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SOIL AMELIORATION AND PLANT ESTABLISHMENT ON SODIUM AFFECTED SOILS ON GALVESTON ISLAND, TEXAS

By

Elaine Harris, Bachelor of Science in Environmental Science

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SOIL AMELIORATION AND PLANT ESTABLISHMENT ON SODIUM AFFECTED SOILS ON GALVESTON ISLAND, TEXAS

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ABSTRACT

The storm surge from Hurricane Ike in 2008 inundated much of Galveston Island, Texas, causing lasting below-ground impacts in the form of elevated soil sodium (Na^+) concentrations. The Na^+ initially killed much of the vegetation on the Island and its persistence in soils and groundwater slowed revegetation with some species. Soil amelioration techniques aimed at reducing soil Na^+ concentrations were evaluated on an area affected by the storm surge. The treatments were: constructed raised beds composed of uncontaminated soil, incorporation of organic mulch, gypsum application, and combinations of these treatments. Inputs of Na^+ from sea-spray aerosols were also quantified using a precipitation/dry-fall automated collector at the study site. In addition, three species of plants, live oak (*Quercus virginiana*), hybrid bald cypress (*Taxodium distichum*), and yellow hibiscus (*Hibiscus hamabo*) were planted on the treatment plots. A randomized factorial design using the eight treatment combinations with the three plant species was replicated six times. Plant survival and growth was monitored over two years. Only exchangeable soil Na^+ and soluble Ca^{2+} concentrations showed statistically significant differences among treatments. Na^+ translocated into the constructed raised beds during the study. Na^+ input from sea spray aerosols was quite variable over a one year period, but the annual contribution to soil Na^+ was relatively small. Plant survival, height, and diameter growth were not significantly impacted by the applied soil amendment treatments for either measurement period during the first year of plant establishment. However, constructed raised beds may have had a statistically significant, but weak, effect on plant volume growth between the first and second measurements. The same effect was not observed on plant volume growth between the second and final measurements.

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INTRODUCTION

Hurricanes have the potential to damage buildings, destroy trees, and flood cities, but the severity of impact depends on the magnitude of the storm. Hurricanes range from Category 1 storms, which are the least damaging, to Category 5 storms which are the most impactful. Although hurricanes may be destructive during landfall, hurricanes may also create lasting effects long after the storm has ended. In addition to flooding from abundant rainfall during hurricane events, coastal environments are often inundated by an accompanying storm surge. Storm surges are generally associated with flooding of roads, houses, and cars with seawater in coastal regions, but storm surges also impact soils, groundwater, and vegetation. Once the waters recede, salts are left behind in the soils and groundwater. Depending on concentrations of the storm deposited salts, the soils, groundwater, and vegetation can be severely affected and may be slow to recover.

In 2008 Galveston Island, Texas suffered considerable above-ground damage from Hurricane Ike, a Category 2 storm, with 170 km $hour^{-1}$ winds and a storm surge of approximately 4.5 m (Texas Forest Service, 2009). The storm surge also caused long lasting below-ground impacts in the form of elevated soil and groundwater sodium (Na^+) concentrations. Na^+ deposited by the storm will likely eventually leach out of the plant rooting zone, but Na^+ enriched shallow groundwater can be a source of continued contamination for a longer time frame. Groundwater may accumulate Na^+ and if the water table is shallow (approximately 1.5 to 1.8 m) it can be a source of salts for surface soils, including plant rooting zones (United States Salinity Laboratory Staff, 1954). There are several different types of ions associated with seawater, but the focus of this study was Na^+, which is the most problematic for plants. High soil Na^+ concentrations can be detrimental to soil biology and plant growth. A combination of damage by wind and debris with elevated soil Na^+ greatly affected the historic live oak trees of Galveston Island, many of which were over 100 years old.

While Na^+ can leach out of soil profiles over time, there are soil management techniques for expediting Na^+ remediation. Principal methods of elevated soil Na^+ amelioration include increasing Na^+ leaching via irrigation, incorporating organic matter into the soil, employing elevated, or raised, planting beds, and adding chemical amendments that promote Na^+ leaching. Implementation of these remediation practices may also hasten revegetation of storm surge affected areas. Reestablishment of vegetation may aid in reduction of soil Na^+ by increasing soil porosity. In addition, identifying plant species which are better suited for survival in seawater contaminated soils may improve survival of vegetation if future hurricanes impact the area.

The effectiveness of soil remediation techniques in arid, Na^+ affected agricultural regions has been extensively studied, but information describing the effectiveness of soil remediation techniques on storm surge affected soils is currently lacking. After hurricanes, vegetation mortality is often attributed to damage caused by the storm, but not specifically to Na^+ contamination from the accompanying storm surge. Further study is required to fully understand how storm surge contaminated soils and groundwater may be remediated after a hurricane occurs. Vegetation trials also need to be performed to determine the efficacy of specific plants for survival in Na^+ impacted conditions. The study of salt tolerant vegetation is necessary to find suitable species to revegetate coastal areas after storm surge damage.

Research performed on potential amelioration methods for elevated soil Na^+ is also essential to restoring historic vegetation communities and may perhaps help to save existing vegetation after storm surge occurrences. Timely application of remediation practices may aid in more rapid displacement of harmful soil salts. The storm surge contaminated soils on Galveston Island offered an opportunity to study both the effectiveness of soil remediation techniques as well as screening plant materials for salt tolerance.

In this study, several different soil Na^+ amelioration practices were studied: 1) growing plants on constructed raised beds versus on natural surface, 2) a chemical amendment (gypsum) application, 3) organic matter incorporation, and

4) combination of chemical amendment application and organic matter incorporation. Elevated beds were constructed with soil originating from an off-island source that was not contaminated by saltwater. Fine composted pine bark was incorporated into the soil as the mulch treatment. The chemical amendment was ground gypsum ($CaSO_4 \cdot 2H_2O$). The study evaluated the effectiveness of the soil management treatments using the survival and growth of three plant species, live oak (*Quercus virginiana*), hybrid bald cypress (*Taxodium distichum var distichum X Taxodium distichum var mexicanum*), and yellow hibiscus (*Hibiscus hamabo*) and by measuring changes in soil chemical properties. A randomized factorial design using the eight treatment combinations with the three plant species was replicated six times on an area that was salt affected from the hurricane storm surge near Galveston Bay.

