITES AT HACKBERRY, LA.

<table>
<thead>
<tr>
<th>Property</th>
<th>Marsh</th>
<th>Canal</th>
<th>LSD(0.05)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Na (%)</td>
<td>0.18a</td>
<td>0.17b</td>
<td>0.004</td>
</tr>
<tr>
<td>Mg (%)</td>
<td>0.031a</td>
<td>0.022b</td>
<td>8.42x10^{-6}</td>
</tr>
<tr>
<td>Ca (%)</td>
<td>0.018a</td>
<td>0.011b</td>
<td>6.24x10^{-6}</td>
</tr>
<tr>
<td>K (%)</td>
<td>0.008a</td>
<td>0.008a</td>
<td>5.37x10^{-6}</td>
</tr>
<tr>
<td>S (%)</td>
<td>0.031a</td>
<td>0.020b</td>
<td>0.001</td>
</tr>
<tr>
<td>pH</td>
<td>7.7a</td>
<td>7.5b</td>
<td>0.032</td>
</tr>
<tr>
<td>EC (dS/m)</td>
<td>4.69a</td>
<td>4.22b</td>
<td>0.117</td>
</tr>
<tr>
<td>TDS (mg/L)</td>
<td>3002.0a</td>
<td>2701.0b</td>
<td>74.864</td>
</tr>
<tr>
<td>IS (moles/L)</td>
<td>748.0a</td>
<td>654.0b</td>
<td>36.148</td>
</tr>
<tr>
<td>OP (bar)</td>
<td>1.782a</td>
<td>1.603b</td>
<td>0.044</td>
</tr>
<tr>
<td>Nitrate (mg/L)</td>
<td>65.3a</td>
<td>46.7b</td>
<td>3.605</td>
</tr>
<tr>
<td>Chloride (mg/L)</td>
<td>7967.0a</td>
<td>7011.0b</td>
<td>94.987</td>
</tr>
<tr>
<td>Bromide (mg/L)</td>
<td>48.0b</td>
<td>51.0a</td>
<td>0.539</td>
</tr>
<tr>
<td>Flouride (mg/L)</td>
<td>52.0a</td>
<td>45.0b</td>
<td>1.045</td>
</tr>
</tbody>
</table>

*Means on each row followed by the same letter are not significantly different at p=0.05 using LSD.
Figure 2a.13. Comparative analyses of Na, Mg, Ca, K, and S content between marsh and canal water samples.
Figure 2a.14. Comparative distribution of TDS, IS, and OP water sample between the marsh and the canal.
Figure 2a.15. Comparative analyses of NO$_3^-$, Cl$^-$, Br$^-$, and F$^-$ content of water sample between the marsh and the canal.
the marsh samples.

The overall results presented in this section could be summarized into a single observation, i.e., marsh water samples had higher pH, EC, IS, OP, and concentrations of Na, Mg, Ca, S, Cl⁻, NO₃⁻, Br⁻, and F⁻ than the canal samples. This generalization can be explained by the "concentration effect" in the marsh because of fluctuating level of water as opposed to the "dilution effect" in the canal. This can be described as the renewal rate (RR). The RR is defined by Mitsch and Gosselink (1986) as the ratio of total inflow rate (Qt) to the average volume of water storage (V). Chemical and biotic properties might have been affected by the openness of the system (canal) and the frequency of water replacement in the system (marsh's environment). An environment like the marsh with high concentration effect would have much higher concentration of EC, TDS, IS, OP, Na, and many other biogeochemical properties.

Results in this study were consistent to the earlier study of Sigua and Hudnall (1989). They reported that drying the marsh would result in the detrimental alteration of the physicochemical properties of soil and water. They found that the EC and the concentration of water soluble Na, Fe, Mn, and Ca increased significantly from dried marsh soils and were significantly correlated to soil moisture. Mitsch and Gosselink (1986) also stressed that the depth of water, flow patterns, and duration and frequency of flooding, which are the results of all the hydrologic inputs and outputs, would influence the biochemistry of water and soils in the marsh.
SUMMARY AND CONCLUSIONS

Results disclosed temporal variations over time on some selected chemical properties of the brackish marsh water. The analysis of variance exhibited strong support to these temporal variations. Temporal variations were significantly correlated to precipitation and maximum and minimum temperature in the area. Consistently higher pH, EC, Na, Mg, S, TDS, IS, OP, Cl⁻, NO₃⁻, and F⁻ were observed from the marsh water samples than the canal.

The different temporal variations of the different chemical properties of brackish water were likely to affect the overall productivity of the marsh. They were indeed very crucial factors that should not be overlooked during the planning and management of operations in the marsh.

CHAPTER 2b: SEASONAL VARIABILITY OF SELECTED CHEMICAL PROPERTIES OF BRACKISH MARSH SOILS AT HACKBERRY, LOUISIANA

ABSTRACT

This study was conducted to determine the seasonal variations of some selected chemical properties of brackish marsh soils at Hackberry, LA and to evaluate the effect of gypsum addition on the seasonal variability of some selected properties of brackish soils.

Results indicated very strong seasonal variations in electrical conductivity (EC), pH, total dissolved solids (TDS), ionic strength (IS), and concentrations of water-soluble Fe, Al, Mn, S, Na, Ca, Mg, and K of the brackish marsh soils. Variations were also observed for the ratios of Ca/Mg, Na/K, and Na/Ca.
Application of 7 Mg gypsum ha\(^{-1}\) significantly increase soil pH, but reduced soil EC, TDS, IS, and the concentrations of water-soluble Na, Fe, Al, Mn, and S over time. These soil chemical properties were linearly and cubically related to the total precipitation and maximum temperature in the area.

Stochastic regression models that described the overall behavior of soil pH, EC, TDS, and IS in brackish marsh environment were established. The R\(^2\)-value for soil pH was 0.89, 0.99 for EC, 0.99 for TDS, and 0.98 for IS.

MATERIALS AND METHODS

Soil and Soil Analyses:

Soil samples were obtained from the flooded experimental plots that were previously amended with 7 Mg gypsum ha\(^{-1}\) and from the adjacent plots without gypsum treatment at Hackberry, LA. Four composite samples were obtained randomly at a depth of 0-25 cm from each 3x4 m plot. Each sample was mixed and stored at 5-10°C until the chemical analyses were initiated. Soil analyses included electrical conductivity (Rhoades, 1982), pH (McLean, 1982), and water-soluble Fe, Al, Mn, S, Ca, Mg, Na, and K by inductively coupled plasma spectroscopy (ICP). Soil extraction was performed via an automatic soil extractor. Distilled water was the extracting solution for the water-soluble cations. A 1:2 soil to water ratio was used for all the extractions.

Sampling Time:

Soil samples were collected at four different times of the year as listed below:

a. FALL (November 11, 1988)
Similar sampling procedures were followed for each sampling time specified.

Statistical Analysis:

Univariate and multivariate techniques of variance analysis and the Least Significant Difference (LSD) were conducted to evaluate the seasonal variations of some selected chemical properties of gypsum- and non-gypsum-amended brackish marsh soils (SAS, 1985). The principles of the regression and stepwise regression techniques as outlined in SAS Statistics Guide (SAS, 1985) were followed to determine the best fit in describing the effect of temperature and rainfall on some selected soil chemical properties. The different regression models describing the behavior of soil pH, electrical conductivity (EC), total dissolved solids (TDS), and ionic strength (IS) in brackish marsh soils were also evaluated.

Monthly precipitation and temperature:

Daily and monthly precipitation and temperature data were obtained from the Office of State Climatologist, Department of Anthropology and Geography, LSU.

RESULTS AND DISCUSSION

Seasonal variability and Gypsum addition:

Iron, Al, Mn, and S. The seasonal distribution, the effect of gypsum addition and the ANOVA of water-soluble Fe, Al, Mn, and S in brackish marsh soils are shown in Table 2b.1. Highly significant seasonal variations were observed on the concentrations of these nutrients. The
Table 2b.1. SEASONAL DISTRIBUTION OF WATER-SOLUBLE Fe, Al, Mn, AND S IN GYPSUM-AMENDED BRACKISH MARSH SOILS.

<table>
<thead>
<tr>
<th>Season ('88-'89)</th>
<th>Fe</th>
<th>Al</th>
<th>Mn</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mg kg(^{-1})</td>
<td>(%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FALL</td>
<td>5.53b</td>
<td>17.53a</td>
<td>0.85a</td>
<td>0.04a^a</td>
</tr>
<tr>
<td>WINTER</td>
<td>5.58b</td>
<td>13.80bc</td>
<td>0.33b</td>
<td>0.04a</td>
</tr>
<tr>
<td>SPRING</td>
<td>5.68b</td>
<td>13.47c</td>
<td>0.25c</td>
<td>0.03b</td>
</tr>
<tr>
<td>SUMMER</td>
<td>8.70a</td>
<td>16.03ab</td>
<td>0.43b</td>
<td>0.02c</td>
</tr>
<tr>
<td>LSD (0.05)</td>
<td>1.02</td>
<td>2.48</td>
<td>0.17</td>
<td>0.007</td>
</tr>
</tbody>
</table>

Gypsum addition (Mg kg\(^{-1}\))

<table>
<thead>
<tr>
<th></th>
<th>Fe</th>
<th>Al</th>
<th>Mn</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>7.39a</td>
<td>14.63a</td>
<td>0.65a</td>
<td>0.04a</td>
</tr>
<tr>
<td>7</td>
<td>5.35b</td>
<td>15.78a</td>
<td>0.28b</td>
<td>0.03b</td>
</tr>
<tr>
<td>LSD (0.05)</td>
<td>0.72</td>
<td>1.75</td>
<td>0.12</td>
<td>0.005</td>
</tr>
</tbody>
</table>

ANOVA

<table>
<thead>
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<th></th>
<th>F-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Season (Se)</td>
<td>20.84**</td>
</tr>
<tr>
<td>Gypsum (Gyp)</td>
<td>35.80**</td>
</tr>
<tr>
<td>Se x Gyp</td>
<td>30.82**</td>
</tr>
<tr>
<td>R(^2) model</td>
<td>0.92**</td>
</tr>
</tbody>
</table>

^a Means in column followed by common letter(s) are not significantly different at p=0.05.

** - Significant at p=0.01.
*  - Significant at p=0.05.
ns - Not significant
highest concentration of 8.70 mg kg\(^{-1}\) for Fe was observed during the summer while the least was during the fall. The average Fe concentrations were: fall (5.53 mg kg\(^{-1}\)), winter (5.58 mg kg\(^{-1}\)), and spring (5.58 mg kg\(^{-1}\)). The highest Mn concentration was observed during the fall (0.85 mg kg\(^{-1}\)) followed by summer (0.43 mg kg\(^{-1}\)) and winter (0.33 mg kg\(^{-1}\)). The least Mn concentration of 0.25 mg kg\(^{-1}\) was from the spring sample. Between fall and winter sampling, S did not show any variation while a slight increased in S concentration was noted for the summer and spring samples with means of 0.04, 0.04, 0.02, and 0.03%, respectively.

The addition of 7 Mg gypsum ha\(^{-1}\) significantly lowered the concentrations of Fe, Mn, and S, but there was no effect on Al concentration (Table 2b.1). The concentration of Fe in gypsum-amended plots was 2.04 mg kg\(^{-1}\) lower than the non-gypsum-amended plots or 38% lower due to addition of 7 Mg gypsum ha\(^{-1}\). Similarly, the concentration of Mn was lowered from 0.65 to 0.28 mg kg\(^{-1}\) while the concentration of S was reduced from 0.04 to 0.03%.

Data presented in Figure 2b.1 shows the interaction effect of gypsum and season on the concentrations of Fe, Mn, Al, and S in the brackish marsh soils. Significant interaction effects were observed on Fe, Mn, and Al, but not on S concentration (Table 2b.1). There was an upward seasonal trend on the concentrations of Mn, Fe, Al, and S, but generally a lower concentration of these nutrients on gypsum-amended plots. The highest mean concentrations of Mn, Fe, Al, and S were observed in the fall (1.4 mg kg\(^{-1}\)), summer (13.0 mg kg\(^{-1}\)), summer (20.0 mg kg\(^{-1}\)), and winter (0.06%) on plots without gypsum addition, respectively.
Figure 2b.1. Seasonal variability of Mn, Al, Fe, and S in brackish marsh soils as affected by gypsum addition.
Sodium, Mg, Ca, and K. Data given in Table 2b.2 shows the significant effect of season, gypsum, and their interaction effects on the concentrations of Na, Mg, Ca, and K on brackish marsh soils. Seasonal distribution of Na shows that the highest concentration was observed from the fall samples on plots without gypsum addition with a mean of 0.16% (Table 2b.2). The highest concentrations of Mg, Ca, and K were observed from the fall, winter, and winter samples with mean concentration of 0.02, 0.17, and 0.07%, respectively. However, the mean concentrations of Na, Mg, Ca, and K between the fall and winter sampling were statistically comparable. The lowest concentrations of these elements: Na (0.11%), Mg (0.005%), Ca (0.006%), and K (0.003%) were all obtained from the summer samples. Further, these elements showed a very significant concentration reduction from fall to summer, i.e., 0.16 to 0.11%, 0.02 to 0.005%, 0.015 to 0.006%, and 0.07 to 0.003%.

Plots that were applied with 7 Mg gypsum ha⁻¹ had lower concentrations of Na, Mg, and Ca when compared to the plots without gypsum treatment. No significant effect of gypsum addition was observed on the concentration of K (Table 2b.2). The concentration of Na in gypsum-amended plots was 0.014% lower than the control plots. The concentrations of Mg and Ca were lowered in response to gypsum from 0.020 to 0.010% and 0.014 to 0.010% or equivalent reduction of 50.0% and 28.6%, respectively. The level of K for both plots were the same with a mean concentration of 0.04%.

pH, EC, TDS, and IS. The seasonal distribution of pH, electrical conductivity (EC), total dissolved solids (TDS), and ionic strength (IS) are shown in Table 2b.3. The effect of gypsum addition and the interaction
Table 2b.2. SEASONAL DISTRIBUTION OF WATER-SOLUBLE NA, MG, CA, AND K IN GYPSUM-AMENDED BRACKISH MARSH SOILS.

<table>
<thead>
<tr>
<th>Season ('88-'89)</th>
<th>Na (%)</th>
<th>Mg (%)</th>
<th>Ca (%)</th>
<th>K (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FALL</td>
<td>0.16a</td>
<td>0.02a</td>
<td>0.015a</td>
<td>0.07a</td>
</tr>
<tr>
<td>WINTER</td>
<td>0.15ab</td>
<td>0.02bc</td>
<td>0.017a</td>
<td>0.07a</td>
</tr>
<tr>
<td>SPRING</td>
<td>0.14b</td>
<td>0.01b</td>
<td>0.010b</td>
<td>0.02b</td>
</tr>
<tr>
<td>SUMMER</td>
<td>0.11c</td>
<td>0.005c</td>
<td>0.006c</td>
<td>0.003c</td>
</tr>
<tr>
<td>LSD (0.05)</td>
<td>0.02</td>
<td>0.001</td>
<td>0.001</td>
<td>0.006</td>
</tr>
</tbody>
</table>

Gypsum addition (Mg kg⁻¹)

<table>
<thead>
<tr>
<th></th>
<th>Na (%)</th>
<th>Mg (%)</th>
<th>Ca (%)</th>
<th>K (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.142a</td>
<td>0.020a</td>
<td>0.014a</td>
<td>0.04a</td>
</tr>
<tr>
<td>7</td>
<td>0.028b</td>
<td>0.010b</td>
<td>0.010b</td>
<td>0.04a</td>
</tr>
<tr>
<td>LSD (0.05)</td>
<td>0.012</td>
<td>0.001</td>
<td>9x10⁻⁶</td>
<td>0.004</td>
</tr>
</tbody>
</table>

ANOVA F-value

<table>
<thead>
<tr>
<th></th>
<th>F-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Season (Se)</td>
<td>17.06**</td>
</tr>
<tr>
<td>Gypsum (Gyp)</td>
<td>0.04**</td>
</tr>
<tr>
<td>Se x Gyp</td>
<td>3.21**</td>
</tr>
<tr>
<td>R² model</td>
<td>0.79**</td>
</tr>
</tbody>
</table>

*a*Means in column followed by common letter(s) are not significantly different at p=0.05.

** - Significant at p=0.01.

* - Significant at p=0.05.

ns - Not significant
Figure 2b.2. Seasonal variability of pH, IS, and TDS in brackish marsh soils as affected by gypsum addition.
Table 2b.3. SEASONAL DISTRIBUTION OF pH, ELECTRICAL CONDUCTIVITY (EC), TOTAL DISSOLVED SOLIDS (TDS), AND IONIC STRENGTH (IS) IN GYPSUM-AMENDED BRACKISH MARSH SOILS.

<table>
<thead>
<tr>
<th>Season('88-'89)</th>
<th>pH</th>
<th>EC</th>
<th>TDS&lt;sup&gt;a&lt;/sup&gt;</th>
<th>IS&lt;sup&gt;b&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>(dS m&lt;sup&gt;-1&lt;/sup&gt;)</td>
<td>(mg kg&lt;sup&gt;-1&lt;/sup&gt;)</td>
<td>(moles L&lt;sup&gt;-1&lt;/sup&gt;)</td>
</tr>
<tr>
<td>FALL</td>
<td>5.73c</td>
<td>7.80a</td>
<td>4992.0a</td>
<td>1726.0ac</td>
</tr>
<tr>
<td>WINTER</td>
<td>5.70c</td>
<td>7.03b</td>
<td>4501.3b</td>
<td>1451.0b</td>
</tr>
<tr>
<td>SPRING</td>
<td>6.27b</td>
<td>5.00c</td>
<td>3200.0c</td>
<td>728.1c</td>
</tr>
<tr>
<td>SUMMER</td>
<td>6.65a</td>
<td>3.50d</td>
<td>2240.0d</td>
<td>381.3d</td>
</tr>
<tr>
<td>LSD (0.05)</td>
<td>0.32</td>
<td>0.442</td>
<td>80.6</td>
<td>175.2</td>
</tr>
</tbody>
</table>

Gypsum addition (Mg kg<sup>-1</sup>)

<table>
<thead>
<tr>
<th></th>
<th>pH</th>
<th>EC</th>
<th>TDS&lt;sup&gt;a&lt;/sup&gt;</th>
<th>IS&lt;sup&gt;b&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>5.92b</td>
<td>6.30a</td>
<td>4032.0a</td>
<td>1281.6a</td>
</tr>
<tr>
<td>7</td>
<td>6.26a</td>
<td>5.37b</td>
<td>3434.7b</td>
<td>861.5b</td>
</tr>
<tr>
<td>LSD (0.05)</td>
<td>0.23</td>
<td>0.31</td>
<td>198.42</td>
<td>123.9</td>
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</tbody>
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ANOVA

<table>
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<th></th>
<th>F-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Season (Se)</td>
<td>17.83**</td>
</tr>
<tr>
<td>Gypsum (Gyp)</td>
<td>10.01**</td>
</tr>
<tr>
<td>Se x Gyp</td>
<td>1.53ns</td>
</tr>
<tr>
<td>R&lt;sup&gt;2&lt;/sup&gt; model</td>
<td>0.98**</td>
</tr>
</tbody>
</table>

<sup>a</sup>TDS = EC x 640 (Richards, 1954)

<sup>b</sup>IS = 0.001 + 15.90EC + 25.89EC<sup>2</sup> (Ponnampremeruma et al., 1966)

<sup>c</sup>Means in column followed by common letter(s) are not significantly different at p=0.05.