Hurricane storm surges create an acute, high concentration exposure of Na^+ to soils and the groundwater. A more chronic, low concentration exposure that requires further study is deposition of aerial salinity in coastal areas. Aerial salinity (or sea spray) steadily transports salts inland through aerial suspension of oceanic water droplets. Quantification of sea spray deposition is important in understanding the dynamics of Na^+ in coastal soils. Without accounting for this additional Na^+ source the total input of Na^+ into a system might be underestimated. In order to better understand sodium loading in the ecosystem, current inputs of Na^+ salts from sea-spray aerosols and during precipitation events were quantified using a precipitation/dry-fall automated collector at the study site.

The Moody Gardens Foundation provided a study site location and funding for this project. The overall purpose of this research was to test soil amelioration techniques, aimed at lowering soil sodium concentrations in storm surge affected soils, and to test the effectiveness of these techniques in allowing vegetation reestablishment.

Objectives

The specific objectives of this proposed were to:

- Quantify the salinity of soils found at the storm surge impacted coastal site.
- Evaluate soil Na^+ amelioration practices for efficacy in displacement and reduction of soil Na^+.
- Conduct a plant trial of live oak (*Quercus virginiana*), hybrid bald cypress (*Taxodium distichum var distichum X Taxodium distichum var mexicanum*), and yellow hibiscus (*Hibiscus hamabo*).
- Measure survival and growth response of the three plant species to applied soil amelioration treatments.
- Quantify the aerial input of Na^+ (sea spray) to the site through deposition during both wet and dry weather events.

LITERATURE REVIEW

1. Impacts of Hurricane Ike

Galveston Island, Texas is susceptible to hurricanes with hurricane season lasting from early June to late November. Galveston Island has a history of large impact hurricane occurrences, such as the Galveston Hurricane of 1900 and Hurricane Alicia in 1983, but the most recent was Hurricane Ike in 2008 (NOAA, 2016). Hurricane Ike was classified by Hope (2013) as a strong category two storm when it reached Galveston Island. According to models simulating the storm, Hurricane Ike was rated 5.4 out of 6 on the Surge Destructive Potential Scale. The combination of a forerunner surge, wind patterns, and the additional storm surge which accompanied the landfall of Hurricane Ike, caused severe flooding of the island. Most of Galveston and surrounding areas remained inundated after landfall of the storm due to the pushing of already elevated water levels from Galveston Bay inland.

Hurricane Ike caused severe damage on Galveston Island. The long-term effect from the storm of particular interest to this study is the elevated soil sodium (Na^+) concentrations caused by sea water flooding from the storm surge. Elevated soil Na^+ concentrations, along with above-ground damage from the storm, greatly affected the historic live oak population of Galveston Island. A tree survey that was conducted by the Texas Forest Service (2009), performed on only 15 km (of the 328 total km) of streets in Galveston Island, resulted in an estimate of approximately 11,000 trees that died or were close to death after the storm. Mortality of the live oaks led to the eventual removal of a substantial number of trees. Since the removal of the impacted trees, residents of Galveston have worked towards restoring the population of live oaks on the island. However, persistence of sea water contamination of some soils on the island has made reestablishment difficult (Personal communication, Dr. David Creech, 2015).

2. Site Characteristics / Background Information

The study site was located on Galveston Island, Texas, on the Moody Gardens property adjacent to Scholes International Airport. The approximate location of the site is 29.275462 latitude, -94.858925 longitude. On images obtained from Google Earth the site appears to have had some added fill and is graded. The annual average temperature of the project site ranges from 18 to 25^0 C and the average annual precipitation is approximately 130 cm (NOAA, 2017a).

The native soils of the site are Mustang fine sand (Typic Psammaquents) and Madre fine sand (Sodic Psammaquents) (Soil Survey Staff, 2017). Mustang fine sands are characterized as having a zero to one percent slope, a fine sand texture, occurrences of frequent flooding and ponding, and a classified salinity of nonsaline to very slightly saline. The drainage class is poorly drained, the maximum SAR is 13, the depth to the water table ranges from 0 to 15cm, and the Saturated Hydraulic Conductivity (Ksat) is 8.73 μm sec^{-1}. The Madre soils are similar to the Mustang soils in both slope and frequency of ponding, but are only occasionally flooded. The classified salinity is very slightly saline to moderately saline and the texture is fine sand. The drainage class is poorly drained, the maximum SAR is 40, the depth to the water table ranges from 0 to 15cm, and the Saturated Hydraulic Conductivity (Ksat) is 17.980 μm sec^{-1}. In addition to the native soils, the site was leveled with fill materials (Dr. Kenneth Farrish, personal communication, March, 2017).

3. Sodium

Na^+ is generally transported by water into soil systems. The major cations of seawater contaminated soils include Na^+, magnesium (Mg^{2+}), calcium (Ca^{2+}), and less frequently potassium (K^+). The major anions associated with these cations are chloride (Cl^-), sulfate (SO_4^{2-}), carbonate (CO_3^{2-}), nitrate (NO_3^-), and bicarbonate (HCO_3^-) (Qadir et al., 2000).

Salt contamination of soils can originate from both natural occurrences and anthropogenic processes. Once contamination occurs, biotic (vegetation, wildlife, microorganisms, etc.) and abiotic factors (soil, water, etc.) may be impacted for extended periods of time.

i. Sources of Salt Contamination

Some natural sources of salt contamination include salt water intrusion, sea spray, hurricanes, and flooding. A few of the anthropogenic origins of salt contamination are irrigation with Na^+ rich water, winter salting of roads, and spilled brine water produced from petroleum production.

Oceans cover approximately 70% of the Earth's surface and are a major source of natural salt contamination in coastal areas. Oceans contain substantial concentrations of salts, which typically enter oceans in ionic form from rivers, streams and other runoff. The salt ions originate from rocks which release ions due to chemical weathering by rainwater with slightly acidic properties. Rainwater becomes acidic due to carbon dioxide present in the atmosphere. Once the ions enter oceans, marine organisms utilize much of the other mineral ions, but Na^+ and Cl^- remain and accumulate over time, with Na^+ and Cl^- accounting for about 90% of the dissolved ions in the ocean. Although seawater Na^+ concentrations are somewhat variable, the salinity concentration is generally about 35 ppt (NOAA, 2017b).