** - Significant at p=0.01.
* - Significant at p=0.05.
ns - Not significant
The ANOVA in Table 2b.3 and Figures 2b.2 and 2b.3 show highly significant interaction effect of season and gypsum addition on EC, TDS, and IS. However, no significant interaction effect was observed on soil pH.

Soil samples taken from plots with gypsum treatment have significantly higher pH values than those samples taken from the control plots. The EC of gypsum-amended soils was 0.93 dS m\(^{-1}\) lower than the soils without gypsum treatment. Application of 7 Mg gypsum ha\(^{-1}\) reduced TDS (4032 to 3435 mg kg\(^{-1}\)) and IS (1282 to 862 moles L\(^{-1}\)). These differences were statistically significant (Table 2b.3).

Mg/Ca, Na/K, and Na/Ca Ratios. The seasonal distribution of Mg/Ca, Na/K, and Na/Ca ratios in brackish marsh soils are shown in Table 2b.4. The effect of gypsum addition on their distribution and interaction effect of season and gypsum are also shown in Table 2b.4. The highest Mg/Ca ratio
Figure 2b.3. Seasonal variability of EC, Na, and Na/Ca ratio in gypsum-amended brackish marsh soil.
Table 2b.4. SEASONAL DISTRIBUTION OF Mg/CA RATIO, Na/K RATIO, AND Na/CA RATIO IN GYPSUM-AMENDED BRACKISH MARSH SOILS.

<table>
<thead>
<tr>
<th>Season ('88-'89)</th>
<th>Mg/CaRatio</th>
<th>Na/KRatio</th>
<th>Na/CaRatio</th>
</tr>
</thead>
<tbody>
<tr>
<td>FALL</td>
<td>1.42a</td>
<td>2.38c</td>
<td>10.88c</td>
</tr>
<tr>
<td>WINTER</td>
<td>1.38a</td>
<td>2.04c</td>
<td>10.24c</td>
</tr>
<tr>
<td>SPRING</td>
<td>1.43a</td>
<td>7.49b</td>
<td>13.11b</td>
</tr>
<tr>
<td>SUMMER</td>
<td>0.84b</td>
<td>32.20a</td>
<td>18.22a</td>
</tr>
<tr>
<td>LSD (0.05)</td>
<td>0.17</td>
<td>3.82</td>
<td>1.37</td>
</tr>
</tbody>
</table>

Gypsum addition (Mg kg⁻¹)

<table>
<thead>
<tr>
<th></th>
<th>Mg/CaRatio</th>
<th>Na/KRatio</th>
<th>Na/CaRatio</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1.28a</td>
<td>12.19b</td>
<td>12.19b</td>
</tr>
<tr>
<td>7</td>
<td>1.26a</td>
<td>14.03a</td>
<td>14.03a</td>
</tr>
<tr>
<td>LSD (0.05)</td>
<td>0.12</td>
<td>2.73</td>
<td>0.98</td>
</tr>
</tbody>
</table>

ANOVA

<table>
<thead>
<tr>
<th></th>
<th>F-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Season (Se)</td>
<td>25.83**</td>
</tr>
<tr>
<td>Gypsum (Gyp)</td>
<td>0.04ns</td>
</tr>
<tr>
<td>Se x Gyp</td>
<td>13.87**</td>
</tr>
<tr>
<td>R² model</td>
<td>0.88**</td>
</tr>
</tbody>
</table>

*a Means in column followed by common letter(s) are not significantly different at p=0.05.

** - Significant at p=0.01.

* - Significant at p=0.05.

ns - Not significant
of 1.43 was observed from samples in the spring, followed by fall and winter sampling with mean ratio of 1.42 and 1.38. The lowest Mg/Ca ratio of 0.84 was obtained from the summer samples. The seasonal distribution of Na/K ratio shows a range of 2.04 to 32.20 with the highest ratio observed during the summer and the lowest ratio was during the winter sampling. A Na/K ratio of 7.49 was observed during the spring sampling. The seasonal distribution of Na/Ca ratio as shown in descending order: summer > spring > fall > winter with mean ratios of 18.22, 13.11, 10.88, and 10.24, respectively.

Seasonal variations of some selected chemical properties of brackish marsh soils have been presented. Very significant seasonal variations were observed for almost all soil chemical parameters. These variations are explained by some related and interrelated factors that are operating and active in the marsh environment. These factors included the quantity and quality of hydrologic conditions, tidal action, wind factor, temperature, precipitation, and vegetative factors in the area. Earlier studies conducted by Brannon (1973) and DeLaune et al., (1976) stressed similar factors. Brannon (1973) reported that the spring tidal action was probably responsible for the increase in soil pH, initiating microbial reduction and increasing the pH of acid soils during the spring. According to Mitsch and Gosselink (1986), the periodic and predictable tidal inundation of coastal marshes act as a stress by causing submergence and soil anaerobiosis; it acts as subsidy by removing excess salts, reestablishing aerobic conditions, and providing nutrients. Likewise, Ho and Jane (1973) stressed the phenomenon of seasonal variability of sediments in Barataria Bay, LA. They attributed these variations to tidal and wind actions.
that play important roles in the vertical mixing process. DeLaune et al., (1976) have attributed nutrient transformation in LA marshes to the prevailing southerly winds keeping the soil inundated during the summer months and northerly winds during the winter months that tended to keep the tidal water away from the marsh. They also stressed the importance of temperature on nutrient transformation. Cho and Ponnampemura (1971) reported that low temperature during the winter months favors accumulation of volatile organic acids.

In the study conducted by Sigua and Hudnall (1989), they reported that drying marsh soils would significantly increase the soil EC and the concentrations of water-soluble Na, Fe, Mg, and Ca. They reported a significant decrease in soil pH. A significant correlation between these soil properties and soil moisture were also observed.

Another important result was the significant effect of gypsum addition on seasonal variations of some selected chemical properties of brackish marsh soils. Except for Al, K, and Mg/Ca ratio, all other chemical properties were significantly affected by gypsum addition. The importance of gypsum addition is also discussed in Chapters 3, 4, and 5. The EC of the samples that were treated with 7 Mg gypsum ha⁻¹ had a lower value of 5.37 dS m⁻¹, or 0.93 dS m⁻¹ lower than the samples without gypsum treatment. Gypsum is used as a source of soluble Ca for reclaiming sodic soils, preventing soil crusting, and ameliorating water quality (Gobran et al., 1982; Oster, 1982; Gobran and Miyamoto, 1985). Bower (1969) reported that the application of gypsum followed by leaching is the most common method employed to replace adsorbed Na.
Effects of Temperature and Rainfall:

Monthly precipitation and temperature distribution. The monthly total distribution of precipitation and variations in the minimum and maximum temperature at Hackberry, LA are shown in Figure 2b.4. Data given in Figure 2b.4 showed that the highest recorded precipitation of 55.0 cm in the area was in June, 1989 and the lowest precipitation of 2.0 cm was in November, 1988 and February, 1989. Monthly distribution of precipitation in the area was very variable with few months of increasing precipitation followed by several months of very low precipitation especially during the months of September, 1988 to April, 1989.

The highest recorded temperature was in the months of August, 1988 and August, 1989 with mean maximum temperature of 33 and 32°C, respectively. The distribution of the minimum temperature was very similar to the trend of the maximum temperature. The months of September, 1988 and August, 1989 have the highest minimum temperature while the months of December, 1988 and February, 1989 have the lowest recorded minimum temperature with means of 25 and 24°C and 8 and 7°C, respectively.

Sodium and Ca concentrations. The linear and cubic relationships of Na and Ca concentration to total precipitation and maximum temperature are shown in Figures 2b.5 and 2b.6. The concentrations of Na and Ca were both negatively related to precipitation and maximum temperature. The linear model shows a negative slope of -0.0006 and -0.0001 and -0.004 and -0.0009 for Na and Ca, respectively. The R² value was improved from the linear model to cubic model: Na (0.21 to 0.66) and Ca (0.26 to 0.66) on the effect of precipitation and Na (0.49 to 0.66) and Ca (0.54 to 0.57) as
Figure 2b.4. Monthly and seasonal (average) distribution of precipitation, minimum and maximum temperature at Hackberry, LA.
Figure 2b.5. Regression analysis on the relationship of Na and Ca concentrations and total precipitation in brackish marsh soils.
Figure 2b.6. Regression analysis on the relationship of Na and Ca concentrations to maximum temperature in brackish marsh soils.
affected by maximum temperature in the area. Equations 2b.1, 2b.2, 2b.3, 2b.4, show the linear relationship while equations 2b.5, 2b.6, 2b.7, and 2b.8 depict the cubic relationships of Na and Ca to precipitation (P) and maximum temperature (MT), respectively.

\[ \text{Na} = 0.16 - 0.0006(P) \]  \[2b.1\]
\[ \text{Na} = 0.23 - 0.004(MT) \]  \[2b.2\]
\[ \text{Ca} = 0.02 - 0.0001(P) \]  \[2b.3\]
\[ \text{Ca} = 0.02 - 0.0009(MT) \]  \[2b.4\]
\[ \text{Na} = 0.008 - 0.01(P) + 0.003(P^2) - 0.000003(P^3) \]  \[2b.5\]
\[ \text{Na} = -0.25 + 0.04(MT) - 0.001(MT^2) + 0.00001(MT^3) \]  \[2b.6\]
\[ \text{Ca} = -0.06 + 0.007(P) + 0.0002(P^2) - 0.00004(P^3) \]  \[2b.7\]
\[ \text{Ca} = -0.06 + 0.009(MT) - 0.0004(MT^2) + 0.00004(MT^3) \]  \[2b.8\]

**Electrical conductivity and pH.** The relationship of EC and pH to precipitation and maximum temperature are shown in Figures 2b.7 and 2b.8. The EC of the soil was negatively related to increasing precipitation, but increased by 1.61 dS m\(^{-1}\) for every unit increase in the maximum temperature. Approximately 0.01 and 0.08 unit increase in soil pH are expected for every unit increased in precipitation and maximum temperature. These linear relationships were further improved in the cubic model by virtue of the increasing R\(^2\) value. The linear models for these relationships were described below:

\[ \text{EC} = 8.77 - 0.06(P) \]  \[2b.9\]
\[ \text{EC} = -9.39 + 1.61(MT) \]  \[2b.10\]
\[ \text{pH} = 5.44 + 0.01(P) \]  \[2b.11\]
\[ \text{pH} = 4.15 + 0.08(MT) \]  \[2b.12\]

while the cubic models were given in equations 2b.13 to 2b.16.
Figure 2b.7. Regression analysis on the relationship of EC and pH values and total precipitation in brackish marsh soils.
Figure 2b.8. Regression analysis on the relationship of EC and pH values to maximum temperature in brackish marsh soils.
EC = -0.53 + 0.80(P) - 0.02(P²) + 0.0002(P³) \ [2b.13] \\
EC = -130.43 + 16.92(MT) - 0.67(MT²) + 0.008(MT³) \ [2b.14] \\
pH = 9.41 - 0.32(P) + 0.008(P²) - 0.00007(P³) \ [2b.15] \\
pH = 2.84 -2.12(MT) + 0.08(MT²) - 0.001(MT³) \ [2b.16] 

Total dissolved solids and Na/Ca Ratio. Figures 2b.9 and 2b.10 show the relationship of TDS and Na/Ca ratio to precipitation and maximum temperature. The linear models that described the said relationship are shown in equations 2b.17, 2b.18, 2b.19 and 2b.20 while equations 2b.21, 2b.22, 2b.23, and 2b.24 described the cubic relationship of TDS and Na/Ca ratio to precipitation and maximum temperature.

TDS = 5614.51 - 40.74(P) \ [2b.17] \\
TDS = 8594.79 - 194.07(MT) \ [2b.18] \\
Na/Ca = 9.50 + 0.08(P) \ [2b.19] \\
Na/Ca = -1.64 + 0.59(MT) \ [2b.20] \\
TDS = -343.76 + 512.46(P) - 14.80(P²) + 0.11(P³) \ [2b.21] \\
TDS = -83475.77+10830.65(MT)-429.51(MT²)+5.43(MT³) \ [2b.22] \\
Na/Ca = 45.59 - 2.99(P) + 0.088(P²) - 0.00006(P³) \ [2b.23] \\
Na/Ca = -43.43 + 7.61(MT) - 0.36(MT²) + 0.006(MT³) \ [2b.24] 

Multiple Regression Models:

An attempt was made to establish stochastic regression models. These models were used to describe the behavior of pH, EC, TDS, and IS in brackish marsh environment. Tables 2b.5 and 2b.6 show the different stochastic models describing the overall behavior of pH, EC, TDS, and IS in brackish marsh environment. The different variables in each model were generated using stepwise regression technique and were considered the best combination. The different regression models for soil pH, EC, TDS, and IS
Figure 2b.9. Regression analysis on the relationship of TDS and Na/Ca ratio to total precipitation in brackish marsh soils.
Figure 2b.10. Regression analysis on the relationship of TDS and Na/Ca ratio to maximum temperature in brackish marsh soils.
Table 2b.5. REGRESSION MODEL (BEST-FIT) DESCRIBING THE BEHAVIOR OF pH AND ELECTRICAL CONDUCTIVITY (EC) IN BRACKISH MARSH SOILS.

<table>
<thead>
<tr>
<th>Soil Property</th>
<th>b-value</th>
<th>Std. Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. pH</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intercept (b₀)</td>
<td>0.44</td>
<td>0.05</td>
</tr>
<tr>
<td>Al (mg/kg)</td>
<td>-0.04</td>
<td>0.05</td>
</tr>
<tr>
<td>Mn (mg/kg)</td>
<td>-0.63</td>
<td>0.27</td>
</tr>
<tr>
<td>Na (%)</td>
<td>4.24</td>
<td>5.40</td>
</tr>
<tr>
<td>K (%)</td>
<td>9.01</td>
<td>10.40</td>
</tr>
<tr>
<td>S (%)</td>
<td>-3.19</td>
<td>8.88</td>
</tr>
<tr>
<td>Precipitation (mm)</td>
<td>-0.005</td>
<td>0.009</td>
</tr>
<tr>
<td>Max. Temperature (°C)</td>
<td>0.09</td>
<td>0.05</td>
</tr>
<tr>
<td>R-square</td>
<td></td>
<td>0.88**</td>
</tr>
<tr>
<td>2. Electrical conductivity (EC)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intercept (b₀)</td>
<td>-0.26</td>
<td>0.07</td>
</tr>
<tr>
<td>Fe (mg/kg)</td>
<td>0.07</td>
<td>0.04</td>
</tr>
<tr>
<td>Al (mg/kg)</td>
<td>-0.0006</td>
<td>0.04</td>
</tr>
<tr>
<td>Mn (mg/kg)</td>
<td>-0.51</td>
<td>0.31</td>
</tr>
<tr>
<td>Na (%)</td>
<td>6.23</td>
<td>7.41</td>
</tr>
<tr>
<td>Ca (%)</td>
<td>-22.06</td>
<td>231.67</td>
</tr>
<tr>
<td>MgCaRatio</td>
<td>-0.19</td>
<td>1.56</td>
</tr>
<tr>
<td>Precipitation (mm)</td>
<td>-0.03</td>
<td>0.01</td>
</tr>
<tr>
<td>Max. Temperature (°C)</td>
<td>0.24</td>
<td>0.05</td>
</tr>
<tr>
<td>R-square</td>
<td></td>
<td>0.99**</td>
</tr>
</tbody>
</table>
Table 2b.6. REGRESSION MODEL (BEST-FIT) DESCRIBING THE BEHAVIOR OF TOTAL DISSOLVED SOLIDS (TDS) AND IONIC STRENGTH (IS) IN BRACKISH MARSH SOILS.