Na^+ can also affect groundwater through saltwater intrusion. Withdrawing large volumes of fresh groundwater can often lead to saltwater intrusion. The three types of intrusion listed by Barlow (2010) are lateral intrusion from the ocean through sediments, downward intrusion from waters from the coasts, and upward intrusion from deeper groundwater sources of higher salt concentrations.

Salt water intrusion may also increase the Na^+ content of associated soils and aquifer systems as well.

Sea spray, or aerial salinity, is another source of Na^+ deposition. Winds blowing inland from the ocean continually mobilize airborne sea water droplets which are deposited on coastal areas. Over time, the Na^+ present in sea spray can accumulate on surfaces and leach into soils during precipitation events. Aerial salinity will be further described in the subsequent aerial salinity section of this document.

When hurricanes occur, sea levels near coastal areas often rise, resulting in storm surges that may flood coastal areas with seawater. When the resulting flooding recedes or evaporates, Na^+ is left behind in soils and groundwater. This phenomenon can also occur with other weather events such as tropical storms and tsunamis. In addition to elevating soil Na^+ concentrations, seawater flooding can also damage soil structure and induce short-term anaerobic conditions, which may cause reduction of iron and manganese (Kozlowski, 1997). These anaerobic conditions are caused when soil pores fill with water, displacing air.

Vegetation is adversely affected both directly and indirectly by elevated salt concentrations caused by hurricanes. Immediate damage can be caused when hurricanes affect vegetation directly with wind damage of aboveground plant components, salt on foliage, and also impact roots by altering soil osmotic potentials. In addition, deflocculation of soils by Na^+ can destroy soil structure and reduce macro porosity. Vegetation typically found in coastal settings often have adaptations to endure chronic Na^+ exposure, but acute substantial seawater flooding events may cause mortality of even these adapted species.

Anthropogenic salt contamination originates from a variety of sources, including irrigation of crops with Na^+ rich water, use of salts for road deicing, and generation of brine water from petroleum production. Salt contamination is a notable problem in arid regions. Weathering of minerals in native geologic features, rich in soluble salts, can increase saline concentrations of water sources. Bauder and Brock (2001) found that weathered sediments of sandstone, limestone, siltstones, and gypsiferous shales increased the salinity of the Powder River in Montana. Irrigation water sourced from wells in aquifers with high salt concentrations may lead to an accumulation of Na^+ on the soil surface due to evapotranspiration, adversely impacting soils and vegetation. Evaporation is particularly problematic in an arid agricultural setting where soils are left bare. Without cover, when crops are irrigated, water evaporates from the surface and the salts which were in solution are left behind on the surface. Over-irrigating crops may also raise the water table, which can also bring salts closer to the surface.

Road deicing is a major source of salt contamination in regions which receive significant snowfall and can impact soils, vegetation, biota, and aquatic systems. Runoff from roads which undergo winter salting can enter water bodies and cause a multitude of problems for freshwater organisms. Road salting can even deter biota such as amphibians from crossing roads to avoid injury (Forman, 1998). Corsi et al. (2010) determined that the greatest amounts of salt entering water bodies in Milwaukee, Wisconsin occurred during winter months when road salting took place. Cl^- concentrations were found to exceed the EPA criteria for the acute water-quality concentration of 860 mg L^{-1} for 55% of the measured sites. All of the sites exceeded the EPA criteria for the chronic water-quality concentration of 230 mg L^{-1} of Cl^-, potentially affecting aquatic systems.

Brine is the waste water product of petroleum production. Water is injected deep into the earth's subsurface to aid in the collection of petroleum products and when it resurfaces, the Na^+ content is increased substantially. Atalay (1999) states that the constituents of brine waters include Mg^{2+}, Ca^{2+}, Na^+, K^+, CO_3^{2-}, Cl^-, HCO_3^-, and SO_2^{4-}. The produced water also contains other constituents such as oil, organic acids, radionuclides and heavy metals (Woolard and Irvine, 1995). The Clean Water Act requires that all contaminated water be treated before reintroduction into surface water, but this is not often economically feasible. The alternative to treatment is injection of brine water into deep substrates below freshwater aquifers. Produced brine water must be handled and disposed of carefully to avoid spills and surface contamination.

ii. Impacts

Salt contamination affects waterbodies, soils, vegetation, and other organisms. This study mainly focused on Na^+ impacted soils and the reestablishment of select vegetation. High soil Na^+ concentrations can be detrimental to soil biology and plant growth. The impact Na^+ has on soil, vegetation, and other biota depends on a great number of variables. Some of these variables include the concentration and source of Na^+, the salt tolerance of the biota, the amount of precipitation, the geologic properties of the area (e.g. areas with calciferous materials will not be as greatly impacted by Na^+), and the physical and chemical properties of the soils involved.

One of the hazards to vegetation associated with Na^+ are shifts in soil osmotic potentials which decreases plant water uptake, increases foliar damage through “salt burn”, and decreases nutrient uptake. There are also several additional ways that salinity affects vegetation. Kozlowski (1997) states that salinity can cause injury by modifying the anatomy and morphology of plants, by preventing germination of seeds, and by decreasing the growth and reproductive capabilities of plants. Plants which are not adapted to survival in salt rich environments (nonhalophytes) are often damaged or succumb in salt contaminated areas.

Na^+ can also affect plant growth, chlorophyll content, protein content, and internal osmotic potential. Qados (2011) found that high concentrations of Na^+ stunted plant growth and decreased the number of leaves and leaf area, the osmotic potential of plants, and chlorophyll a concentrations. High Na^+ concentrations caused a decrease in chlorophyll b, total chlorophyll concentrations, but caused an increase in protein content which was attributed to salt stress. Leaf loss, common with salt affected plants, is particularly detrimental to plants since leaves are essential to photosynthesis. Decreased osmotic potential has been considered to be a defense mechanism by Qados for plants to tolerate salt stress and increase absorption of water. Ravindran et al. (2007) state that depending on the concentration of Na^+, if the plant does not perform osmotic adjustment it can face ion toxicity and nutrient imbalances.

Distortion of osmotic potentials is one of the major factors affecting plant growth in salt contaminated soils. Na^+ affects organisms by diminishing mobility of water molecules in soils and decreasing the ease of access to water. Elevated soil Na^+ makes it difficult for plants to draw in water due to the higher ion content of Na^+ in soil relative to plant roots. Water follows the concentration gradient of Na^+, where water is transmitted from zones of lower Na^+ concentrations toward zones of higher concentrations.