<table>
<thead>
<tr>
<th>Soil Property</th>
<th>b-value</th>
<th>Std. Error</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1. Total dissolved solids (TDS)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intercept (b₀)</td>
<td>-164.32</td>
<td></td>
</tr>
<tr>
<td>Fe (mg/kg)</td>
<td>-45.48</td>
<td>47.76</td>
</tr>
<tr>
<td>Al (mg/kg)</td>
<td>-0.38</td>
<td>24.74</td>
</tr>
<tr>
<td>Mn (mg/kg)</td>
<td>-323.94</td>
<td>201.01</td>
</tr>
<tr>
<td>Na (%)</td>
<td>-4242.88</td>
<td>4743.28</td>
</tr>
<tr>
<td>Mg (%)</td>
<td>95261.25</td>
<td>113255.70</td>
</tr>
<tr>
<td>K (%)</td>
<td>17494.85</td>
<td>7541.14</td>
</tr>
<tr>
<td>S (%)</td>
<td>17319.24</td>
<td>6511.32</td>
</tr>
<tr>
<td>Precipitation (mm)</td>
<td>-19.30</td>
<td>6.69</td>
</tr>
<tr>
<td>Max. Temperature (°C)</td>
<td>158.47</td>
<td>34.00</td>
</tr>
<tr>
<td>R-square</td>
<td>0.99**</td>
<td></td>
</tr>
<tr>
<td><strong>2. Ionic strength (IS)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intercept (b₀)</td>
<td>-1420.94</td>
<td></td>
</tr>
<tr>
<td>Fe (mg/kg)</td>
<td>-12.32</td>
<td>26.90</td>
</tr>
<tr>
<td>Al (mg/kg)</td>
<td>-0.13</td>
<td>13.93</td>
</tr>
<tr>
<td>Mn (mg/kg)</td>
<td>-164.66</td>
<td>113.21</td>
</tr>
<tr>
<td>Na (%)</td>
<td>-5280.64</td>
<td>2671.40</td>
</tr>
<tr>
<td>Mg (%)</td>
<td>55035.17</td>
<td>63785.17</td>
</tr>
<tr>
<td>Ca (%)</td>
<td>5457.43</td>
<td>83501.91</td>
</tr>
<tr>
<td>NaKRatio</td>
<td>-0.79</td>
<td>8.47</td>
</tr>
<tr>
<td>NaCaRatio</td>
<td>-15.49</td>
<td>30.65</td>
</tr>
<tr>
<td>Precipitation (mm)</td>
<td>-10.54</td>
<td>3.77</td>
</tr>
<tr>
<td>Max. Temperature (°C)</td>
<td>96.24</td>
<td>19.15</td>
</tr>
<tr>
<td>R-square</td>
<td>0.98**</td>
<td></td>
</tr>
</tbody>
</table>
are further described in equation 2b.25, 2b.26, 2b.27, and 2b.28, respectively.

\[
pH = 0.44 - 0.04(Al) - 0.63(Mn) + 4.24(Na) + 9.01(K) - 3.19(S) - 0.005(\text{Precip}) + 0.09(\text{MaxT}) \quad \text{R-square} = 0.89^{**} \quad [2b.25]
\]

\[
EC = -0.26 - 0.07(Fe) - 0.0006(Al) - 0.51(Mn) + 6.23(Na) - 22.06(Ca) - 0.19(Mg/Ca) - 0.03(\text{Precip}) + 0.24(\text{MaxT}) \quad \text{R-square} = 0.99^{**} \quad [2b.26]
\]

\[
TDS = -164.32 - 45.48(Fe) - 0.038(Al) - 323.94(Mn) - 4242.88(Na) + 95261.25(Mg) + 17494.85(K) + 17319.24(S) - 19.30(\text{Precip}) + 158.47(\text{MaxT}) \quad \text{R-square} = 0.99^{**} \quad [2b.27]
\]

\[
IS = -1420.94 - 12.32(Fe) - 0.13(Al) - 164.66(Mn) - 5280.64(Na) + 55035.17(Mg) + 5457.43(Ca) - 0.79(Na/Ca) - 15.49(Na/Ca) - 10.54(\text{Precip}) + 96.24(\text{MaxT}) \quad \text{R-square} = 0.98^{**} \quad [2b.28]
\]

**SUMMARY AND CONCLUSIONS**

The objectives of this study were: 1) to determine the seasonal variations of some selected chemical properties of brackish marsh soils in Hackberry, Louisiana and 2) to evaluate the effect of gypsum addition on these seasonal variations. Soil samples were collected from plots from which 7 Mg gypsum ha\(^{-1}\) had been added and plots without gypsum treatment.

Important conclusions drawn from this study are as follows:

1. Seasonal variations of soil pH, EC, TDS, IS, and concentrations of Na, Ca, Mg, Fe, Al, Mn, and S were observed. These variations were significantly related to precipitation, maximum temperature, and the interrelationship among these parameters.

2. The Na and Ca concentrations, pH, EC, TDS, and IS were linearly and cubically related to total precipitation and maximum temperature. Cubic models explained a better relationship because of higher \(R^2\) value when compared to the linear models.
3. The addition of 7 Mg gypsum ha\(^{-1}\) significantly affected some of the selected chemical properties. Significantly lower EC, TDS, IS, and concentrations of Fe, Al, Mn, and S over time were obtained from samples treated with gypsum when compared to the control.

4. Regression models that described the overall behavior of soil pH, EC, TDS, and IS in brackish marsh environment were established.

**LITERATURE CITED**


CHAPTER 3

RELATIONSHIPS OF DRYING AND ELECTRICAL CONDUCTIVITY TO UREASE ACTIVITY IN A BRACKISH MARSH

[A modified version of this chapter was submitted and published in the U. S. Fish, Wildlife, and Biological Report 89(2):86-97]
ABSTRACT

Surface horizons (Oa1 + Oa2) of brackish marsh soils collected at Hackberry, LA were studied to determine the effect of soil drying and electrical conductivity (EC) on soil properties that are related to urease activity.

Soil drying significantly reduced urease activity and increased EC and the concentration of water-soluble Na, Fe, Mn, Mg, and Ca. There was a significant decrease in soil pH after three months of drying. These soils and soil-related factors were significantly correlated to soil moisture (MC). There was a general reduction in urease activity as levels of EC increased. Addition of gypsum, however, did not result in any significant increase of urease activity but there was a numerical increase of 50% in urease activity of soil treated with 20 Mg ha\(^{-1}\) over the control.

Multiple regression analyses of the data showed that variation in urease activity in brackish marsh soil was best accounted for \((R^2 = 0.74)\) by the following equation: \(UA = 29.64 - 4.598(pH) - 0.041(EC) + 0.008(MC) - 0.002(Na)\).

INTRODUCTION

Wetland loss in LA is a widely recognized problem over the entire state. Each year, LA loses approximately 167 square km to natural subsidence, erosion and man's intervention (LA, DNR 1986). Marshes, as part of our land and natural water regime, are irreplaceable natural resources that must be preserved. One of the possible solutions for saving wetlands from natural and accelerated losses is through restoration of vegetation. Restoration with suitable marsh vegetation usually requires some elaborate management practices that include soil drainage,
fertilization, and various other cultural practices. Soil drainage and fertilization are the two most important components for two reasons: a) soil drainage, which is especially important at the seedling or early stage of growth establishment, is likely to affect the microbial and physicochemical properties of the soil, and b) although most marsh soils in LA contain considerable amount of organic C (OC), the marsh is most limited in N (Broome et al., 1975; Patrick and DeLaune, 1976; Mendelssohn, 1979; Smart and Barko, 1980).

The work reported here identifies some of the probable effects on soil properties associated with drying a brackish marsh for an extended period. Data will be presented on the causes of low N availability in the marsh and the relationships between soil urease activity and soil properties at different soil moisture contents. Although there are several studies (Savant et al., 1985; Zantua et al., 1977; Zantua and Bremner, 1975; Pettit et al., 1976; Zantua and Bremner, 1976; Stojanovic, 1959; Conrad, 1940) limited to well-drained soils and a few from waterlogged rice soils (Sahrawat, 1980; DeLaune and Patrick, 1970; Islam and Parsons, 1979), the general principles and concepts of N availability and losses are applicable to N availability in the marsh environment. The ongoing research and the results reported here will have paramount importance to the revegetation plans for brackish and salt marsh soils. The objective of this investigation was to determine the effect of soil drying, gypsum addition, and electrical conductivity (EC) on soil properties that are related to urease activity.
MATERIALS AND METHODS

Soil and sampling procedures:

Soil samples were obtained from Clovelly soil series (clayey, montmorillonitic, euic, thermic Terric Medisaprists) at a depth of 0-25 cm from an open area presently inundated by brackish-water located at Black Ridge, Hackberry, LA. Eight composite samples were collected at approximately 200-300 meter intervals covering a total area of 0.40 ha. Each sample was mixed, divided into three subsamples and stored at 5-10°C until the different treatments were applied.

Soil amendments and treatments:

To evaluate the effects of soil drying, gypsum additions, and salinity on soil properties that are related to urease activity, three experiments, (Table 3.1), were conducted.

TABLE 3.1. Experimental variables and treatments.

<table>
<thead>
<tr>
<th>Experimental Variables</th>
<th>Treatments</th>
<th>Incubation conditions and urea addition</th>
</tr>
</thead>
<tbody>
<tr>
<td>I. Soil Drying</td>
<td>None - DO</td>
<td>30°C, 2000 mg kg(^{-1}) urea</td>
</tr>
<tr>
<td></td>
<td>Air drying (1.5 months) - D1.5</td>
<td>30°C, 2000 mg kg(^{-1}) urea</td>
</tr>
<tr>
<td></td>
<td>Air drying (3.0 months) - D3.0</td>
<td>30°C, 2000 mg kg(^{-1}) urea</td>
</tr>
<tr>
<td>II. Gypsum Additions</td>
<td>0, 5, 10, 20 Mg ha(^{-1})</td>
<td>30°C, saturated, 10 days, 2000 mg ha(^{-1}) urea</td>
</tr>
<tr>
<td>III. Salinity Level</td>
<td>0.1, 0.4, 0.8 1.6 S m(^{-1})(1:1 NaCl-CaCl(_2) mixtures</td>
<td>30°C, saturated, 10 days, 2000 mg ha(^{-1}) urea</td>
</tr>
</tbody>
</table>
Experiment I.

The purpose of the first experiment was to determine the effect of drying on urease activity. Triplicate 5-g samples (Table 3.1, I. Soil Drying) were treated with 5 mL of 2000 mg L\(^{-1}\) urea solution and incubated at 30°C for 5 h. These samples were analyzed for urease activity following the procedure outlined by Tabatabai (1982). The soil was extracted with 50 mL of 2 M KCl–PMA (Phenylmercuric acid) solution as a urease inhibitor. The unhydrolyzed urea recovered in the KCl–PMA extract was determined colorimetrically. The amount of hydrolyzed urea was calculated as the difference between the urea added and the urea remaining.

The effect of soil drying on some soil properties related to urease activity was also determined. Triplicate 5-g samples of the two air-dried and one non air-dried soil samples were analyzed to determine soil pH, EC and water-soluble cations. An automatic soil extraction apparatus was used to extract the water-soluble cations. Concentrations of these cations were analyzed using the ICP (Inductively Couple Plasma) spectrophotometer.

Experiment II.

The objective of experiment II was to determine the effect of gypsum additions on urease activity. Triplicate 5-g samples of saturated soil were treated with 4 rates of gypsum (0, 5, 10, 20 Mg ha\(^{-1}\)) and incubated at 30°C for 10 days. After incubation, the samples were treated with 2000 mg L\(^{-1}\) of urea solution. Urease activity of the soil was determined following the same procedures used in Experiment I.

Experiment III.

The purpose of Experiment III was to determine the effect of
different levels of electrical conductivity on urease activity. Saturated samples were split into 12 subsamples, and electrical conductivity was adjusted to 0.1, 0.4, 0.8, and 1.6 S m\(^{-1}\) by adding artificially salinized water that contained 1:1 NaCl-CaCl\(_2\) mixture, and incubated at 30°C for 10 days. An application of 2000 mg L\(^{-1}\) urea was added to each soil. Urease activity was determined following the procedures outlined in Experiment I.

RESULTS AND DISCUSSION

Soil and Water Analyses:

Some properties of the representative soil profile and water sample analyses are given in Tables 3.2 and 3.3, respectively. Surface soils (Oa1 + Oa2) or the organic horizons have a pH range of 6.62 to 6.50; OC ranged from 20.23 to 33.72 %; and EC ranged from 0.42 to 0.72 S m\(^{-1}\). A general increase in the concentration of water-soluble cations was observed with depth.

Table 3.2. Selected soil chemical properties of undried soils.

<table>
<thead>
<tr>
<th>Horizon</th>
<th>Depth (cm)</th>
<th>pH</th>
<th>OC</th>
<th>EC S m(^{-1})</th>
<th>Fe* mg kg(^{-1})</th>
<th>Mn mg kg(^{-1})</th>
<th>Mg mg kg(^{-1})</th>
<th>Na mg kg(^{-1})</th>
<th>S %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oa1</td>
<td>0-10</td>
<td>6.6</td>
<td>20.2</td>
<td>0.4</td>
<td>0.6</td>
<td>0.02</td>
<td>8.3</td>
<td>66.6</td>
<td>9.4</td>
</tr>
<tr>
<td>Oa2</td>
<td>10-25</td>
<td>6.5</td>
<td>33.7</td>
<td>0.8</td>
<td>0.4</td>
<td>0.04</td>
<td>10.5</td>
<td>99.5</td>
<td>7.2</td>
</tr>
<tr>
<td>A</td>
<td>25-35</td>
<td>6.7</td>
<td>5.2</td>
<td>0.6</td>
<td>38.5</td>
<td>0.20</td>
<td>16.7</td>
<td>73.2</td>
<td>4.5</td>
</tr>
<tr>
<td>Cg1</td>
<td>35-60</td>
<td>7.0</td>
<td>2.5</td>
<td>0.4</td>
<td>56.2</td>
<td>0.20</td>
<td>21.1</td>
<td>67.9</td>
<td>4.5</td>
</tr>
<tr>
<td>Cg2</td>
<td>60+</td>
<td>7.4</td>
<td>1.2</td>
<td>0.4</td>
<td>13.7</td>
<td>0.30</td>
<td>7.3</td>
<td>7.0</td>
<td>4.3</td>
</tr>
</tbody>
</table>

* Water Soluble

OC = Organic Carbon
The water sample from the study area had a pH of 6.8, EC of 0.7 S m\(^{-1}\) and the following ion concentration in mg L\(^{-1}\): Fe, 0.49; Na, 897; Mg, 189; Ca, 85; and S, 145.

**Urease Activity and Soil Related Properties:**

Urease activity of brackish marsh soil as affected by soil drying is given in Figure 3.1. A significantly higher rate of urease activity was observed for D1.5 treatment and the lowest for the D3.0 treatment with an intermediate rate for the D0 treatment. With an extended drying period, many changes occur in the soil system. Ponnamperuma (1972) and DeLaune et al. (1976) showed that there was a significant increase of oxygen flux within the interstitial lattice during the development of aerobic conditions. This result would have occurred immediately with drying when the moisture (oven dry basis) was drastically lowered from 437 % (D0) to 21 % (D3.0), respectively (Table 3.4). It would appear however, that aerobiosis as a result of soil drying in brackish marsh soils did not favor urease activity. At the low moisture level of 21 %, the lack of free water in the soil apparently limited the contact between urea and soil urease while at higher water content of 437 %, urea hydrolysis is reportedly less dependent on soil moisture (Vlek and Carter, 1983; DeLaune and Patrick, 1970).
Figure 3.1. Effect of soil drying on urease activity in brackish marsh.
TABLE 3.4. Effect of soil drying on some soil and soil related properties of brackish marsh soil.

<table>
<thead>
<tr>
<th>Drying (mos)</th>
<th>pH</th>
<th>EC</th>
<th>MC</th>
<th>Na</th>
<th>Mn</th>
<th>Fe</th>
<th>Mg</th>
<th>Ca</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>7.06a</td>
<td>0.4a</td>
<td>437.3a</td>
<td>102.8a</td>
<td>0.1a</td>
<td>0.6a</td>
<td>13.8a</td>
<td>5.4a*</td>
</tr>
<tr>
<td>1.5</td>
<td>6.24b</td>
<td>1.7b</td>
<td>167.6b</td>
<td>493.4b</td>
<td>0.2b</td>
<td>1.0b</td>
<td>57.5b</td>
<td>23.4b</td>
</tr>
<tr>
<td>3.0</td>
<td>6.06c</td>
<td>3.9c</td>
<td>21.4c</td>
<td>853.7c</td>
<td>0.7c</td>
<td>2.0c</td>
<td>235.6c</td>
<td>99.3c</td>
</tr>
</tbody>
</table>

*Means followed by the same letter are not significantly different at p = 0.05

MC = Moisture Content (Oven dry basis)

Reports on the effects of soil submergence and air wetland soil system. The actual processes are not completely understood. Zantua and Bremner (1977) found that air drying of field moist soils had no effect on urease activity. Bremner and Mulvaney (1978) noted that there was a difficulty in accounting for the effect of water content on urease activity in soils. Overrein (1963) reported that oxygen had a significant effect on the rate of hydrolysis of urea added to Indian soils. Conversely, Zantua and Bremner (1977) found that oxygen had no effect on the results obtained from the assay of urease activity in Iowa soils. The findings reported here differ from those of Savant et al. (1985) who disclosed that the order of urease activity of the wetland soil system was: oxidized > reduced > flooded. Presented in Table 3.4 and Figures 3.2, 3.3, and 3.4 are the data obtained as a result of soil drying on some soil properties that were measured in order to evaluate their relationship to urease activity. The EC and the concentrations of water-soluble Na, Mn, Fe, Mg, and Ca increased as the length of time of soil drying increased. Electrical conductivity increased from 0.39 to
Figure 3.2. Effect of soil drying on electrical conductivity in brackish marsh.
Figure 3.3. Effect of soil drying on Mn and Fe concentrations in brackish marsh.
Figure 3.4. Effect of soil drying on Na, Mg, and Ca concentrations in brackish marsh.
3.88 S m$^{-1}$ for an 895% difference between undried soils containing 437% water and soils that were air-dried for 3.0 months containing 21% water. The impact of soil drying on the concentration of water-soluble Na, Mn, Fe, Mg, and Ca, was noted as an increase of 730%, 1700%, 245%, 1606% and 1736%, respectively, when compared with soil without drying. This higher salt concentration resulting from drying of brackish marsh soil for 3.0 months could intensify the problem of nutrient toxicity and detrimentally affect native vegetation and revegetation. Although all mechanisms involved are not well understood, the significant reduction of urease activity at the end of 3.0-month drying can be partially attributed to the behavior of organic and inorganic colloids. Several workers have suggested that the urease in soils is protected by humus or clay colloids (Conrad, 1940; McLaren, 1963, 1975). Similarly, Pettit et al. (1976) suggested that soil urease is usually immobilized within the organic matter of the organo-mineral complex during humus formation. The organic matter at sufficient moisture has pores large enough to allow the passage of substrate (urea and water) and product (ammonia and carbon dioxide) molecules. If the same soils were subjected to irreversible drying, the pore spaces would be blocked and this would tend to trap urease within the crystal lattices. The escape of the urease itself is then prevented. This blocking mechanism associated with irreversible drying of marsh soils rich in organic matter will partially or totally prevent the contact between the soil colloid and the applied urea, thus, ultimately decreasing the amount of urea hydrolysis.

An attempt was made to establish a relationship between the reduction of urease activity and other measured properties in a brackish
marsh during long term drying (Table 3.5). Multiple regression analyses of the data was best accounted for variation in urease activity (R-square = 0.74) by the following equation:

\[
\text{Urease Activity (UA)} = 29.64 - 4.598(\text{pH}) - 0.041(\text{EC}) + 0.008 (\text{Moisture Content, MC}) - 0.002(\text{Na}) \tag{3.1}
\]

It is noteworthy that soil pH, EC, and Na had significant effects on the level of urease activity. It is likely that high salinity can partially or totally block the mechanism of urea hydrolysis because of increased energy expenditures required for the hydrolysis of urea at increasing ionic strength in the soils (Tanji, 1969; Ponnamperuma, 1972; DeLaune et al., 1976).

**TABLE 3.5. Numerical coefficients (b-values) of soil and soil related properties in equations and significance of these coefficients.**

<table>
<thead>
<tr>
<th>SOURCE</th>
<th>b-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Urease Activity (R-square = 0.74</strong>)**</td>
<td></td>
</tr>
<tr>
<td>Intercept</td>
<td>29.640</td>
</tr>
<tr>
<td>pH</td>
<td>-4.598*</td>
</tr>
<tr>
<td>EC (Electrical Conductivity)</td>
<td>-0.041*</td>
</tr>
<tr>
<td>MC (Moisture Content)</td>
<td>0.008*</td>
</tr>
<tr>
<td>Na</td>
<td>-0.002**</td>
</tr>
<tr>
<td><strong>Electrical Conductivity (R-square = 0.96</strong>)**</td>
<td></td>
</tr>
<tr>
<td>Intercept</td>
<td>6.234</td>
</tr>
<tr>
<td>MC</td>
<td>-0.016**</td>
</tr>
<tr>
<td>Na</td>
<td>0.008*</td>
</tr>
<tr>
<td>Mg</td>
<td>0.088**</td>
</tr>
<tr>
<td><strong>Soil pH (R-square = 0.89</strong>)**</td>
<td></td>
</tr>
<tr>
<td>Intercept</td>
<td>6.451</td>
</tr>
<tr>
<td>EC</td>
<td>-0.016*</td>
</tr>
<tr>
<td>MC</td>
<td>0.001*</td>
</tr>
<tr>
<td>Na</td>
<td>0.003*</td>
</tr>
<tr>
<td>Mn</td>
<td>-0.069**</td>
</tr>
<tr>
<td>S</td>
<td>-0.0001*</td>
</tr>
<tr>
<td>Fe</td>
<td>-0.039**</td>
</tr>
<tr>
<td>Mg</td>
<td>0.003*</td>
</tr>
</tbody>
</table>

* Significant at p = 0.05  ** Significant at p = 0.01
Soil EC and soil pH were also significantly affected by soil and soil-related factors. Regression equations developed to explain variation in EC and pH were:

Electrical Conductivity (EC) = 6.234 - 0.016(MC) + 0.008(Mg)  \[3.2\]

\[
\begin{align*}
\text{pH} &= 6.451 - 0.016(\text{EC}) + 0.001(\text{MC}) + 0.003(\text{Na}) - 0.069(\text{Mn}) \\
&\quad - 0.0001(S) - 0.039(\text{Fe}) + 0.003(\text{Mg}) \\
\end{align*}
\]  \[3.3\]

The R-square value were 0.96 and 0.89, respectively.

Urease Activity and Gypsum Additions:

Gypsum (CaSO₄·2H₂O) is used as a source of soluble Ca for reclaiming sodic soils, preventing soil crusting, and ameliorating water quality (Gobran et al., 1982; Gobran and Miyamoto, 1985; Oster, 1982). A favorable positive interactive effect of gypsum and NPK fertilization was reported by Rankov (1967) on saline soils. He stressed that gypsum + dung + NPK had increased the numbers of ammonifying and nitrifying bacteria and also increased ammonification and nitrification. Similar effects were reported by Carter et al., (1978) on the combined application of ammonium nitrate and gypsum.

In the work reported here (Figure 3.5), gypsum additions did not result in any significant increase of urease activity of soils. Nonetheless, there was an increase of 50% in urease activity of soil treated with 20 Mg ha⁻¹ gypsum, compared with the control. Earlier findings of Rankov (1967) showed that application of gypsum alone, particularly at the rate of 25 ton ha⁻¹, tended initially to decrease the number of nitrifying bacteria and inhibit ammonification and nitrification. Bower (1969) reported that application of gypsum followed
Figure 3.5. Gypsum additions on urease activity of brackish marsh soils.
by leaching is the most common method employed to replace adsorbed Na. Leaching with successive dilutions of highly saline water having 30% or more Ca + Mg salts is an effective means of removing adsorbed Na while maintaining soil permeability.

**Urease Activity and Electrical Conductivity:**

Changes on the urease activity in response to different salinity levels is shown in Figure 3.6. The highest urease activity of 0.82 mg kg\(^{-1}\) hr\(^{-1}\) was obtained from the sample at salinity level of 0.1 S m\(^{-1}\) and the least was observed at salinity level of 0.8 S m\(^{-1}\) with a mean of 0.53 mg kg\(^{-1}\) hr\(^{-1}\). It is likely that high salinity can partially or totally block the mechanism of urea hydrolysis because of the increased energy expenditures required for the hydrolysis of urea to ammonium-urea as expected from the increasing ionic strength of the soils (Tanji, 1969; Ponnamperuma, 1972, and DeLaune et al., 1976). It should be recalled that urease activity is negatively related to the increasing concentration of Na (Equation 1). Because of the increased Na and other salt components, it is concluded that these soils have established protective mechanisms that lead to the destruction or inactivation of enzymes (Zantua and Bremner, 1975; Zantua and Bremner, 1976; Zantua et al., 1977).

This depressing effect of increasing levels of electrical conductivity on urease activity is in agreement with the work of Sankhanyan and Shukla (1976) and Myers and McGarity (1968) who found that the rate of hydrolysis of urea was slower in soil samples with high electrical conductivity.
Figure 3.6. Salinity levels on urease activity of brackish marsh.
SUMMARY AND CONCLUSIONS

The results are summarized as follows:

1. Sodium, Fe, Mg, and Ca toxicity may developed during long-term drying and detrimentally affect native vegetation and revegetation establishment.

2. Addition of gypsum did not result in a significant increase of urease activity in dried soils.

3. General reduction of urease activity was observed as EC increased.

The aforementioned results reaffirm the importance of N fertilization and water management for the restoration of suitable marsh vegetation. Because N transformation decreased with increasing salinity and because of the probable increase of N losses via denitrification during soil drying, N fertilization should be included in the revegetation plans for brackish and saline marsh soils.

In an open area like the marsh, where growing plants are few or absent, the fate of fertilizer nitrogen added to the soil as urea is likely controlled by soil urease. Therefore, draining and drying the soil to a maximum (20% MC) should not be practiced because of the reduced urease activity that may eventually lead to lower N availability and fertilizer efficiency. Soil drying also altered the physicochemical properties which were found to be detrimental to the overall productivity of the area.

LITERATURE CITED


McLaren, A. D. 1963. Enzyme activity in soils sterilized by Oionizing radiation and some comments on microenvironments in nature. Recent Progress in Microbiology. 8:221-229.


CHAPTER 4

NITROGEN AND GYPSEM: MANAGEMENT TOOLS IN BRACKISH MARSH

REVEGETATION AND IMPROVEMENT PROGRAMS
ABSTRACT

A greenhouse study was conducted to determine the yield response, protein content, and uptake to nitrogen (N) and gypsum (G) addition to four species of marsh vegetation. The four species: *Spartina patens* MuhL. (marsh hay cordgrass); *Distichlis spicata* L. (salt grass); *Paspalum vaginatum* SW. (joint grass); and *Scirpus americanus* Pers. (freshwater three square) were fertilized with 0, 60, 120, and 240 kg N ha\(^{-1}\). Gypsum (CaSO\(_4\).2H\(_2\)O, 75% Ca) was applied at the rate of 0, 5, and 10 Mg ha\(^{-1}\) prior to planting.

The four species responded significantly to N and gypsum applications. Their overall yield response was described as $\text{DMY} = 2.68 + 1.62N - 0.98N^2 + 0.37N^3 - 0.73G + 0.62G^2$. Nitrogen, P, K, Ca, Mg, Na, S, Fe, Al, and crude protein content (CPC) of each species were significantly correlated to and significantly affected by N fertilization and gypsum addition.

INTRODUCTION

Saltwater damage, subsidence, and man's intervention have caused some marshes in humid southwestern LA to revert to open water. The coastal wetlands of the state, America's largest wetland community, is losing its marshes and swamps to the Gulf of Mexico at a rate of 167 sq km per year (LA DNR, 1986). Over the last twenty years, various solutions have been proposed to save LA coastal wetlands but no comprehensive plan emerged. If current trends continue, these marshes, along with their remaining vegetation will be mostly lost by the turn of the next century.
The focus of this investigation was on the restoration of suitable vegetation for saving wetlands from natural and accelerated losses. Restoration with suitable vegetation, usually requires some elaborate practices that include fertilization, chemical amelioration, and various other cultural practices. Reclamation of soils that have been subjected to sea-water inundation requires soluble Ca for replacing exchangeable Na and careful management combined with sound cultural practices for several years to reestablish the favorable physical and chemical status of the soil (Berg, 1950; Richards, 1954). Plant nutrients that are leached from the soil must be replaced, and fertilizer application following leaching should compensate for plant nutrient losses, especially N. Early published reports (Broome et al., 1975; Patrick and DeLaune, 1976; Mendellssohn, 1979; Smart and Barko, 1980) indicated that the marsh was most limited in N.

Other studies concerning production of plants in coastal marsh ecosystems also suggest that productivity may be limited by availability of N (Piggot, 1969; Valiela and Teal, 1974; Gallagher, 1975; Hanes, 1979). Nitrogen fertilization on the coastal marsh has markedly increased and changed the distribution of plants and plant productivity in the salt marsh (Jefferies and Perkins, 1969; Valiela et al., 1975). Similar findings were also found by Sigua and Hudnall (1989). They reported the importance of N fertilization on the overall productivity of marshes in southwest LA. While these studies suggest that N may be an important limiting factor in the productivity of coastal marshes, few studies have been done to evaluate if this is true in the humid coastal marshes of southwestern LA.
The present research and the results have significant importance to the revegetation plans and improvement program for brackish and salt marsh soils. The principal objective of this study was to determine the influence of gypsum and N on the yield, protein content, and nutrient uptake of four species of marsh vegetation under brackish marsh environment.

MATERIALS AND METHODS

Soil Preparation and Soil Analyses:

Soil samples were obtained from the Clovelly soil series (clayey, montmorillonitic, euic, thermic, Terric Medisaprists) at a depth of 0-20 cm from an open area inundated by brackish-water. The area is located at Hackberry, LA. Eight composite samples were collected randomly at approximately 200-300 meter intervals covering a total area of 0.40 ha. Location of each sampling site is presented in Figure 4.1. Each sample was mixed and stored at 5-10°C until the different treatments were applied. Subsamples were taken for the determination of initial chemical properties. Soil analyses included organic C (OC) (SCS, 1972), electrical conductivity (EC) (Rhoades, 1982), pH (McLean, 1982), and water soluble Ca, Mg, Na, Fe, Mn, and S by inductively coupled plasma spectroscopy (ICP). Soil extraction was performed via an automatic soil extractor. Distilled water was the extracting solution for the water soluble cations.

Greenhouse Study:

Polyethylene-line plastic pots (18 cm in diameter and 20 cm in height) were filled to about 3/4 full with 3 kg of wet brackish soil materials. Lined pots were used to simulate a poorly-drained system where no leaching would occur. The remaining portion of the pots were filled
Figure 4.1. Location of soil sampling sites.
with an artificially salinized water that contained 1:1 NaCl–CaCl₂ mixture. The initial EC of soil was adjusted to 6–7 dS m⁻¹. The soil EC was maintained at a range of 5–7 dS m⁻¹ by periodic addition of artificially salinized water. The EC was monitored once every week using the electrical conductivity meter (YSI Model 33 S–C–J meter). Two weeks after treating the soil materials with artificially salinized water, agricultural gypsum (75% Ca, CaSO₄·2H₂O) was added to the soil at the rate of 0, 5, and 10 Mg ha⁻¹. Nitrogen in the form of urea (45 % N) was added at the rate of 0, 60, 120, and 240 kg ha⁻¹. A blanket application of P in the form of ordinary superphosphate (OSP) at the rate of 20 kg P ha⁻¹ was also added to the soil two weeks before planting. Each treatment was replicated three times and pots were arranged in the greenhouse in a complete randomized design. Greenhouse temperature was maintained at 28°C while the relative humidity was controlled automatically at a favorable range.

Bare root plants of marsh hay cordgrass (*Spartina patens* MuhL.), joint grass (*Paspalum vaginatum* SW.), salt grass (*Distichlis spicata* L.), and sprigs of fresh water three-square (*Scirpus americanus* Pers.) were planted on December 20, 1987. Two plants per pot were maintained throughout the duration of the study.

Plants were harvested 210 days after planting. Harvesting was accomplished by carefully clipping each plant after each pot was totally drained. Prior to harvesting (1 day before clipping), plant height and stem diameter were measured for each plant.

**Analysis of Plants:**

Clippings of each pot were transferred to paper bags, dried for 48
h at 70°C in a convection oven, weighed to determine dry matter yield and ground in a Wiley mill to pass a 40 mesh screen. A portion of plant samples for total N determination was digested with concentrated H₂SO₄ as described by Nelson and Sommers (1973). Nitrogen was determined by steam distillation as described by Bremner and Edwards (1965).

A 0.5 g sample of plant tissue was digested with 5 mL of concentrated HNO₃ using the Technicon BD-40 digestion block at 130°C for 4 h. Phosphorus, K, Na, Ca, Mg, S, Fe, Al, Mn, Cu, and Zn were analyzed by inductively coupled plasma–atomic emission spectroscopy (ICP–AES).

Statistical Analysis:

Three way factorial analysis of variance (ANOVA) was conducted to evaluate the main and interaction effects of gypsum–N–specie treatments on dry matter yield, plant height, diameter of growth, protein content, nutrient concentration and uptake (SAS, 1985). There were four species of vegetation (marsh hay cordgrass, salt grass, joint grass, and three-square); three levels of gypsum (0, 5, and 10 Mg ha⁻¹); and four levels of N (0, 60, 120, and 240 kg ha⁻¹) in this study. Mean separation of the main treatment effects and the interaction effects were made following the principles of the Least Significant Difference (LSD) using the SAS User's Guide: Statistics (SAS, 1985). The principles of the stepwise regression technique as outlined in SAS Statistics Guide (SAS, 1985) was followed to determine the best fit in describing the general yield response model to N and gypsum addition.

RESULTS AND DISCUSSION

Soil Analysis:

The initial soil analyses prior to N and gypsum treatments are
shown in Table 4.1. The soil media that has been classified as brackish has an average EC of 7.2 dS m\(^{-1}\). The soil contained high OC (33.7%). These soils are highly decomposed, classified as Terric Medisaprists (Soil Survey Staff, 1987; Amacher et al., 1989). The soil has an initial neutral pH of 6.6. The initial status of water soluble Ca, Mg, Na, Fe, Mn, and S were 8.8, 10.5, 99.5, 0.6, 0.04, and 9.4 mg kg\(^{-1}\), respectively. These values were relatively low as compared to the data reported by Brupbacher et al. (1973).

**Characteristics and Importance of Four Species of Marsh Vegetation that were used in the study (Chabreck, 1972):**

The different physical and growth features and the importance of four species of marsh vegetation (joint grass, salt grass, marsh hay cordgrass, and three-square) that were used in the study are summarized as follows:

1. **Joint Grass** (*Paspalum vaginatum* Sw.) — a perennial grass, locally abundant in fresh to brackish marshes, but reaching greatest density in intermediate marsh subject to moderate cattle grazing. Seeds of the plant are eaten by ducks and other birds. The other parts of the plant provide food for nutria, rabbits, geese, and cattle. The salt tolerance and pH requirements of this species were: 3270 to 3470 mg kg\(^{-1}\) salts and 5.1 to 6.7, respectively.

2. **Salt grass** (*Distichlis spicata* L.) — a short perennial grass of brackish and saline marsh. It forms dense stands on slightly elevated areas such as bayou and lake banks, ridges, and spoil deposits. The roots, culms, and leaves are fed on by nutria, swamp rabbits, and snow geese. Ducks feed on the seeds they can reach from the water. This plant is an important contributor to the detrital cycle, which provides nutrients to estuarine
<table>
<thead>
<tr>
<th>PROPERTY</th>
<th>UNITS</th>
<th>VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrical Conductivity (EC)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>dS m&lt;sup&gt;-1&lt;/sup&gt;</td>
<td>7.2</td>
</tr>
<tr>
<td>Organic Carbon&lt;sup&gt;b&lt;/sup&gt;</td>
<td>(%)</td>
<td>33.7</td>
</tr>
<tr>
<td>pH&lt;sup&gt;c&lt;/sup&gt;</td>
<td></td>
<td>6.6</td>
</tr>
<tr>
<td>Ca&lt;sup&gt;d&lt;/sup&gt;</td>
<td>mg kg&lt;sup&gt;-1&lt;/sup&gt;</td>
<td>8.8</td>
</tr>
<tr>
<td>Mg&lt;sup&gt;d&lt;/sup&gt;</td>
<td>mg kg&lt;sup&gt;-1&lt;/sup&gt;</td>
<td>10.5</td>
</tr>
<tr>
<td>Na&lt;sup&gt;d&lt;/sup&gt;</td>
<td>mg kg&lt;sup&gt;-1&lt;/sup&gt;</td>
<td>99.5</td>
</tr>
<tr>
<td>Fe&lt;sup&gt;d&lt;/sup&gt;</td>
<td>mg kg&lt;sup&gt;-1&lt;/sup&gt;</td>
<td>0.6</td>
</tr>
<tr>
<td>Mn&lt;sup&gt;d&lt;/sup&gt;</td>
<td>mg kg&lt;sup&gt;-1&lt;/sup&gt;</td>
<td>0.04</td>
</tr>
<tr>
<td>S&lt;sup&gt;d&lt;/sup&gt;</td>
<td>mg kg&lt;sup&gt;-1&lt;/sup&gt;</td>
<td>9.4</td>
</tr>
</tbody>
</table>

Soil Classification<sup>e</sup>: Clayey, Montmorillonitic, Euic, Thermic, Terric Medisaprists

Soil Series: Clovelly muck

---

<sup>a</sup> Electrical Conductivity Bridge (Rhoades, 1982)
<sup>b</sup> Dry Combustion (SCS, 1972)
<sup>c</sup> 1:2 soil:water paste (Peech, 1965)
<sup>d</sup> Water soluble using the ICP
<sup>e</sup> Soil Survey Staff (1987) and Amacher et al. (1989)
organisms. It has a salt tolerance of 6700 to 13,320 mg kg\(^{-1}\) and pH requirement of 4.1 to 8.0.

3. Marsh hay cordgrass (*Spartina patens* Muhl) - a perennial grass with long and slender rhizomes. Culms are slender, mostly erect, but occasionally trailing, and 2 to 4 feet long; leaf blades are long and slender. It is an important food of nutria, muskrats, and rabbits, and it provides forage for cattle. Plants detritus is of major importance to aquatic food chains and for soil building. This species has a salt tolerance that ranges from 6330 to 8550 mg kg\(^{-1}\) and pH that ranges from 3.7 to 7.9.