The impact elevated salinity has on plants is greatly dependent on the salt tolerance of the species involved. Tolerance ranges vary with environmental factors including soil properties and fertility, climate, irrigation practices, and the dispersal of Na^+ within the soil profile (Kozlowski, 1997). Variation in tolerance can also occur in a single species depending on the age of a plant, genetics, and adaptations the plant may have made to local influences such as close proximity to a Na^+ source.

While foliar accumulated Na^+ can be rinsed off by precipitation or irrigation water, soils with accumulated Na^+ are more difficult to remedy. Salts can be detrimental to soil health, structure, porosity, pH, etc. Brady and Weil (2004) point out that in 2004 it was estimated that approximately 320 million hectares of land were impacted by salts. Salt impacted soils can be classified into three different categories: saline soils, saline-sodic soils, and sodic soils. The category a soil falls into is dependent on which salts are present, in what concentrations, and soil pH.

Saline soils are soils which have accumulated soluble salts in quantities which could be harmful to normal soil function. Saline soils have greater concentrations of Mg^{2+} and Ca^{2+} than Na^+. In order for a soil to be considered saline, the electrical conductivity (EC) must be greater than 4 dS m^{-1}, the sodium adsorption ratio (SAR) must not exceed 13, and the pH must not be greater than 8.5 (Brady and Weil, 2004).

Saline-sodic soils have high concentrations of Na^+, Mg^{2+}, and Ca^{2+}. The concentrations of Ca^{2+} and Mg^{2+} can help maintain soil structure, but structure is impacted if the concentration of Na^+ is higher. The EC of saline-sodic soils are greater than 4 dS m^{-1} and the SAR must be greater than 13, but pH is less than 8.5.

Sodic soils are soils which have accumulated an excess of exchangeable Na^+ ions which can be damaging to the soil. Sodic soils have poor soil structure because Na^+ disperses soil colloids and prevents cohesion, resulting in deflocculation. Sodic soils have an EC of less than 4 dS m^{-1}, a SAR of more than 13, and a pH greater than 8.5 due to the presence of sodium carbonate ($NaCO_3$).

Na^+ contamination has the potential to adversely affect the structure of soils and interfere with the interaction between soils and vegetation. Changes in soil structure can be detrimental to vegetation growth and to soil properties such as porosity and permeability.

Na^+ inhibits flocculation of soil particles and causes aggregates to break down due to Na^+ causing repulsion between clay particles (Lakhdar et al., 2009). Inhibition of flocculation can interfere with soil porosity and permeability and impact the rooting zones of vegetation. Strong bonding properties of Na^+ also increase the difficulty of removing Na^+ ions from the soil. Depending on the severity of the Na^+ impact, in order to regain use of these soils, remediation practices are often required.

Salt cations such as Ca^{2+}, K^+, Mg^{2+}, and Na^+ also increase the pH of soils by displacing hydrogen ions from soil cation exchange sites. Areas with naturally high soil salt concentrations, such as arid regions, can become alkaline over time (Brady and Weil, 2004).

4. Soil Management Practices

Although coastal Na^+ amelioration has not been as extensively studied as that of arid regions, the principles of Na^+ amelioration can be applied in this situation. Na^+ contamination can be addressed through several amelioration practices including leaching, incorporation of organic matter, application of chemical amendments to displace Na^+ from soil cation exchange sites, and construction of raised beds. The aim of many Na^+ amelioration practices is to improve soil chemical and physical properties, often by translocating Na^+ below the rooting zone of plants.

i. Leaching

Leaching involves the forced movement or flushing of soil Na^+ with percolating water out of the soil zone of concern, such as the rooting zone of plants. Through leaching, Na^+ is mobilized and translocated deeper in the soil profile. Ideally, Na^+ is leached to a great enough depth to be outside of the rooting zone. Once the rooting zone has had the concentration of Na^+ reduced, vegetation can be established to further aid in reducing Na^+ concentrations in soils. The process of how vegetation reduces soil Na^+ concentrations will be more thoroughly discussed in the vegetation portion of this section.

ii. Organic Matter

The addition of organic mulch on the soil surface decreases evaporation of soil moisture and enhances water infiltration and percolation, and organic content of surface soil. An application of organic mulch on the surface of soils that are high in Na^+ can decrease evaporation, and therefore, decrease Na^+ accumulation at the soil surface. Surface applied mulch could also potentially intercept some aerial salts from sources such as sea spray.

Incorporation of organic matter into the mineral soil can also aid in amelioration of Na^+ impacted soils. Atalay and Lynch (1999) describe organic matter as being influential in improving the biological, physical, and chemical properties of soils. The addition of organic matter can improve water retention, hydraulic conductivity, porosity, soil tilth, bulk density, and aggregation of the soil. Incorporation of organic matter increases the average size of soil pores and allows for improved aeration, permeability, and infiltration rates. The increased soil pore sizes (macropores) may promote aeration in soils, which can help address the loss of soil structure from deflocculation. Increasing the permeability of soils is beneficial in that it promotes leaching of salts deeper into the soil profile. Incorporation of organic matter is also beneficial because it can increase soil microbial populations and their activity.

iii. Chemical Amendments

Commonly utilized chemical additives to address high Na^+ concentrations include gypsum ($CaSO_4 \cdot 2H_2O$) and calcium chloride ($CaCl_2$). A less common additive is magnesium sulfate ($MgSO_4 \cdot 7H_2O$). These additives work by displacing Na^+ ions through cation exchange with either Ca^{2+} or Mg^{2+} ions

(Bauder and Brock, 2001). For example, one Ca^{2+} ion replaces two soil Na^+ ions on cation exchange sites. After Na^+ ions have been displaced, they are more easily leached by percolating rainwater. Dirr and Biederman (1980) state that gypsum reduces Na^+, and possibly Cl^-, uptake and allows plants to better endure saline conditions. Agriculture Handbook No. 60 (USDA, 1954) is useful in determining gypsum application rates. Handbook 60 considers soil properties to determine adequate gypsum application rates. The decision of which amendment and rate to use should be site specific and be based on soil properties, such as soil porosity and native soil chemistry, on the concentration of contaminants, on the desired timeframe of the remediation, and on economic feasibility. Gypsum is one of the most popular chemical amelioration methods due to an abundant supply and low cost. Gypsum is slowly soluble and is therefore a slow acting treatment. Other treatments such as $CaCl_2$ are more rapid acting, but are more costly (Dr. Kenneth Farrish, personal communication, March, 2015).

iv. Bedding

The general theory behind the implementation of a bedded system is that raised beds may help to provide an area for plant roots to become established above soil with elevated Na^+ concentrations. Early in development, plants are particularly susceptible to damage caused by salt stress, so it is beneficial to provide an environment with minimal contamination during establishment.

Shallow groundwater can cause soils to become waterlogged and if the groundwater has high Na^+ concentrations, which can rise by capillary action through soils, the soils may become unproductive (Bakker et al., 2010). In order to address concerns, raised beds can be constructed. Raised beds improve vegetation survival by lifting the vegetation to where the rooting zone is elevated further above the groundwater level. Raised beds allow vegetation to grow in a more favorable soil environment during establishment, while also promoting leaching of Na^+. Using uncontaminated offsite soil materials to construct raised beds also aids in the establishment of vegetation. Bakker, Hamilton, and Spann (2010) found that the efficacy of raised beds varied by site depending on the underlying geology, weather patterns, and soil properties. Site characteristics should be considered to determine if raised beds will be effective.

5. Vegetation

As previously discussed, many plant species are susceptible to injury and even mortality if exposed to elevated Na^+ concentrations, but there are a few species that are adapted to withstand elevated Na^+ concentrations. Some species with greater tolerance for Na^+ may simply survive in elevated Na^+, but there are other species, called halophytes, which are adapted to inhabit high Na^+ soils specifically. Certain halophytes can also be utilized to ameliorate Na^+ impacted soils through phytoremediation (Ravindran et al., 2007).

i. Plants Used In This Study

Three plant species were evaluated in this study: live oak (*Quercus virginiana*), hybrid bald cypress / Montezuma cypress (*Taxodium distichum var distichum* X *Taxodium distichum var mexicanum*), and yellow hibiscus (*Hibiscus hamabo*).

Live oak was evaluated to determine its salt tolerance and response to soil remediation techniques because of wide interest in the reestablishment of the species on Galveston Island. Live oak is generally documented as being Na^+ tolerant, through resistance to elevated soil Na^+ concentrations and also to sea spray (NRCS, 2002). However, there is disagreement among scientists about the degree of live oak Na^+ tolerance. Miyamoto (2008) suggested that classification of live oak as being Na^+ tolerant has been based on controlled bench studies and believes that live oak should be classified as only moderately tolerant. Miyamoto (2008) states that in field conditions there is spatial variation of Na^+ concentration and that live oaks preferentially obtain water from areas of low Na^+ concentration within the rooting zone. When water sources within the soil areas of low Na^+ concentration are exhausted, live oaks simply survive until more favorable conditions develop, such as rain, to dilute the salts.

Live oak is a popular ornamental tree which can be found in the southeastern coastal plains of the United States in soils ranging from high to low moisture content. Well-drained sandy soils are ideal; however, live oaks may also become established in the more porous, finer textured, soils such as clays. Occasional flooding can also be withstood, but live oaks are not tolerant of prolonged saturation (NRCS, 2002). Certain live oak populations native to coastal areas are generally better adapted to withstand hurricane conditions. Survival after a storm generally depends on the severity of the storm and the properties of the native trees. A Floridian live oak population impacted by Hurricane Andrew in 1992 was reported to have recovered a few years after the storm (USDA, 2016).

Bald cypress was included in the study because a hybrid bald cypress / Montezuma cypress (*Taxodium distichum var distichum* X *Taxodium distichum var mexicanum*) has shown tolerance to salt affected soils and may potentially serve as an ornamental on Galveston Island. The degree of Na^+ tolerance of bald cypress is also disputed among scientists. Allen et al. (1996) reported bald cypress as being moderately salt-tolerant. Conner and Inabinette (2005) differ in opinion by referencing bald cypress as sensitive to Na^+, but they did recognize that bald cypress with greater Na^+ tolerances do occur in regions such as Louisiana. Na^+ tolerance of bald cypress varies among individual populations depending on environmental adaptations to Na^+ exposure.

The specific bald cypress that was used in this study was a hybrid bald (*Taxodium distichum var distichum* X *Taxodium distichum var mexicanum or Taxodium* X 'T406') which is a hybrid cross of bald cypress with Montezuma cypress, a species native to Mexico. With permission from Dr. Yin Yunlong of the Nanjing

Botanical Garden *Taxodium* X ‘T406’ is more commonly known by the varietal name ‘LaNana’. *Taxodium* X ‘T406’ possesses characteristics which made it an ideal candidate for use in this study including salt tolerance and resistance to needle blight (Personal communication, Dr. David Creech, 2017).

Zhou et al. (2010) found that a bald cypress x Montezuma cypress hybrid, similar to the one used in this study, and Montezuma cypress had greater salt tolerance than bald cypress. Montezuma cypress is generally more salt tolerant, but cannot withstand prolonged periods of water inundation. Bald cypress is better suited to surviving prolonged inundation, so the hybrid combination of bald cypress and Montezuma cypress yields a more salt tolerant tree which can still withstand prolonged inundation.

Denny and Arnold (2007) discuss the varying opinions about the nomenclature used to describe bald cypress, Montezuma cypress, and pond cypress. *Taxodium* was once believed to consist of three species including *Taxodium distichum* (bald cypress), *Taxodium mucronatum* (Montezuma cypress), and *Taxodium ascendens* (pond cypress). One of the more modern theories is that bald cypress and pond cypress should be classified as two subspecies of *Taxodium* due to the overlap in range of occurrence. A third theory is that *Taxodium* should be classified into one species, with three botanical varieties. In this theory bald cypress would be classified as *Taxodium distichum* var. *distichum* (L.) Richard , Montezuma cypress as *Taxodium* *distichum* var. *mexicanum* Gordon and pond cypress as *Taxodium distichum* var. *imbricarium* (Nutt.) Croom.

Tsumura et al. (1999) also stated that the range of bald cypress and pond cypress overlap, but that habitats differ between the taxa. In order to better understand the relationship between bald cypress and pond cypress, Tsumura performed a study set out to investigate the genetic diversity between bald cypress and pond cypress using DNA analysis. They found that the cleaved amplified polymorphic sequences (CAPS) did not indicate that pond cypress and baldcypress had enough genetic difference to be classified as two distinct species.