4. Three-square (*Scirpus americanus* Pers) - a perennial sedge with extensively creeping rhizomes. Culms are 3 to 4 feet long, triangular, and twisting with sparse leaves at the base. Seeds are eaten by ducks and rhizomes and tubers are eaten by geese, muskrats, and nutria. The salt tolerance of this species ranged from 1150 to 1500 mg kg\(^{-1}\) and pH that ranged from 6.70 to 7.80.

**Growth Parameters:**

**Plant Height.** The plant height at harvest of the four species of marsh vegetation are shown in Figure 4.2. The overall ANOVA and individual ANOVA on plant height for each species of marsh vegetation are shown in Tables 4.2 and 4.3, respectively. An average plant height of 54 cm was observed for joint grass (*Paspalum vaginatum*). The other three species, salt grass (*Distichlis spicata*), marsh hay cordgrass (*Spartina patens*), and three-square (*Scirpus americanus*) had mean height of 38, 40, and 40 cm at harvest, respectively.
Figure 4.2. Comparative analyses on dry matter yield, growth diameter, and plant height of different species of marsh vegetation.
TABLE 4.2. PLANT HEIGHT AND DIAMETER OF GROWTH OF FOUR SPECIES OF MARSH VEGETATION AS AFFECTED BY DIFFERENT RATES OF NITROGEN ADDITION.

<table>
<thead>
<tr>
<th>NITROGEN LEVEL</th>
<th>Plant Height</th>
<th>Diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>(kg ha⁻¹)</td>
<td>cm</td>
<td>cm</td>
</tr>
</tbody>
</table>

I. *V1 - Paspalum vaginatum* SW.

<table>
<thead>
<tr>
<th></th>
<th>Plant Height</th>
<th>Diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>33b</td>
<td>9c</td>
</tr>
<tr>
<td>60</td>
<td>29b</td>
<td>12b</td>
</tr>
<tr>
<td>120</td>
<td>48b</td>
<td>15ab</td>
</tr>
<tr>
<td>240</td>
<td>104a</td>
<td>17a</td>
</tr>
<tr>
<td>LSD (0.05)</td>
<td>22.7</td>
<td>2.5</td>
</tr>
</tbody>
</table>

II. *V2 - Distichlis spicata* L.

<table>
<thead>
<tr>
<th></th>
<th>Plant Height</th>
<th>Diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>34c</td>
<td>8c</td>
</tr>
<tr>
<td>60</td>
<td>36bc</td>
<td>10bc</td>
</tr>
<tr>
<td>120</td>
<td>40ab</td>
<td>14ab</td>
</tr>
<tr>
<td>240</td>
<td>43a</td>
<td>15a</td>
</tr>
<tr>
<td>LSD (0.05)</td>
<td>5.6</td>
<td>4.5</td>
</tr>
</tbody>
</table>

III. *V3 - Spartina patens* MuhL.

<table>
<thead>
<tr>
<th></th>
<th>Plant Height</th>
<th>Diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>35b</td>
<td>5b</td>
</tr>
<tr>
<td>60</td>
<td>35b</td>
<td>6b</td>
</tr>
<tr>
<td>120</td>
<td>37b</td>
<td>6b</td>
</tr>
<tr>
<td>240</td>
<td>55a</td>
<td>9a</td>
</tr>
<tr>
<td>LSD (0.05)</td>
<td>13.7</td>
<td>2.3</td>
</tr>
</tbody>
</table>

IV. *V4 - Scirpus americanus* Pers.

<table>
<thead>
<tr>
<th></th>
<th>Plant Height</th>
<th>Diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>37a</td>
<td>13b</td>
</tr>
<tr>
<td>60</td>
<td>37a</td>
<td>10b</td>
</tr>
<tr>
<td>120</td>
<td>41a</td>
<td>12b</td>
</tr>
<tr>
<td>240</td>
<td>42a</td>
<td>20a</td>
</tr>
<tr>
<td>LSD (0.05)</td>
<td>6.92</td>
<td>3.6</td>
</tr>
</tbody>
</table>

* Means followed by the same letter(s) are not significantly different at p = 0.05 using LSD.
TABLE 4.3. ANALYSIS OF VARIANCE (GENERAL) ON THE GROWTH, YIELD, AND CRUDE PROTEIN CONTENT (CPC) OF FOUR SPECIES OF MARSH VEGETATION.

<table>
<thead>
<tr>
<th>SOURCES OF VARIATION</th>
<th>PLANT HEIGHT (cm)</th>
<th>DIAMETER (cm)</th>
<th>DRY YIELD (Mg ha(^{-1}))</th>
<th>CPC (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>VARIETY (V)</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td>GYPSUM (G)</td>
<td>**</td>
<td>ns</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td>Linear</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>Quadratic</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>Cubic</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>NITROGEN (N)</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td>Linear</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td>Quadratic</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td>Cubic</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td>V x G</td>
<td>ns</td>
<td>*</td>
<td>**</td>
<td>ns</td>
</tr>
<tr>
<td>V x N</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td>G x N</td>
<td>ns</td>
<td>ns</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td>V x G x N</td>
<td>ns</td>
<td>ns</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td>R(^2)</td>
<td>0.70**</td>
<td>0.77**</td>
<td>0.95**</td>
<td>0.82**</td>
</tr>
</tbody>
</table>

** - significant at p=0.01  
* - significant at p=0.05  
ns - not significant
Data given in Tables 4.2 and 4.3 show that plant height was significantly increased by N application. Plant height of each marsh specie was cubically increased for every unit of N applied. Application of 240 kg N ha\(^{-1}\) resulted in remarkable improvement of plant height. This rate of N application increased the height of joint grass by 213%; salt grass by 26%; marsh hay cordgrass by 54%; and by 13% for three-square over the control plants. Addition of N at the rate of 60 and 120 kg N ha\(^{-1}\) did not significantly increased the plant height at harvest. Plants at these rates were statistically comparable to the unfertilized plants (control). A high N demand of each specie of marsh vegetation was noted before any significant improvement in plant height. Application of 240 kg N ha\(^{-1}\) as urea (45% N) was the threshold level to effect any significant increased in plant height.

Under the condition of this study, it is proposed that the plant must maintain a state of non-equilibrium with its environment in order to survive. This observation was in good agreement with the early data reported by Gale (1975). If plants are growing in normal soils that contained low concentration of nutrient ions, the plants must increase the concentration and balance of the said nutrient in their protoplasm to a level suitable for the normal functioning of the cell. Maintenance of the unbalanced and steady state conditions requires the continuous expenditure of energy. Meanwhile, if plants are growing in saline environment, they must also concentrate and balance the ions over and above the concentration of ions in the plants. These plants must decrease the concentration of Na or other ions in its protoplasm below that in the soil in order to maintain ionic concentrations that support normal functioning.
of the cell. The maintenance of a lower Na salt concentration in its protoplasm than the surrounding soil requires the expenditures of energy that would otherwise be available for growth processes. The preponderance of Na⁺ on the exchange sites and in soil solution therefore, provided a strong ionic competition. Apparently, more nutrients or much higher concentration of NH₄⁺ or NO₃⁻ ions must be present in order to overcome the specific ion effect of Na⁺, which tend to dominate the whole soil-root interface. A much lesser concentration of ions in the soil solution would not give any beneficial effect. Application of growth stimulating nutrient like N at much higher rate was beneficial for plant growth in the presence of high concentration of competing ions like Na⁺ and other electrolytes.

Diameter of growth. Diameter of growth at harvest for each species of marsh vegetation is shown in Figure 4.2. Data in Tables 4.2, 4.3, and 4.4 show that the diameter of growth of each plant was significantly affected by N fertilization, but not by gypsum addition. No significant gypsum-N interaction effects were further observed. There was a very significant difference on the diameter among the four species (Table 4.3). Average growth diameter of 13, 12, 6, and 14 cm at harvest were observed from joint grass, salt grass, marsh hay cordgrass, and three-square, respectively (Figure 4.2).

Similar to plant height, N application resulted in significant improvement in the diameter of growth at harvest. Significantly wider stems were observed among fertilized plants when compared to the unfertilized plants. Application of 60 kg N ha⁻¹ increased the diameter of joint grass and salt grass by 3.7 and 2.6 cm, respectively, over the control plants. However, growth diameter of marsh hay cordgrass and
TABLE 4.4. ANALYSES OF VARIANCE (BY VARIETY) ON THE GROWTH, YIELD, AND CRUDE PROTEIN (CPC) CONTENT OF FOUR SPECIES OF MARSH VEGETATION.

<table>
<thead>
<tr>
<th>SOURCE OF VARIATION</th>
<th>PLANT HEIGHT (cm)</th>
<th>DIAMETER (cm)</th>
<th>DRY YIELD (Mg ha(^{-1}))</th>
<th>CPC (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I. VI — <em>Paspalum vaginatum</em> SW. (Joint-grass)</td>
<td>ns</td>
<td>ns</td>
<td>**</td>
<td>ns</td>
</tr>
<tr>
<td>GYPSUM (G)</td>
<td>ns</td>
<td>ns</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td>NITROGEN (N)</td>
<td>ns</td>
<td>ns</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td>Linear</td>
<td>ns</td>
<td>ns</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td>Quadratic</td>
<td>ns</td>
<td>ns</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td>Cubic</td>
<td>ns</td>
<td>ns</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td>G x N</td>
<td>ns</td>
<td>ns</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td>R(^2)</td>
<td>0.73**</td>
<td>0.74**</td>
<td>0.96**</td>
<td>0.96**</td>
</tr>
<tr>
<td>II. V2 — <em>Distichlis spicata</em> L. (Salt grass)</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>*</td>
</tr>
<tr>
<td>GYPSUM (G)</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>*</td>
</tr>
<tr>
<td>NITROGEN (N)</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>*</td>
</tr>
<tr>
<td>Linear</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>*</td>
</tr>
<tr>
<td>Quadratic</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>*</td>
</tr>
<tr>
<td>Cubic</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>*</td>
</tr>
<tr>
<td>G x N</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>*</td>
</tr>
<tr>
<td>R(^2)</td>
<td>0.46*</td>
<td>0.56*</td>
<td>0.73**</td>
<td>0.80**</td>
</tr>
<tr>
<td>III. V3 — <em>Spartina patens</em> MuhL. (Marsh hay cordgrass)</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>GYPSUM (G)</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>NITROGEN (N)</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>Linear</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>Quadratic</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>Cubic</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>G x N</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>R(^2)</td>
<td>0.38*</td>
<td>0.51**</td>
<td>0.46*</td>
<td>0.70**</td>
</tr>
<tr>
<td>IV. V4 — <em>Scirpus americanus</em> Pers. (Freshwater three-square)</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>GYPSUM (G)</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>NITROGEN (N)</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>Linear</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>Quadratic</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>Cubic</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>G x N</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>R(^2)</td>
<td>0.47ns</td>
<td>0.73**</td>
<td>0.77**</td>
<td>0.61**</td>
</tr>
</tbody>
</table>

** - significant at p=0.01
* - significant at p=0.05
ns - not significant
three-square were not significantly affected by the addition of 60 kg N ha⁻¹. Doubling the rate of N application to 120 kg N ha⁻¹ increased the growth diameter of the latter by 2.4 and 4.2 cm, respectively, but not for the former. The growth diameter of marsh hay cordgrass and three-square remained unchanged even though the rate of N application was doubled.

When the rate of N was increased to 240 kg N ha⁻¹, a very significant increase in growth diameter was observed for all species. This rate had the widest effective growth area per pot. The growth area of joint grass, salt grass, marsh hay cordgrass, and three-square was increased by 95, 101, 105, and 54%, respectively, when compared to the unfertilized plants. The results observed were similar to those observed from plant height data i.e., different species of marsh vegetation would require or demand high rate of N application before any significant increase in growth diameter was observed. Therefore, similar reasoning presented in the previous section is appropriate to explain the results in this section.

Yield:

Dry matter yield. The dry matter yield (DMY) response of four species of marsh vegetation to gypsum and N application are presented in Figures 4.2, 4.3, and 4.4. Yield data in Table 4.2 and Figure 4.2 show very significant variation among the different species of marsh vegetation. The average DMY of 5.7, 1.9, 1.6, and 1.1 g kg⁻¹ were obtained from joint grass, salt grass, marsh hay cordgrass, and three-square, respectively. The effects of gypsum, N, and various treatment interactions on DMY were all significant at alpha level of 0.01 and had an R² of 0.95 (Table 4.3).
Figure 4.3. Dry matter yield and crude protein content of four species as affected by gypsum addition.
Figure 4.4. Relationship of dry matter yield and crude protein content of four species of marsh vegetation with nitrogen fertilization.
The DMY of plants was significantly increased by gypsum and N application (Figures 4.3). The yield of joint grass and salt grass were increased 5.2 to 7.1 and 1.8 to 1.9 g kg\(^{-1}\) when treated by 10 Mg gypsum ha\(^{-1}\) but the yield of marsh hay cordgrass and three-square were not affected at this level. The DMY of each species was cubically related to N fertilization. Application of 240 kg N ha\(^{-1}\) produced the highest yield improvement. This N rate increased the yield of joint grass by 278\%; salt grass, marsh hay cordgrass, and three-square by 156, 176, and 94\%, respectively. No yield increase was observed for marsh hay cordgrass and three-square when fertilized at rates of 60 and 120 kg N ha\(^{-1}\). A slight yield increase was observed for joint grass and salt grass that were fertilized with 60 and 120 kg N ha\(^{-1}\). The DMY of the former was increased from 4.0 to 5.7 g kg\(^{-1}\) while the latter increased from 1.6 to 1.9 g kg\(^{-1}\), respectively.

A cubical yield relationship with N was found to be better than linear and quadratic relationships via stepwise regression technique (SAS, 1985) in describing the yield response model. A much better degree of approximation was obtained to explain the variability of yield behavior of each specie of marsh vegetation using this technique. The regression analyses (Equations 4.1 to 4.4) were found to be the best yield response model to describe the yield response of individual specie to N fertilization. Regression equations developed to explain variation in the yield for joint grass, salt grass, marsh hay cordgrass, and three-square with R\(^2\) of 0.80, 0.46, 0.39, and 0.44 were:

\[
\begin{align*}
\text{DMY} &= 5.83 + 3.73N - 2.61N^2 + 1.06N^3 \\
\text{DMY} &= 2.17 + 0.45N + 0.61N^2 - 0.15N^3
\end{align*}
\]
DMY = 2.01 + 1.52N - 1.64N^2 + 0.52N^3 \quad [4.3]

and

DMY = 1.58 - 0.20N + 0.17N^2 + 0.002N^3 \quad [4.4]

respectively. The different yield response models presented above generally suggest that the yield of plants would be significantly increase on the first increment of N followed by a yield slacked or minimal yield increase when the rate of N was doubled, and later followed by significant increase in yield when the level of N was tripled. This generalization is presented in Figure 4.4, where yield was increased significantly from 0 to 60 kg N ha^{-1} addition, followed by minimal yield increase between 60 to 120 kg N ha^{-1}. The final stage of yield response curve between 120 and 240 kg N ha^{-1} was characterized by another significant increase in yield. Similar results were reported by Gallagher (1975) and Patrick and DeLaune (1976). Gallagher (1975) observed an increased in the aerial biomass and sharp reduction in the C:N ratio of *Spartina alterniflora* when applied with 200 kg N ha^{-1}. Patrick and DeLaune (1976) had reported a 15% increase in the yield of *S. alterniflora* when fertilized with 200 kg N ha^{-1}.

The trend of the interaction effects of applied gypsum and N on the DMY of the four species are shown in Figure 4.5. An overall positive response was noted among species to gypsum and N addition. However, a much better yield response to N fertilization was noted. Application of 10 Mg gypsum ha^{-1} of and 240 kg N ha^{-1} had the highest DMY. The observed yield response for joint grass was 28.10 Mg ha^{-1} while the yield response of 3.6, 2.9, and 1.7 g kg^{-1} were observed from salt grass, marsh hay cordgrass, and three-square, respectively. These yield responses were 497, 261, 124, and 72% more when compared to the unfertilized plants, respectively.
Figure 4.5. Comparative analyses on the dry matter yield of four species of marsh vegetation by gypsum and nitrogen addition.
Further, an attempt was made to include the effect of gypsum on the yield response model for each species. A general yield response model was formulated. The overall yield response model was cubically related to N and quadratically related to gypsum (G) addition and was described as:

\[ \text{DMY} = 2.68 + 1.62N - 0.98N^2 + 0.37N^3 - 0.73G + 0.62G^2 \]  \[4.5\]

The yield response model for each species like the general yield model (Equation 4.5), was cubically related to N and quadratically related to gypsum addition. The relationships of yield to gypsum and N addition for joint grass, salt grass, marsh hay cordgrass, and three-square are shown in equations 4.6, 4.7, 4.8, and 4.9, respectively.

\[ \text{DMY} = 4.47 + 3.72N - 2.61N^2 + 1.06N^3 - 0.95G + 1.39G^2 \]  \[4.6\]
\[ \text{DMY} = 2.09 + 0.89N + 0.19N^2 - 0.06N^3 - 1.52G + 0.68G^2 \]  \[4.7\]
\[ \text{DMY} = 2.72 + 1.52N - 1.64N^2 + 0.52N^3 - 1.57G + 0.52G^2 \]  \[4.8\]
\[ \text{DMY} = 0.11 - 0.16N + 0.09N^2 - 0.02N^3 - 0.08G + 0.03G^2 \]  \[4.9\]

The regression coefficient (R^2) of 0.40, 0.34, and 0.40 for equations 4.7, 4.8, and 4.9 were rather low but significant (p=0.01). A highly significant relationship was obtained from salt grass with R^2 value of 0.86 (Equation 4.6).

The favorable and significant results on the effect of gypsum and N addition were in good agreement with the gypsum and NPK data reported by others (Rankov, 1967; Carter et al., 1977; Carter, 1978;). Other previous researchers (Broome at al., 1975; Patrick and DeLaune, 1976; Mendellssohn, 1979) stressed the importance of N fertilization while others (Bower and Turk, 1946; LaHaye and Epstein, 1969; Ayoub, 1974) reported the beneficial effect of gypsum addition. LaHaye and Epstein (1969) stressed the crucial role of Ca^{2+} ions in the regulation of salt specifically in the selective
transport or exclusion of Na and other mineral ions by plant cell membranes. They observed that plants grew well in both appearance and weight at higher concentrations of gypsum. They also reported the efficacy of Ca in protecting plant species against the deleterious effects of NaCl present in the medium. Similar findings were obtained by Rains (1972). He reported the importance of Ca in maintaining the integrity of plant cell membranes that prevent the free diffusion of potentially toxic ions prevalent in a saline environment.

In addition to the removal of excess salts and exchangeable Na, other practices are usually required for complete reclamation of Na affected soils. Plant nutrients that are leached from the soil must be replaced and fertilizer application following leaching should compensate for plant nutrients losses, especially, N, which is the principal nutrient that is lost.

Protein Content, Nutrient Composition and Uptake:

Crude Protein content. The comparative crude protein content (CPC) of four species of marsh vegetation and the CPC of each species as affected by gypsum and N addition are shown in Figure 4.6 and Figure 4.7. Highly significant results were also noted for gypsum, N, and their interaction effects for each species (Table 4.2). Comparative CPC analysis among four species was in the order: three-square > salt grass > marsh hay cordgrass > joint grass with an average protein content of 5.44, 5.04, 4.11, and 3.72%, respectively.

When the CPC among the four species was compared, the trend was very variable. The highest CPC of 4.92% for joint grass was obtained from the plants that were fertilized with 10 Mg gypsum ha⁻¹ and 60 kg N ha⁻¹. The
Figure 4.6. Crude protein content and nutrient concentrations (N, P, K) of different species of marsh vegetation.
Figure 4.7. Comparative analyses on the crude protein content of four species as influenced by gypsum and nitrogen addition.
highest CPC of 5.91, 5.25, and 6.62% for salt grass, marsh hay cordgrass, and three-square were observed from the application of 5 and 120; 10 and 0; and 0 and 120 Mg gypsum ha\(^{-1}\) and kg N ha\(^{-1}\), respectively. These results are likely to be a species response. The individual genetic composition and metabolic behavior for each species of vegetation would have an enormous influence on these results. These plant attributes were far from the scope of this study and therefore will not be discussed except for some minor discussion later.

The beneficial effects of gypsum and N on the yield and CPC of the four species (Table 4.2) suggest the positive impact of these management combination on the revegetation process of brackish marsh soils. Early published works (Kahane and Mayber, 1968; Solovev, 1969; Poonia et al., 1972; Melander and Horvath, 1977) show the importance of Ca (gypsum) on plant growth and protein content under saline environment. Kahane and Mayber (1968) proposed that the effect of salinity on incorporation of amino acids into root tip protein was apparently of dual nature. In the presence of salts, the uptake was depressed and the normal metabolic pathways were disturbed. Their results showed that the higher the medium salinity, the lower is the incorporation of the amino acid. Melander and Horvath (1977) reported that salts have two antagonistic effects on protein synthesis: 1) they tend to break the electrostatic bond of protein structure, and 2) increase the hydrophobic interactions.

**Nutrient composition and uptake.** The different nutrient composition and nutrient uptake of the four species are shown in Figures 4.8 and 4.9. Sodium and S are the two dominant macronutrients with mean concentration ranging from 1.2 to 1.9 and 0.9 to 1.7%, respectively (Figure 4.8). The
Figure 4.8. Comparative analyses on the different elemental composition of four species of marsh vegetation.
Figure 4.9. Nutrient uptake of the different species of marsh vegetation at harvest.

1. P. virginiana Species 1, P. virginiana Species 2, P. palustris Species 4 - species 4 - C. arctata

Species of Marsh Vegetation

**Calcium & Magnesium Uptake (g/ha)**

- Sodium
- Calcium
- Sulfur

Species of Marsh Vegetation

**Potassium Uptake (g/ha)**

- Sodium
- Calcium
- Sulfur

Species of Marsh Vegetation

**Nitrogen & Phosphorus Uptake (g/ha)**

- Sodium
- Calcium
- Sulfur

Species of Marsh Vegetation

**Sodium & Sulfur Uptake (g/ha)**

- Sodium
- Calcium
- Sulfur

Species of Marsh Vegetation

**Nitrogen & Phosphorus Uptake (g/ha)**

- Sodium
- Calcium
- Sulfur
dominant micronutrients were Zn and Fe with means ranging from 132 to 738 and 149 to 199 mg kg\(^{-1}\), respectively. The mean separation for the nutrient composition of four species of marsh vegetation as affected by different rates of gypsum are presented in Tables 4.5 and 4.6. A combination of significant and non-significant results were evident in these tables. Overall analysis of data suggested the significant effect of gypsum addition on the nutrient composition of the species.

Results of the nutrient uptake analyses disclosed a varietal differences in terms of N, P, K, Na, Ca, Mg, and S uptake (Figure 4.9). The average N uptake for joint grass was 64.02 kg N ha\(^{-1}\) while salt grass, marsh hay cordgrass, and three-square had 26.01, 21.34, and 17.81 kg N ha\(^{-1}\), respectively. Phosphorus uptake does not show any marked variation among species of plants yielding a narrow range of 1.52 to 4.54 kg P ha\(^{-1}\). The highest amount of Na, Ca, Mg, and S were observed from joint grass followed in descending order by salt grass, marsh hay cordgrass, and three-square.

**SUMMARY AND CONCLUSIONS**

The overall results and observations in this study could be briefly outlined and summarized as follows:

1. Results disclosed highly significant yield responses and CPC to gypsum and N addition of four species of marsh vegetation. Increase growth, yield, and CPC were observed from the fertilized plants.
2. The overall yield responses and individual yield response of each species were cubically related to N and quadratically related to gypsum additions.
3. The N, P, K, Ca, Mg, Na, S, Fe, Al, and Mn uptake and CPC of four
TABLE 4.5. NUTRIENT COMPOSITION OF FOUR SPECIES OF MARSH VEGETATION AS AFFECTED BY DIFFERENT RATES OF GYPSUM ADDITION.

<table>
<thead>
<tr>
<th>GYPSUM LEVEL (Mg ha⁻¹)</th>
<th>N</th>
<th>P</th>
<th>K</th>
<th>Ca</th>
<th>Mg</th>
<th>Na</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>%</td>
<td>%</td>
<td>%</td>
<td>%</td>
<td>%</td>
<td>%</td>
</tr>
<tr>
<td>I. V1 — <em>Paspalum vaginatum</em> SW.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| 0                      | 0.74a | 0.06a | 1.19a | 0.41b | 0.38c | 0.63a
| 5                      | 0.75a | 0.06a | 1.25ab | 0.89a | 0.43b | 1.46b
| 10                     | 0.68b | 0.08b | 1.16b | 0.94a | 0.49a | 1.46b
| II. V2 — *Distichlis spicata* L. |     |     |     |     |     |     |
| 0                      | 0.81ab | 0.05b | 0.68a | 1.05a | 0.30c | 1.13b
| 5                      | 0.85a | 0.06a | 0.66a | 0.91b | 0.39a | 1.35a
| 10                     | 0.76b | 0.06a | 0.61b | 0.35c | 0.34b | 1.07b
| III. V3 — *Spartina patens* MuhL. |     |     |     |     |     |     |
| 0                      | 0.61b | 0.05a | 0.81ab | 0.34b | 0.33c | 1.75b
| 5                      | 0.72a | 0.06a | 0.86a | 0.84a | 0.46b | 1.90ab
| 10                     | 0.64ab | 0.15a | 0.72b | 0.73a | 0.52a | 2.09a
| IV. V4 — *Scirpus americanus* Pers. |     |     |     |     |     |     |
| 0                      | 0.89a | 0.08a | 1.88b | 0.49b | 0.54a | 2.20a
| 5                      | 0.88a | 0.08a | 2.11a | 0.67a | 0.47a | 1.32b
| 10                     | 0.81a | 0.06b | 2.29a | 0.71a | 0.49a | 1.42b

Means followed by the same letter(s) are not significantly different at p = 0.05 using LSD.
TABLE 4.6. NUTRIENT COMPOSITION OF FOUR SPECIES OF MARSH VEGETATION AS AFFECTED BY DIFFERENT RATES OF GYPSUM ADDITION.

<table>
<thead>
<tr>
<th>GYPSUM LEVEL (Mg ha⁻¹)</th>
<th>S (%)</th>
<th>Fe</th>
<th>Al</th>
<th>Mn</th>
<th>Cu</th>
<th>Zn</th>
<th>mg kg⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>I. V1 - Paspalum vaginatum SW.</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>1.12c</td>
<td>123.0b</td>
<td>153.22b</td>
<td>152.08a</td>
<td>12.2a</td>
<td>44.03a</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>1.62b</td>
<td>141.7b</td>
<td>162.54b</td>
<td>126.92b</td>
<td>11.8ab</td>
<td>31.24b</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>2.25a</td>
<td>182.5a</td>
<td>277.31a</td>
<td>118.38b</td>
<td>14.1a</td>
<td>35.64b</td>
<td></td>
</tr>
<tr>
<td><strong>II. V2 - Distichlis spicata L.</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>0.43b</td>
<td>192.91a</td>
<td>320.34b</td>
<td>227.82a</td>
<td>16.63a</td>
<td>45.28a</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>1.21a</td>
<td>217.34a</td>
<td>502.93a</td>
<td>175.55b</td>
<td>17.90a</td>
<td>41.34b</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>1.24a</td>
<td>188.00a</td>
<td>255.75c</td>
<td>215.55a</td>
<td>16.10a</td>
<td>35.54c</td>
<td></td>
</tr>
<tr>
<td><strong>III. V3 - Spartina patens MuhL.</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>0.58c</td>
<td>176.16a</td>
<td>51.44b</td>
<td>284.71a</td>
<td>13.84a</td>
<td>34.14c</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>1.58b</td>
<td>182.12a</td>
<td>141.69ab</td>
<td>254.84ab</td>
<td>15.50a</td>
<td>63.70a</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>1.31a</td>
<td>173.88a</td>
<td>155.56a</td>
<td>225.78b</td>
<td>10.92b</td>
<td>44.92b</td>
<td></td>
</tr>
<tr>
<td><strong>IV. V4 - Scirpus americanus Pers.</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>0.98c</td>
<td>195.0a</td>
<td>169.4b</td>
<td>692.4b</td>
<td>9.57a</td>
<td>278.2a</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>1.47b</td>
<td>176.4ab</td>
<td>332.7a</td>
<td>825.2a</td>
<td>9.34a</td>
<td>261.6a</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>1.87a</td>
<td>144.6b</td>
<td>163.3b</td>
<td>678.9b</td>
<td>6.98b</td>
<td>270.2a</td>
<td></td>
</tr>
</tbody>
</table>

*Means followed by the same letter(s) are not significantly different at p = 0.05 using LSD.*
species of marsh vegetation were significantly affected by N fertilization and gypsum addition.

A further verification study under field condition is still appropriate and recommended to further substantiate the findings reported in this study. Inclusion of other field parameters like wet and dry marsh would be an interesting follow up study.

LITERATURE CITED


CHAPTER 5

GYPSUM-WATER MANAGEMENT INTERACTIONS ON THE SURVIVAL,
YIELD, AND PROTEIN CONTENT OF SELECTED
SPECIES OF MARSH VEGETATION

[A modified version of this chapter is in-review for submission to the Journal of Agriculture Ecosystem and Environment]
ABSTRACT

A field study evaluating the effect of gypsum and water management on the survival, yield, and protein content of selected species of marsh vegetation was conducted on an open area inundated by brackish water at Hackberry, LA. The overall growth and yield response of four species of marsh vegetation: joint grass (*Paspalum vaginatum* SW.), marsh hay cordgrass (*Spartina patens* Muhl.), salt grass (*Distichlis spicata* L.), and american three-square (*Scirpus americanus* Pers.) to gypsum addition (0 vs. 7 Mg ha$^{-1}$) and water management (flooded vs. non-flooded plots) were statistically evaluated.

Soil drying was very detrimental to the overall growth and yield of all marsh vegetation. There was zero plant survival in the unflooded plots except that marsh hay cordgrass had a survival rate of 32.8%.

Plots receiving 7 Mg gypsum ha$^{-1}$ had significantly higher dry matter production than the control. Gypsum application (7 Mg gypsum ha$^{-1}$) increased dry yield of joint grass (5.44 to 8.08 Mg ha$^{-1}$), marsh hay cordgrass (1.90 to 6.91 Mg ha$^{-1}$), salt grass (0.97 to 2.79 Mg ha$^{-1}$), and three-square (1.55 to 2.84 Mg ha$^{-1}$) in flooded plots. The yield of marsh hay cordgrass, the only surviving species in the non-flooded plots produced a yield increase of 0.40 Mg ha$^{-1}$ in response to gypsum.

Significantly higher survival rates were observed in flooded plots treated with gypsum than in the non-flooded plots receiving no gypsum. The mean survival rate for the gypsum-treated plots was 68.2%, as opposed to 21.9 % for the untreated plots.
INTRODUCTION

The coastal wetlands of Louisiana (LA) constitute 40% of all United States (U.S.) coastal wetlands and support a major portion of the U.S. fishing, hunting, and trapping industries. They will be destroyed in the next century because of natural subsidence, erosion, and man's activities. Each year, LA losses approximately 167 sq km of marshes and swamps to the Gulf of Mexico (LA, DNR 1986). Saltwater damage and subsidence have caused most of this area to revert to open water, void of vegetation.

Aerial photographs of the marshes located in Cameron Parish, LA., covering the period between 1940 and 1983 provide a dramatic illustration of the changes that have occurred in this area. The 1940 photographs show the area to have a percentage ratio of emergent vegetation to open water of 99.0:1; 11.2:88.8 in 1968; 5.9:94.1 in 1978; and 1.8:98.2 in 1983 (Soil Survey Staff, 1985). The loss of remaining vegetation will continue under present conditions. This will have a long-term detrimental effect on the productivity of associated fisheries, waterfowl, and other wildlife.

Marshes, as part of our land and water regimes are irreplaceable natural resources that must be preserved. One of the possible solutions for saving wetlands from natural and accelerated losses is through restoration with suitable vegetation. Restoration usually requires some elaborate management practices that include water management, fertilization, chemical treatments, and various other cultural practices. Irrigation methods and drainage practices could provide uniformity of application and downward movement of water through soils which favor salinity control. Vanden Berg (1950) and Richards (1954) have stressed
that the reclamation of soils that have been subjected to sea-water inundation is an agricultural problem of considerable economic importance and must be given a great deal of attention by soil and plant scientists. Inundation by sea-water in humid regions is particularly serious because of the lack of soluble Ca for replacing exchangeable Na. Reclamation of the marshes in the humid southwest section of LA requires soluble Ca for replacing exchangeable Na and careful management and cultural practices, i.e., fertilization and water management, to reestablish favorable physical characteristics of the soil.

Field studies and other investigations that considered the interactive effects of gypsum and water management have not been conducted in this region. The present research and the results reported have paramount importance to the revegetation plans for brackish and salt marsh soils.

The objective of this investigation was to evaluate the growth and yield response of some selected species of marsh vegetation to soil drying and gypsum addition.

MATERIALS AND METHODS

Description of the study area:

An open area presently inundated by brackish water located Hackberry, LA was selected for this study. The specific location of this site is presented in Figure 5.1. The soils of the area were classified as clayey, montmorillonitic, euic, thermic, Terric Medisaprist (Amacher et al., 1989). Tables 5.1 and 5.2 show the results of the initial composite profile and water analyses.

The surface horizons (Oa1 + Oa2) were categorized as brackish
Figure 5.1. Location, field layout, and experimental treatments of the study.
TABLE 5.1. SOME SELECTED SOIL CHEMICAL PROPERTIES IN THE STUDY AREA.

<table>
<thead>
<tr>
<th>SOIL PROPERTY</th>
<th>0a1 (0-10 cm)</th>
<th>0a2 (10-25)</th>
<th>A (25-35)</th>
<th>Cgl (35-60)</th>
<th>Cg2 (60-100)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EC (dS m⁻¹)ᵃ</td>
<td>6.2</td>
<td>7.2</td>
<td>6.2</td>
<td>4.2</td>
<td>4.0</td>
</tr>
<tr>
<td>Org. C (%)ᵇ</td>
<td>20.2</td>
<td>33.7</td>
<td>5.2</td>
<td>2.5</td>
<td>1.2</td>
</tr>
<tr>
<td>pHᶜ</td>
<td>6.6</td>
<td>6.5</td>
<td>6.7</td>
<td>7.0</td>
<td>7.1</td>
</tr>
<tr>
<td>Naᵈ (mg kg⁻¹)</td>
<td>66.6</td>
<td>99.5</td>
<td>73.2</td>
<td>67.9</td>
<td>7.1</td>
</tr>
<tr>
<td>Sᵈ (mg kg⁻¹)</td>
<td>9.4</td>
<td>7.2</td>
<td>4.5</td>
<td>4.5</td>
<td>4.3</td>
</tr>
<tr>
<td>Feᵈ (mg kg⁻¹)</td>
<td>0.6</td>
<td>0.4</td>
<td>38.5</td>
<td>56.2</td>
<td>13.7</td>
</tr>
<tr>
<td>Mnᵈ (mg kg⁻¹)</td>
<td>0.02</td>
<td>0.04</td>
<td>0.2</td>
<td>0.2</td>
<td>0.3</td>
</tr>
<tr>
<td>Mgᵈ (mg kg⁻¹)</td>
<td>8.3</td>
<td>10.5</td>
<td>16.7</td>
<td>21.1</td>
<td>7.3</td>
</tr>
<tr>
<td>Caᵈ (mg kg⁻¹)</td>
<td>8.8</td>
<td>11.5</td>
<td>50.7</td>
<td>60.8</td>
<td>55.8</td>
</tr>
</tbody>
</table>

ᵃ Electrical Conductivity Bridge (Rhoades, 1982)
ᵇ Dry Combustion (SCS, 1971)
ᶜ 1:2 soil:water paste (Peech, 1965)
ᵈ Water soluble using automatic extractor, ICP method

TABLE 5.2. WATER ANALYSES IN THE STUDY AREA PRIOR TO PLANTING.