Yellow hibiscus (*Hibiscus Hamabo*) was also included in this study due to its recognized salt tolerance. Yellow hibiscus is a halophyte, which is native to salt marshes in the coastal areas of China, Japan, and Korea. The natural habitat of yellow hibiscus typically includes tidally influenced salt marshes such as those ranging from the Yangtze Province to the Jiangsu Province in rivers such as the Yangtze River (Creech, 2016).

A study performed on Soan Island, Korea found only two wild yellow hibiscus which were located in sunny locations on the edge of forested areas on well-drained soils (Ahn, Chung, and Park, 2003). Yellow hibiscus is not widely distributed due to its habitation requirements and has even been designated as a preserved plant by the Korean Ministry of Environment.

Despite its decline in natural ecosystems, yellow hibiscus has become a popular plant for use in salt impacted areas. Yellow hibiscus is often cultivated in these regions to aid in reclamation of land from the sea. Li et al. (2012) found that yellow hibiscus could withstand low to moderate salinity with a NaCl survival concentration range between 5 and 10mM or 1.1 to 1.5%. The salt tolerance of yellow hibiscus makes it an ideal candidate for this study. If yellow hibiscus is found to successfully grow in the environment of Galveston Island with elevated soil salt concentrations, it could serve as another ornamental plant option for the area in the future, and might serve to improve sites contaminated by seawater. Additional studies on the properties and possible future uses of yellow hibiscus are currently being performed at Stephen F. Austin State University by Dr. Dave Creech, Dr. Josephine Taylor and Dr. Steve Wagner.

ii. Amelioration Vegetation

Salt tolerant species have been tested and established in Na^+ contaminated sites. These species include, but are not limited to, various plants and microorganisms. When native species cannot survive increased salinity, managers may attempt to introduce new species from other areas that are genetically better suited to endure the harsher conditions. Salt tolerant vegetation may be used to remove Na^+ from soils through uptake and serve as a means of phytoremediation. Once Na^+ has been absorbed into vegetation, the aerial plant parts can be harvested and removed, reducing soil Na^+

concentrations. Qadir (2000) found that a combination of this crop harvest and leaching was the most sustainable and effective method of soil Na^+ amelioration.

Kozlowski (1997) discusses several adaptations that plants have developed to endure elevated Na^+ concentrations including tolerance, avoidance, or both. Tolerance is generally achieved by osmotic adjustment by sequestration of Na^+ and Cl^- into the vacuoles and generation of organic solutes which can balance out the internal salinity of the plant. Generation of such solutes typically reduce the growth rate of plants in that some of the plant's energy has to be re-allotted to solute synthesis. Avoidance typically involves active Na^+ extrusion, passive Na^+ exclusion, and dilution of salts upon entrance to the plant space. Ravindran et al. (2007) agreed with Kozlowski that in order for a vegetative species to be Na^+ tolerant, it must compartmentalize Na^+ ions into vacuoles, accumulate compatible solutes in the cytoplasm, and have genes for salt tolerance.

According to Bauder and Brock (2001), establishment of salt tolerant species can increase permeability of the soil through root growth, which may further improve the leaching process. Their study compared Na^+ tolerance of three different crops: barley, alfalfa, and sordan. Barley was found to remove the greatest amount of Na^+ from the soils. Ravindran et al. (2007) tested six different species of herbs and one species of tree and found that *Sesuvium portulacastrum* and *Suaeda maritima* had the greatest efficacy at removing Na^+ from the soil. This was accomplished by the plants compartmentalizing the Na^+

ions into vacuoles by increasing the vacuolar volume to accommodate the accumulation of cytosolic Na^+, K^+, and Ca^{2+} ions.

Planting salt tolerant species along with a chemical amendment application can further improve soils. Plants aid in the incorporation of chemical amendments when their roots penetrate the soils and increase porosity. One of the major concerns with introduction of new species is the possibility of an exotic species becoming invasive. If the species is nonnative to the environment, it may outcompete native species, and if not controlled, it can become problematic. An example is the presence of nonnative salt-tolerant coastal plants along roadways which have undergone road salting in the Netherlands (Forman, 1998). Nonnative species may cause additional problems in the future that are not yet understood. Introduced species should be carefully monitored and removed if they become invasive.

6. Soil Tests

Soil tests are conducted to characterize the properties and quality of soils. In this study, some of the specific parameters which were considered included the Sodium Adsorption Ratio (SAR), Electrical Conductivity (EC), and Soil Reaction (pH).

i. SAR

Sodium Adsorption Ratio (SAR) is a comparison index of the ratio of Na^+ to Ca^{2+} and Mg^{2+} in soils. SAR compares the ratio of Na^+ to Ca^{2+} and Mg^{2+}

because the latter two can offset problems caused by Na^+. Higher SAR values indicate greater concentrations of Na^+ relative to Ca^{2+} and Mg^{2+} concentrations. Therefore, lower SAR values indicate more favorable conditions for plants. Lower SAR values are preferable because Ca^{2+} and Mg^{2+} have the potential to mitigate Na^+ ions in soils and reduce the impact on vegetation and soil health (Brady and Weil, 2004). SAR is calculated using the following equation where the concentrations of Na^+, Ca^{2+}, and Mg^{2+} are expressed in mmol of charge liter^{-1}. However, the SAR index does not have units.

$$SAR = \frac{[Na^+]}{(0.5[Ca^{2+}] + 0.5[Mg^{2+}])^{1/2}}$$

SAR values range from 0-30 where 0-10 indicates a low sodium hazard, 10-18 is a medium sodium hazard, and 18-30 is a high sodium hazard (United States Salinity Laboratory Staff, 1954). SAR values for saline soils are typically less than 13 (meaning that there is a greater ratio of Ca^{2+} and Mg^{2+} satisfied cation exchange sites to Na^+ exchange sites) and saline-sodic and sodic soils have SAR values of greater than 13 (Brady and Weil, 2004).

ii. Electrical Conductivity

Electrical conductivity, or EC, serves as a means of indirectly measuring the amount of ionic substances present in a soil. EC is typically measured using a saturated paste extract prepared from a soil sample. The three types of salt affected soils have different EC values. Saline and saline-sodic soils typically have an EC value greater than 4 dS m^{-1} and sodic soils have an EC value of less than 4 dS m^{-1} (Brady and Weil, 2004).

iii. Soil Reaction (pH)

When hydrogen ions in soils are replaced by salt ions, such as Na^+, Ca^{2+}, Mg^{2+}, and K^+, it can cause an increase in pH. The pH of saline and saline sodic soils is less than 8.5, while the pH of sodic soils is greater than 8.5 due to the presence of $NaCO_3$ (Brady and Weil, 2004).

7. Aerial Salinity

Two types of aerial salinity were quantified in this study, including deposition during precipitation events and dry deposition during periods without precipitation events. Edwards and Claxton (1964) claimed that there are two mechanisms responsible for passage of salts from the sea into aerial suspension. They found that small droplets of salt in the air are formed when the film of bubbles on the ocean surface break while the larger droplets form when the crater of the broken bubble refills with water. These bubbles form in wave breaks which can be produced throughout the ocean, but often occur near coastlines.

Areas in close proximity to saline waterbodies are more likely to have elevated aerial Na^+ deposition. Generally, the further away from the ocean, the less likely an area is to be impacted because the heavy, aerially mobilized particles fall out of suspension. However, the amount of Na^+ carried in sea spray is dependent on weather patterns. More rapid wind speeds allow for the transport of aerial particles further inland and for increased mobilization of aerosolized oceanic salts (Edwards and Claxton, 1964).

The Na^+ and Cl^- concentrations within sea spray are also variable throughout the year depending on weather, amount of rainfall, and wind patterns. Precipitation deposits aerial salts that accumulate in the atmosphere, but precipitation can also aid plants in rinsing off a portion of the foliar accumulated Na^+. Hingston and Galbraith (1990) found that damage could be caused to grapevines in southwest Australia during dry weather events when salts were allowed to accumulate on plant leaves and were not rinsed off by rain. They also determined that sea spray Cl^- concentrations were seasonally variable with a maximum of 250 mg Cl L^{-1} and an average of 10 mg Cl L^{-1}.

Salt deposition is more evident on plant leaves because the damage can often be observed, however, salts are also being simultaneously deposited on soil surfaces as well. The principle of salt accumulation on vegetation, and other surfaces, could contribute to elevated soil Na^+ concentrations over time in soils.

8. Microorganisms

Although not the focus of this study, microorganism involvement in amelioration of Na^+ contaminated soils should be considered. Microorganisms play vital roles in soil health and plant success. One role for soil health includes nutrient cycling in soils through decomposition. If Na^+ contamination impacts the soil microorganism population, the entire soil ecosystem and plants will be impacted.

Similar to what was previously discussed with Na^+ tolerant vegetation, Na^+ tolerant microorganisms exist as well. Introduction of helpful microorganisms may serve as another remediation approach. Woolard and Irvine (1995) collected halophilic bacteria from a naturally hypersaline site in Great Salt Lake, Utah to utilize in a salt contaminated site. These bacteria were found to specifically require Na^+ for survival. Nonnative, Na^+ tolerant species can be introduced to improve the relationship of plants and soil to offset Na^+ contamination.

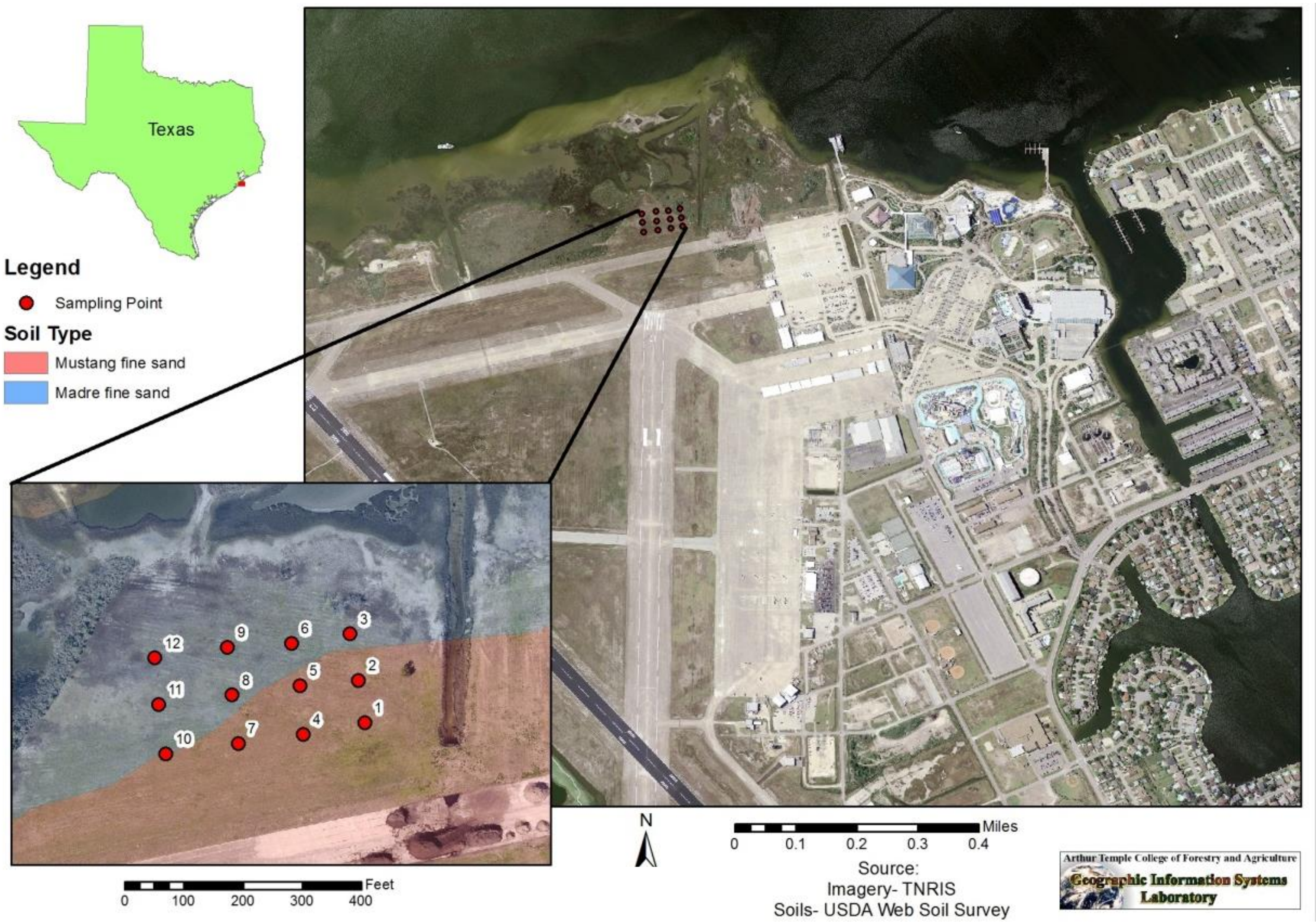
A companion study to this project was performed by Elaine Fowler (2017) to characterize and compare the microbial communities which occurred within the applied soil treatments. Her study found that there was not a significant statistical difference between microbial communities among the different treatment plots. Fowler’s study will be later described in the Additional Research section of this study.