<table>
<thead>
<tr>
<th>PROPERTY</th>
<th>UNITS</th>
<th>VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>pHᵃ</td>
<td></td>
<td>6.8</td>
</tr>
<tr>
<td>ECᵇ</td>
<td>dS m⁻¹</td>
<td>7.0</td>
</tr>
<tr>
<td>Naᶜ</td>
<td>mg L⁻¹</td>
<td>896.5</td>
</tr>
<tr>
<td>Caᶜ</td>
<td>mg L⁻¹</td>
<td>85.5</td>
</tr>
<tr>
<td>Mgᶜ</td>
<td>mg L⁻¹</td>
<td>189.3</td>
</tr>
<tr>
<td>Scᶜ</td>
<td>mg L⁻¹</td>
<td>145.2</td>
</tr>
<tr>
<td>Feᶜ</td>
<td>mg L⁻¹</td>
<td>0.5</td>
</tr>
</tbody>
</table>

ᵃ Expandomatic pH meter (Peech, 1965)
ᵇ Electrical Conductivity Bridge (Rhoades, 1982)
ᶜ ICP method
because of their average electrical conductivity (EC) of 6.2 to 7.2 dS m⁻¹. Subsurface horizons (A, Cgl, and Cg2) were classified similarly because their average EC were 6.2, 4.2, and 4.0 dS m⁻¹, respectively. The organic carbon (OC) in the surface horizon was high, ranging from 20.2 to 33.7% while the subsurface horizons had low OC content, ranging from 1.2 to 5.2%. A very uniform near neutral soil pH distribution was observed with soil depth with mean values ranging from 6.5 to 7.1. The initial status of Na, S, Fe, Mn, and Mg at the upper soil depth (0-25 cm) ranged from 66.6 to 99.5; 7.2 to 9.4; 0.4 to 0.6; 0.02 to 0.04; and 8.3 to 10.5 mg kg⁻¹, respectively. These values were lower than the previous data reported by Brupbacher et al. (1973). The pH reading of water was near neutral (6.8) with initial EC status of 7.0 dS m⁻¹. These initial readings are not absolute because they are likely to vary with time and season (Sigua and Hudnall, 1989). The initial concentration of Na, Ca, Mg, S, and Fe of the water sample were 896.5, 85.5, 189.3, 145.2, and 0.5 mg L⁻¹, respectively.

**Site Preparation and Field Layout:**

The initial site preparation consisted of levee construction, total drainage of the area, clearing, plot layout, and treatment distribution. An area approximately 800 sq m was thoroughly cleaned to avoid any interference of indigenous species of vegetation. A levee, 1 m high x 1.5 m wide was constructed around the study area using a marsh buggy backhoe. Another levee was constructed cutting across the longest side of the study area. This levee divided the main treatment (flooded vs. non-flooded plots). The entire area was drained totally just prior to planting and later flushed with water from the surrounding marsh. Indigenous species of
vegetation were totally eliminated by hand weeding and chemical treatment. After removing all the tall growing species, "Round-Up" herbicide was sprayed at a doubled rate, two times at a 10-day interval to effectively eliminate all the vegetation within the study site. A third supplementary spraying of Round-Up was made at the regular concentration 10 days before planting. Each main plot (9m x 16m) was further subdivided into two sub-plots, each with dimensions of 3m x 16m. This subdivision represented the gypsum treatment (0 vs. 7 Mg ha⁻¹). Each subplot was further subdivided into 12 sub-subplots, having dimensions of 1m x 4m each. In each of these sub-subplots, four species of marsh vegetation were randomly assigned. Each treatment was replicated three times. Plot layout and treatment distribution are shown in Figure 5.1.

Soil Treatment and Planting:

Prior to planting, agricultural gypsum (CaSO₄·2H₂O, 75% Ca) at the rate of 7 Mg ha⁻¹ (2.8 kg plot⁻¹) was thoroughly incorporated into the soil. Blanket application of N at the rate of 100 kg N ha⁻¹ or 260 g urea (45% N) plot⁻¹ was applied at planting. The flooded plots were irrigated with water from the surrounding marsh to a depth of about 10 cm while the non-flooded (dry) plots were flushed bi-weekly except when there was sufficient rainfall to maintain the moisture content slightly below or equal to field capacity. The level of water on the flooded plots was maintained at about 8-10 cm with marsh water exchange with the surrounding marsh twice a month during the first four months. Thereafter, the water level was maintained at a depth of about 8-10 cm either by adding or draining.
Bare-root plants of marsh hay cordgrass (*Spartina patens* MuhL.),
joint grass (*Paspalum vaginatum* SW.), salt grass (*Distichlis spicata* L.),
and sprigs of fresh water three-square (*Scirpus americanus* Pers.)
were planted on September 23, 1988. These planting materials were obtained
from one of the commercial growers in Tampa, Florida. Plants were first
harvested for the yield and nutrient content on July 25, 1989. The second
and third harvesting (clipping) for tissue analyses were completed on
September 25, 1989 and November 25, 1989, respectively.

**Analysis of Plants:**

Clippings of each plot were transferred to paper bags, dried for 48 h
at 70°C in a convection oven, weighed to determine dry matter yield and
ground in a Wiley mill to pass a 40 mesh screen. A portion of plant
samples for total N determination was digested with concentrated
H₂SO₄ as described by Nelson and Sommers (1973). Nitrogen was
determined by steam distillation as described by Bremner and Edwards (1965).
Another sample of plant tissue was digested with HNO₃ (Isaac and Johnson,
1975) and analyzed for P, K, Na, Ca, Mg, S, Fe, Al, Mn, Cu, and Zn
were analyzed by inductively coupled plasma–atomic emission spectroscopy
(ICP–AES).

**Statistical Analysis:**

Three way split-plot analysis of variance (ANOVA) was used to
evaluate the main and interaction effects of gypsum–soil moisture–specie
treatments on survival rate, yield, crude protein content (CPC), and
nutrient composition (SAS, 1985). Mean separation of the main treatment
effect and interaction effects were made following the principles of the
(SAS, 1985). The yield and CPC data were adjusted because of missing
values in the non-flooded plots in accordance with the procedures outline in the SAS User's Guide: Statistics (SAS, 1985). The principles of the stepwise regression technique (SAS, 1985) were followed to determine the best fit to describe the behavior and distribution of nutrient composition over time for each species of marsh vegetation.

RESULTS AND DISCUSSION

Survival Rate:

The survival rate at harvest of the four species on flooded and non-flooded plots are shown in Figure 5.2. Data given in Figure 5.3 represents the significant effects of gypsum and water management on survival rate. Comparative analysis of the survival rate among species of marsh vegetation under the flooded condition was joint grass (100.0%) > salt grass (71.2%) > marsh hay cordgrass (66.7%) > three-square (59.3%). No plants survived in non-flooded plots except for the marsh hay cordgrass which had a mean survival rate of 32.8% as compared to 66.7% grown under flooded conditions.

Application of 7 Mg ha⁻¹ of gypsum significantly increased the rate of survival of all plants in flooded plots except for the joint grass. Survival of marsh hay cordgrass was increased from 41.5 to 91.9% while the survival rate were increased from 49.7 to 92.7% for salt grass and 33.6 to 85.0% for three-square due to gypsum addition. No complete evaluation on the overall effect of gypsum could be made because of the missing values (Figures 5.2 and 5.3).

The result of the statistical analysis of marsh hay cordgrass as shown in Figure 5.3 was used to partially evaluate the interaction effect
Figure 5.2. Comparative analyses on the survival rate and crude protein content of four species of marsh vegetation grown in flooded and non-flooded plots.
Figure 5.3. Survival rate and crude protein content of marsh hay cordgrass as affected by gypsum and water management.
of gypsum and water management. Results of the data analyses disclosed a significantly higher survival rate in flooded plots that were treated with gypsum than the non-flooded plots that were not treated with gypsum. The former had an average survival rate of 91.9% while the latter had 21.3%. The overall mean survival rate for the gypsum treated plots was 68.2% as opposed to 21.9% for the non-gypsum treated plots.

Interaction of gypsum and water management on survival rate of each species are shown in Figure 5.4. Results disclosed an overwhelming influence of gypsum and water management on the growth and survival of different species. This claim was exhibited by a much higher rate of survival on flooded plots than on non-flooded plots and from the plants treated with gypsum as opposed to the plants without gypsum. Their ability to make necessary adjustment against some environmental adversity, i.e., climate, soil structure, soil reaction, direct toxicity and deficiency of ions, and other effects, were the key for survival. No plants had survived in the non-flooded plots except for the marsh hay cordgrass with low survival rate of 32.8% (Figure 5.3). Soil moisture had played a tremendous role on the survival of plants in this study. The loss of cell turgor as induced by water stress accompanied by stomatal closure decreases photosynthesis to zero. Tobiessen and Buchsbaum (1970) reported that physiological changes resulting from long periods of stomatal closure and consequent starvation may predispose plants to infection, leading to dieback and decline. Ayers et al. (1943) stressed that consideration should be given to the moisture stresses within plants and the soil-root relationships that may affect these stresses. These relationships can be summarized as: a) increase work necessary to obtain water from the soil as
Figure 5.4. Interaction effect of gypsum and water management on the survival rate of four marsh vegetation species.
the soil moisture tension increases; b) increased work necessary to obtain water from the soil solution as the osmotic concentration of the soil solution is increased; and c) the inability of the plant to produce new roots.

Results were in good agreement with the previous findings of Wadleigh and Ayers (1945). They suggested that the response of crops was affected by the integrated total moisture potential which is the sum of the osmotic potential and the soil moisture tension. With increasing osmotic concentration of the plant sap, the growth rate of plants were eventually stopped (Eaton, 1927; Furr and Taylor, 1939; Aldrich et al., 1940; Ratner, 1958). High transpiration rates of plants on saline soils were very damaging because of increased salt absorption. High transpiration simply increases the moisture deficit in the plants, thereby impairing growth (Eaton, 1927; Ratner, 1958).

The beneficial effect of gypsum addition on the survival rate of plants is illustrated in terms of energy expenditures. With respect to the energy relations, more work is required to remove a gram of water from a solution as its salt concentration increases. Plants growing in saline soils must do more work to obtain a given amount of water and nutrients than plants growing in a less concentrated soil solution (Eaton, 1941; Wadleigh and Ayers, 1945; Meiri and Mayber, 1970). The high survival rate of gypsum treated-plants and very low rate of plants survival in plots without gypsum was related to the expenditures of energy. Addition of gypsum minimized energy expenditures, thereby increasing available energy for other growth and metabolic processes in the plants (Gale, 1975).
The beneficial effect of gypsum addition can be further explained in terms of the specific ion effect. The specific ion effect states: "increasing the supply of other cation species in the nutrient medium can thus depress the levels of cation species in the plant" (Scharrer and Jung, 1955). Some investigators suggested this effect in terms of carrier competition. If this was true, it would mean that the three major cations (Ca, Mg, and K) were competing for the same carrier binding site (Leggett and Gilbert, 1969; Mengel, 1973). Application of gypsum as a Ca\textsuperscript{2+} carrier to Na\textsuperscript{+}-rich organic soils could lower the concentration of Na\textsuperscript{+} ion in the carrier binding site. While there is high concentration of Na\textsuperscript{+} in the carrier binding site, it continuously depressed the availability of other major cations like Ca, Mg, and K. If this condition persists, the detrimental effect of Na\textsuperscript{+} to the growing plants is only expected. However, if concentrations of other cations were increased via chemical amendment like gypsum addition, the preponderance of Na\textsuperscript{+} ion in the carrier binding site would decrease below the threshold limit of Na toxicity. The early published report of Pearson and Hayward (1958) illustrates specific ion effect. They found that the Na concentration in the leaf blades of grain crops increased with increasing ESP values in the soil. Increasing levels of exchangeable Na in the soil resulted in decreasing K concentration. Calcium in the soil also decreased as the percent exchangeable Na in the soil increased. There was also a decrease in the amount of Ca accumulated by the plants. Chang and Dregne (1955) proposed the term "Na-induced Ca deficiency" to describe the above situation.
Dry Matter Yield:

The dry matter yield (DMY) of the four species grown under flooded and non-flooded conditions is presented in Figure 5.5. Yield comparison showed that the highest yield was observed for joint grass (5.76 Mg ha\(^{-1}\)), followed by marsh hay cordgrass (4.40 Mg ha\(^{-1}\)), three-square (2.19 Mg ha\(^{-1}\)), and salt grass (1.88 Mg ha\(^{-1}\)). Marsh hay cordgrass was the only surviving species in non-flooded plots, with an average dry yield of 0.55 Mg ha\(^{-1}\). On flooded plots, a yield increase of 700.0% or about 3.85 Mg ha\(^{-1}\) was observed. These findings were in agreement with the early data reported by Mendelssohn and Seneca (1980) and Linhurst and Seneca (1980). Mendelssohn and Seneca (1980) reported that the growth and survival of *Spartina alterniflora* was directly related to marsh soil drainage and aeration in North Carolina. Total biomass of tall and medium *Spartina* and the areal standing crop of short *Spartina* were significantly reduced when soil drainage was experimentally imposed. Similarly, Linthurst and Seneca (1980) suggested that the drainage and various depths of standing water affect the growth of *Spartina alterniflora* in the salt marsh. They observed a decrease in both density and living biomass when substrate surface was elevated 10 cm above the natural marsh surface.

Decreased cell growth (enlargement) is the most sensitive response of the plant to water stress, and since cell growth is quantitatively related to cell turgor, cell turgor decreases with any dehydration (Sands and Correl, 1976). In many, if not most cases, this causes the drop in photosynthesis, and eventually the death of plants (Tobiessen and Buchsbaum, 1976). The experimental evidence presented above supports the concept that decreased growth or death of plants on saline substrate is
Figure 5.5. Dry matter yield of four species of marsh vegetation on flooded and non-flooded plots.

Species 1 - P. vaginatus
Species 2 - S. patens
Species 3 - O. epiotae
Species 4 - S. americanus
related to decreased water availability.

The overall yield performance of the four species was very much affected by water management and gypsum addition (Table 5.3). A highly significant interaction was also observed between water management and gypsum and between gypsum and specie of marsh vegetation (Table 5.3). Plants receiving 7 Mg ha\(^{-1}\) had significantly higher DMY than those plants from plots not receiving gypsum. The DMY of joint grass, marsh hay cordgrass, salt grass, and three-square was increased from 5.44 to 8.08, 1.90 to 6.91, 0.97 to 2.79, and 1.55 to 2.84 Mg ha\(^{-1}\), respectively, when treated with 7 ton ha\(^{-1}\) of gypsum. Marsh hay cordgrass, the only surviving specie in the non-flooded plots, had a yield increase of 0.40 Mg ha\(^{-1}\) over the plants without gypsum.

The combined effect of gypsum and water management on the DMY of the four species and for marsh hay cordgrass are presented in Figures 5.6 and 5.7. Plants in the flooded plots had much higher DMY than the plants in the non-flooded plots. The most DMY production of 6.91 Mg ha\(^{-1}\) was observed from plants in the gypsum-treated flooded plots while the least dry yield of 0.35 Mg ha\(^{-1}\) was obtained from the plants in the flooded plots that had no gypsum treatment. Both gypsum addition and water management treatment combinations should become a major part of any marsh revegetation program. The DMY of each species of marsh vegetation in flooded plots was tremendously increased because of gypsum addition. The favorable effect of gypsum addition and leaching reported elsewhere (Kanwar, 1962; Bridge and Kleinig, 1968; Bower, 1969; Khosla et al., 1979) strongly support the results reported here. Kanwar (1962) pointed out that 30 to 90 cm leaching water with 2 Mg gypsum ha\(^{-1}\) was possible to reclaim soil and bring it to
TABLE 5.3. ANALYSIS OF VARIANCE (GENERAL) ON THE EFFECT OF WATER MANAGEMENT AND GYPSUM ADDITION ON DRY MATTER YIELD (DMY); FRESH MATTER YIELD (FMY); SURVIVAL RATE (SR); AND CRUDE PROTEIN CONTENT (CPC) OF FOUR SPECIES OF MARSH VEGETATION.

<table>
<thead>
<tr>
<th>SOURCES OF VARIATION</th>
<th>DMY(^d) (Mg ha(^{-1}))</th>
<th>FMY (Mg ha(^{-1}))</th>
<th>SR(^e) (%)</th>
<th>CPC(^f) (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WATER MGT (WM)(^a)</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td>GYPSUM (G)(^b)</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>*</td>
</tr>
<tr>
<td>VARIETY (V)(^c)</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td>WM x G</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>ns</td>
</tr>
<tr>
<td>G x V</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td>R²</td>
<td>0.98(^**)</td>
<td>0.99(^**)</td>
<td>0.99(^**)</td>
<td>0.86(^**)</td>
</tr>
</tbody>
</table>

\(^a\) Include flooded and non-flooded plots (main treatment effects)
\(^b\) Include 0 and 7 Mg CaSO₄·2H₂O/ha
\(^c\) Include V1 (Paspalum vaginatum SW.); V2 (Spartina patens MuhL.); V3 (Distichlis spicata L.); and V4 (Scirpus americanus Pers.)
\(^d\) Adjusted yield (Dried @ 70°C) based on plot size (3x4 m) yield
\(^e\) SR = (# of plants survived at harvest/population density per plot) x 100
\(^f\) Protein Content = Kjeldhal Nitrogen (%) x 6.25

** = significant at p=0.01
*  = significant at p=0.05
ns = not significant
Figure 5.6. Interaction effect of gypsum and water management on the dry matter yield.
Figure 5.7. Dry matter yield of marsh hay cordgrass as affected by gypsum addition on flooded and non-flooded plots.
normal production. Bridge and Kleinig (1968) found that gypsum addition significantly increased soil moisture storage before and after irrigation. Their laboratory experiment showed that gypsum application increases the hydraulic conductivity of the subsoil, increases the exchangeable Ca in the soil profile and decreases the exchangeable Na. In 1969, Bower suggested that application of gypsum followed by leaching as a method to replace adsorbed Na. He stressed that leaching with successive dilutions of highly saline water having 30% or more Ca salts as an effective means of removing adsorbed Na while maintaining adequate soil permeability.

Earlier reports on the crucial role of Ca in the regulation of the salt economy in the plants, selective ion transport and exclusion of Na and other mineral ions (Ratner, 1944; LaHaye and Epstein, 1969; Ayoub, 1974) used to further explain the results in this study. The progressive decrease in growth with increasing osmotic pressure of the external solutions can be explained explicitly by the classical osmotic theory. The decrease in diffusion pressure gradient between the medium and the plants because of decreasing soil moisture content and increasing osmotic pressure were related positively to the degree of growth inhibition and the greater accumulation of solutes in the cells of the stunted plants in the plots without gypsum treatment (Berstein and Hayward, 1958).

Protein Content:

The crude protein content (CPC) of each species of marsh vegetation on flooded and non-flooded plots is shown in Figure 5.2. Table 5.3 shows a significant differences on the CPC among species and significant effect of gypsum and water management. Among species of marsh vegetation in flooded plots, the three-square had the highest CPC at first harvest with
a mean of 9.72% followed by joint grass (9.38%), salt grass (9.27%), and marsh hay cordgrass (7.98%). The CPC of the lone surviving marsh hay cordgrass in non-flooded plots was 6.29% which is approximately 1.69% lower than the CPC of the plants in the flooded plots. Protein breakdown as a metabolic drought injury is suggested by Mothes (1928). He reported that protein synthesis in general decreases with decreasing water content. Reduction in plant respiration and photosynthesis associated to water stress resulted to a decreased net hydrolysis of protein.

Plants receiving gypsum had higher CPC than those plants in the non-gypsum treated plants. Crude protein content of the former was 14% more on the average than the latter. Kahane and Mayber (1968) showed a dual effect of salinity on incorporation of amino acid into root tip protein. In the presence of salts, the uptake is depressed and the metabolic pathways were disturbed. They reported that the higher the salinity level in the medium, the lower the incorporation of the amino acid. Wadleigh and Gauch (1942) found a progressive diminution in the percentage of protein, especially in the leaves with increasing salt concentration.

The data trend given in Figure 5.8 shows the behavioral and distributional patterns of CPC at various times of clipping. An attempt was made to describe this pattern via regression model. A general behavioral pattern was formulated for each species. The pattern was described via stepwise regression model. The different regression model for each species are shown in Table 5.7. The intent of this analysis was to monitor the CPC of each species of marsh vegetation over time to establish a useful model that has implication on the nutritional aspect of waterfowl and wildlife in the marsh. A good estimate on the protein content of each
Figure 5.8. Behavioral and distributional pattern of crude protein content at various time of harvest (clipping).
species over time is very important if the primary establishment of vegetation in the marsh is for wildlife, whether for shelter or as a food source. If the primary concern was on the former, then the model presented would be very helpful, especially in planning the right time of seeding and planting. If the peak demand for food of different wildlife in the marsh and the peak of protein content coincided, the nutritional value of the plant to wildlife is increased.

Nutrient Composition:

The comparative analyses on the nutrient composition of four species of marsh vegetation in flooded plots are shown in Tables 5.4 and 5.5. Data given in these tables showed significant variation on the nutrient composition among different species of marsh vegetation. High and low concentrations of different nutrients varied from one species to another. Making any generalization about the trend of results was not likely possible because of tremendous variability among species. The only consistent result was on the concentration of N, P, K, Ca, and Mg. These were observed from the three-square with mean high of 1.56, 0.14, 2.22, 0.26, and 0.22%, respectively.

The regression analyses on the relationships of elemental composition and time of clipping for each species of marsh vegetation are shown in Tables 5.6 and 5.7. The distribution and concentration of each nutrient for each species are shown in Figures 5.9 to 5.12. Elemental composition of each species of marsh of vegetation was quadratically related to the time of clipping. With the exception of Mg concentration in salt grass, Fe concentration in marsh hay cordgrass, and N concentration in joint grass and three-square, all the relationships were valid and
TABLE 5.4. COMPARATIVE ANALYSIS ON THE ELEMENTAL COMPOSITION (N, P, K, Ca, Mg, and S) OF FOUR SPECIES OF MARSH VEGETATION.

<table>
<thead>
<tr>
<th>VARIETY</th>
<th>N</th>
<th>P</th>
<th>K</th>
<th>Ca</th>
<th>Mg</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td>VI</td>
<td>1.50a</td>
<td>0.11b</td>
<td>1.59b</td>
<td>0.18c</td>
<td>0.14c</td>
<td>2.39a</td>
</tr>
<tr>
<td>V2</td>
<td>1.28b</td>
<td>0.12b</td>
<td>1.13c</td>
<td>0.22b</td>
<td>0.18b</td>
<td>1.71b</td>
</tr>
<tr>
<td>V3</td>
<td>1.48a</td>
<td>0.10b</td>
<td>1.28c</td>
<td>0.18c</td>
<td>0.14c</td>
<td>1.45c</td>
</tr>
<tr>
<td>V4</td>
<td>1.56a</td>
<td>0.14a</td>
<td>2.22a</td>
<td>0.26a</td>
<td>0.22a</td>
<td>1.19a</td>
</tr>
</tbody>
</table>

VI (Paspalum vaginatum Sw.); V2 (Spartina patens Muhl); V3 (Distichlis spicata L.); V4 (Scirpus americanus Pers.)

Means followed by same letter(s) are not significantly different at p=0.05

TABLE 5.5. COMPARATIVE ANALYSIS ON THE ELEMENTAL COMPOSITION (Na, Fe, Al, Mn, Cu, and B) OF FOUR SPECIES OF MARSH VEGETATION.

<table>
<thead>
<tr>
<th>VARIETY</th>
<th>Na</th>
<th>Fe (mg kg⁻¹)</th>
<th>Al</th>
<th>Mn (mg kg⁻¹)</th>
<th>Cu</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td>VI</td>
<td>0.67b</td>
<td>415.8a</td>
<td>168.8b</td>
<td>102.2c</td>
<td>75.7d</td>
<td>13.7b</td>
</tr>
<tr>
<td>V2</td>
<td>0.62b</td>
<td>195.3d</td>
<td>177.3b</td>
<td>155.1bc</td>
<td>92.0c</td>
<td>8.8c</td>
</tr>
<tr>
<td>V3</td>
<td>0.46c</td>
<td>281.3b</td>
<td>365.5a</td>
<td>183.9b</td>
<td>121.3c</td>
<td>11.8b</td>
</tr>
<tr>
<td>V4</td>
<td>1.19e</td>
<td>245.7c</td>
<td>132.5c</td>
<td>877.7a</td>
<td>163.8a</td>
<td>22.0a</td>
</tr>
</tbody>
</table>

VI (Paspalum vaginatum Sw.); V2 (Spartina patens Muhl); V3 (Distichlis spicata L.); V4 (Scirpus americanus Pers.)

Means followed by same letter(s) are not significantly different at p=0.05
<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>N</th>
<th>P</th>
<th>K</th>
<th>Ca</th>
<th>Mg</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td>INTERCEPT</td>
<td>1.62</td>
<td>0.12</td>
<td>1.67</td>
<td>0.18</td>
<td>0.14</td>
<td>2.36</td>
</tr>
<tr>
<td>b1</td>
<td>-0.12</td>
<td>-0.09</td>
<td>-1.74</td>
<td>-0.16</td>
<td>-0.09</td>
<td>-3.10</td>
</tr>
<tr>
<td>b2</td>
<td>-0.22</td>
<td>0.05</td>
<td>0.69</td>
<td>0.05</td>
<td>0.04</td>
<td>1.18</td>
</tr>
<tr>
<td>R-square</td>
<td>0.16ns</td>
<td>0.82**</td>
<td>0.96**</td>
<td>0.66**</td>
<td>0.62**</td>
<td>0.82**</td>
</tr>
</tbody>
</table>

**Paspalum vaginatum SW.**

| INTERCEPT  | 1.56 | 0.12 | 1.12 | 0.21 | 0.19 | 1.72 |
| b1        | -0.16 | -0.06 | -1.31 | -0.18 | -0.21 | -2.11 |
| b2        | -0.06 | 0.03 | 0.49 | 0.09 | 0.09 | 0.86 |
| R-square  | 0.47** | 0.43ns | 0.86** | 0.59** | 0.94** | 0.70** |

**Spartina patens MuhL.**

| INTERCEPT  | 1.63 | 0.11 | 1.33 | 0.19 | 0.14 | 1.39 |
| b1        | -0.11 | -0.07 | -0.89 | -0.15 | -0.11 | -1.19 |
| b2        | -0.02 | 0.03 | 0.28 | 0.07 | 0.06 | 0.41 |
| R-square  | 0.21* | 0.77** | 0.95** | 0.50* | 0.28ns | 0.52* |

**Distichlis spicata L.**

| INTERCEPT  | 1.57 | 0.15 | 2.30 | 0.25 | 0.21 | 1.79 |
| b1        | -0.02 | -0.17 | -2.59 | -0.21 | -0.22 | -1.72 |
| b2        | 0.01 | 0.09 | 0.95 | 0.15 | 0.13 | 0.61 |
| R-square  | 0.14ns | 0.81** | 0.95** | 0.89** | 0.92** | 0.94** |

**Scirpus americanus Pers.**

**— significant at p=0.01  * — significant at p=0.05  
ns — not significant
TABLE 5.7. REGRESSION ANALYSIS ON THE RELATIONSHIPS OF ELEMENTAL COMPOSITION (Na, Fe, Mn, Al) AND CRUDE PROTEIN CONTENT (CPC) AND TIME OF CLIPPING FOR FOUR SPECIES OF MARSH VEGETATION.

<table>
<thead>
<tr>
<th>PARAMETER ESTIMATES</th>
<th>Na (%)</th>
<th>Fe mg kg⁻¹</th>
<th>Mn mg kg⁻¹</th>
<th>Al mg kg⁻¹</th>
<th>CPC (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Paspalum vaginatum</strong> SW.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intercept (b₀)</td>
<td>0.70</td>
<td>428.50</td>
<td>103.30</td>
<td>164.20</td>
<td>10.10</td>
</tr>
<tr>
<td>b₁</td>
<td>-0.73</td>
<td>-370.60</td>
<td>-101.60</td>
<td>-207.70</td>
<td>-0.70</td>
</tr>
<tr>
<td>b₂</td>
<td>0.42</td>
<td>105.10</td>
<td>46.30</td>
<td>71.40</td>
<td>3.60</td>
</tr>
<tr>
<td>R-square</td>
<td>0.93**</td>
<td>0.64**</td>
<td>0.52**</td>
<td>0.96**</td>
<td>0.16ns</td>
</tr>
<tr>
<td><strong>Spartina patens</strong> Muhl.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intercept (b₀)</td>
<td>0.59</td>
<td>185.50</td>
<td>157.80</td>
<td>184.80</td>
<td>9.70</td>
</tr>
<tr>
<td>b₁</td>
<td>-0.36</td>
<td>-152.40</td>
<td>-219.20</td>
<td>-257.40</td>
<td>-0.90</td>
</tr>
<tr>
<td>b₂</td>
<td>0.16</td>
<td>66.30</td>
<td>120.90</td>
<td>95.50</td>
<td>-0.20</td>
</tr>
<tr>
<td>R-square</td>
<td>0.64**</td>
<td>0.35ns</td>
<td>0.67**</td>
<td>0.50**</td>
<td>0.47**</td>
</tr>
<tr>
<td><strong>Distichlis spicata</strong> L.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intercept (b₀)</td>
<td>0.47</td>
<td>281.80</td>
<td>178.20</td>
<td>384.80</td>
<td>10.20</td>
</tr>
<tr>
<td>b₁</td>
<td>-0.29</td>
<td>-217.00</td>
<td>-202.10</td>
<td>-565.40</td>
<td>-0.70</td>
</tr>
<tr>
<td>b₂</td>
<td>0.14</td>
<td>64.70</td>
<td>114.30</td>
<td>196.10</td>
<td>-0.10</td>
</tr>
<tr>
<td>R-square</td>
<td>0.35ns</td>
<td>0.94**</td>
<td>0.53*</td>
<td>0.99**</td>
<td>0.22*</td>
</tr>
<tr>
<td><strong>Scirpus americanus</strong> Pers.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intercept (b₀)</td>
<td>1.09</td>
<td>233.5</td>
<td>773.3</td>
<td>143.0</td>
<td>9.8</td>
</tr>
<tr>
<td>b₁</td>
<td>-0.50</td>
<td>-157.8</td>
<td>-680.3</td>
<td>-151.2</td>
<td>-0.2</td>
</tr>
<tr>
<td>b₂</td>
<td>0.30</td>
<td>46.4</td>
<td>405.7</td>
<td>46.9</td>
<td>-0.1</td>
</tr>
<tr>
<td>R-square</td>
<td>0.91**</td>
<td>0.66**</td>
<td>0.92**</td>
<td>0.94**</td>
<td>0.15ns</td>
</tr>
</tbody>
</table>

** - significant at p=0.01  * - significant at p=0.05  
ns - not significant
Figure 5.9. Relationship between nutrient concentration of joint grass (*Paspalum vaginatum* SW.) and time of harvest (clipping).
Figure 5.10. Relationship between nutrient concentration of marsh hay cordgrass (*Spartina patens* MuhL.) and time of harvest (clipping).
Figure 5.11. Relationship between nutrient concentration of salt grass (Distichlis spicata L.) and time of harvest (clipping).
Figure 5.12. Relationship between nutrient concentration of three square (Scirpus americanus Pers.) and time of harvest (clipping).
significant with $R^2$ ranging from 0.52 to 0.99. Figures 5.9 to 5.12 show significant reduction in all the nutrient concentration from the first harvest (July 25, 1989) to third harvest (November 25, 1989).

**SUMMARY AND CONCLUSIONS**

The results are summarized as follows:

1. Higher plant survival and greater DMY were observed from plants grown in flooded plots than in non-flooded plots. Soil drying was very detrimental to the growth and yield of marsh vegetation.
2. Plants that were grown on flooded plots with gypsum treatment of 7 Mg ha$^{-1}$ had a higher survival rate, DMY, and CPC.
3. For the purposes of year-round erosion control and food availability for wildlife in the marsh, marsh hay cordgrass (*Spartina patens* MuhL.) exhibited superior growth and cover over other species of marsh vegetation because of its ability to grow either in flooded or non-flooded conditions.
4. The CPC of each species of marsh vegetation was significantly enhanced by gypsum and water management. A quadratic relationship was observed between the CPC and various time of clipping.

The aforementioned results had convincingly reaffirmed the importance of gypsum addition and the proper soil moisture regime for the restoration of suitable marsh vegetation. An ideal management combination for effective brackish marsh revegetation and improvement program is to maintain a flooded marsh environment by avoiding excessive drainage and application of gypsum at the rate of 7 Mg ha$^{-1}$. 
LITERATURE CITED


_________. 1941. Water uptake and root growth as influenced by inequalities in the concentration of the substrate. Plant Physiol. 16:545-564.


SUMMARY AND CONCLUSIONS

Laboratory, greenhouse, and field experiments were conducted on a brackish marsh soils of Hackberry, LA. This area was inundated by brackish-saline water, and is now open water, almost totally void of vegetation. This study was initiated to obtain detailed information on some soil- and water-based management factors that were applicable to the revegetation and productivity improvement of the area. A comprehensive evaluation of plant-soil-water relationships designed to provide information on plant survival, plant-site relationships, and establishment of management techniques to improve plant adaptability in the brackish environment comprised the core of this study.

Important results and conclusions drawn from this study are as follows:

1. Spatial variability of some selected physicochemical properties of soil in the area showed significant results. The variability of individual properties as indicated by coefficients of variation (CV) differed significantly.

2. Temporal variations of some selected chemical properties of water were significantly correlated to precipitation and maximum and minimum temperatures in the area. Consistently higher pH, EC, NA, Mg, S, TDS, IS, OP, Cl\textsuperscript{−}, NO\textsubscript{3}\textsuperscript{−}, and F\textsuperscript{−} were observed from the marsh water samples than the canal samples.

3. Seasonal variations of soil pH, EC, TDS, IS, and concentrations of Na, Mg, Ca, K, Fe, Al, Mn, and S were observed. Sodium and Ca concentration, pH, EC, TDS, and IS were linearly and cubically related to total precipitation and maximum temperature. Cubic models explained a better
relationship because of higher \( R^2 \) value when compared to the linear models.

4. Addition of 7 Mg gypsum ha\(^{-1}\) significantly affected some of the selected chemical properties of brackish marsh soils. Significantly lower EC, TDS, IS, and concentrations of Fe, Al, Mn, and S over time were observed from samples treated with gypsum as opposed to the control.

5. Soil drying significantly reduced urease activity in the area and was detrimental to the overall growth and yield of marsh vegetation. There was zero plant survival in the non-flooded plots except for the marsh hay cordgrass with survival rate of 32.8%.

6. The four species of marsh vegetation: \textit{Spartina patens} MuhL. (marsh hay cordgrass), \textit{Distichlis spicata} L. (salt grass), \textit{Paspalum vaginatum} SW. (joint grass), and \textit{Scirpus americanus} Pers. (freshwater three-square) responded significantly to N and gypsum application.

7. The CPC and nutrient concentrations (N, P, K, Ca, Mg, Na, S, Fe, Al) in the tissues of four species of marsh vegetation were significantly affected by N fertilization and gypsum addition.

8. Plants that were grown on flooded plots with gypsum treatment (7 Mg ha\(^{-1}\)) had higher survival rate, yield, and protein content than those plants on the non-flooded plots with no gypsum treatment.

9. For the purposes of year-round erosion control and food availability for wildlife in the marsh, marsh hay cordgrass was superior over the other species because of its ability to grow either in flooded and non-flooded conditions.

10. The CPC of each species of marsh vegetation was significantly enhanced by gypsum addition and water management.
Results of this study strongly reaffirmed the importance of N fertilization, gypsum addition, and proper soil moisture regime for the restoration of suitable marsh vegetation. An ideal management combination for effective brackish marsh vegetation and productivity improvement is to maintain the flooded marsh environment by avoiding excessive drainage and the application of gypsum at the rate of 7 Mg ha\(^{-1}\) with supplemental application of 100–150 kg N ha\(^{-1}\).
LITERATURE CITED


_________. 1941. Water uptake and root growth as influenced by inequalities in the concentration of the substrate. Plant Physiol. 16:545-564.


VITA

Gilbert Castaneda Sigua was born on October 14, 1957 in San Pablo, Isabela, Philippines. He received his elementary education from Partida Elementary School and graduated from San Miguel High School in 1973. He obtained his Bachelor of Science degree in Agriculture (Soil Science) from the Central Luzon State University, Philippines in 1978.

He began his professional career as an instructor and a researcher in the Central Luzon State University in 1978. Three years later, he received a USAID scholarship grant for his graduate study at the University of Arkansas. He obtained his M. S. in Agronomy (Soil Science) in 1983 and returned to his post in the Philippines.

In 1986, he was a recipient of the Freedom from Hunger Scholarship Grant supported by the Rotary Foundation to pursue a Ph. D. program in Land Resources Management. He attended Louisiana State University in August, 1986 for his advanced study. He is presently a candidate for the degree of Doctor of Philosophy with a major in Agronomy (Soil Science) and minor in Geography and Geology.

He is married to the former Ms. Celia F. Avellanoza. They have a six year old son, Gerald.
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Major Field: Agronomy

Title of Dissertation: Soil and Water Based Management Strategies for Revegetation and Productivity Improvement of Brackish Marsh Soils

Approved:

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Date of Examination:

September 10, 1990