METHODS OF STUDY

1. Preliminary Study

In order to better understand the extent of the Na^+ impact on the study site, a preliminary sampling of the area was performed. Samples were collected in a grid of three rows with an approximate spacing of 40 x 24 m. Row 1 (sample points 1, 4, 7, 10) was located proximal to a taxiway of Scholes International Airport and Row 3 (sample points 3, 6, 9, 12) was located in closer proximity to Offat's Bayou. Approximate placement of sampling locations and soil series at the site are illustrated in Figure 1.

A 7.62 cm diameter bucket auger was used to collect soil samples in 30 cm intervals to a depth of 150 cm below ground surface. Soil samples were taken to the Stephen F. Austin State University Soil, Plant & Water Analysis Laboratory for analyses. The laboratory analyses of the samples are described in the laboratory analyses section. Tabular results for the measured parameters of pH, EC, Na^+, Ca^{2+}, Mg^{2+}, and SAR are shown in Tables 1 and 2. Graphical representations of the analytical results for Na^+, Ca^{2+}, and Mg^{2+}, and SAR, are shown in Figures 2, 3, 4, and 5.



Source:
Imagery- TNRIS
Soils- USDA Web Soil Survey

Figure 1. Map of the study site location showing distribution of preliminary sampling points, and soil series mapped at the site located near Scholes International Airport adjacent to Offat's Bayou and Moody Gardens in Galveston, Texas.

Table 1. Mean exchangeable Na^+, Ca^{2+}, and Mg^{2+} concentrations for soil samples taken from 12 preliminary soil sampling points (from the 0-30 cm depth sample) located on the site near Scholes International Airport adjacent to Moody Gardens in Galveston, Texas.

Sample Point	**Na^+ (mg kg^{-1})**	**Ca^{2+} (mg kg^{-1})**	**Mg^{2+} (mg kg^{-1})**
1	107	9,167	190
2	95	1,111	148
3	280	13,023	287
4	211	8,630	183
5	262	7,428	166
6	827	6,226	386
7	249	2,899	295
8	182	6,190	141
9	174	3,503	328
10	80	2,195	314
11	92	3,598	245
12	812	3,140	413

Table 2. Measured values of pH, EC, water soluble Na^+, Ca^{2+}, and Mg^{2+}, and SAR for samples taken from the preliminary soil sampling points located on the site near Scholes International Airport adjacent to Moody Gardens in Galveston, Texas.

Sample Point	Depth (cm)	pH	Electrical Conductivity (dSm^{-1})	Na^+ ($mg\ kg^{-1}$)	Ca^{2+} ($mg\ kg^{-1}$)	Mg^{2+} ($mg\ kg^{-1}$)	SAR
1	0-30	8.09	0.0763	36	83	29	0.86
	30-60	8.19	0.0376	25	60	10	0.77
	60-90	8.43	0.0698	159	14	7	8.78
	90-120	8.50	0.0932	142	0	3	18.60
	120-150	8.35	1.075	240	9	8	14.31
2	0-30	8.49	0.0862	104	22	17	4.00
	30-60	8.50	0.0781	110	13	12	5.24
	60-90	8.31	1.671	229	13	12	11.09
	90-120	7.94	4.21	565	151	57	9.95
	120-150	7.80	4.5	593	171	59	9.97
3	0-30	8.24	1.277	205	34	25	6.54
	30-60	8.26	7.5	1,596	170	126	22.60
	60-90	7.50	11.53	1,959	341	230	20.10
	90-120	7.09	13.35	1,612	377	247	15.85
	120-150	7.30	12.23	1,623	360	248	16.11
4	0-30	8.56	0.0788	116	14	12	5.54
	30-60	8.36	0.0409	54	8	9	3.14
	60-90	8.28	1.359	164	12	8	8.92
	90-120	8.14	3.2	446	119	36	9.20
	120-150	8.13	3.62	458	152	43	8.45
5	0-30	8.59	1.15	251	10	11	12.82
	30-60	8.48	0.0513	118	11	9	6.45
	60-90	8.58	0.0909	187	1	6	15.65
	90-120	8.49	2.67	464	20	11	20.50
	120-150	8.59	3.28	427	41	17	14.18
6	0-30	8.26	6.14	1,097	82	64	22.11
	30-60	8.30	5.09	799	43	28	23.21
	60-90	7.81	7.84	1,342	131	82	22.66
	90-120	7.77	7.61	1,304	243	134	16.65
	120-150	7.85	7.09	881	210	104	12.43

Table 2. (continued).

7	0-30	8.85	1.449	287	43	20	9.02
	30-60	8.00	0.0261	115	15	7	6.20
	60-90	8.08	0.0267	32	7	6	2.14
	90-120	8.09	0.0802	121	13	8	6.55
	120-150	7.91	1.345	230	29	10	9.35
8	0-30	8.45	0.0871	150	13	10	7.61
	30-60	8.76	0.0746	134	2	6	11.19
	60-90	8.44	1.052	250	2	5	21.91
	90-120	8.11	1.738	310	17	7	16.07
	120-150	8.10	2.04	400	34	14	14.62
9	0-30	8.44	1.112	182	56	31	4.82
	30-60	8.14	0.0941	150	1	4	15.86
	60-90	7.84	2.31	429	34	18	14.86
	90-120	7.68	3.35	552	99	41	11.79
	120-150	7.38	2.86	597	166	62	10.03
10	0-30	8.49	0.0843	72	111	38	1.50
	30-60	7.79	0.035	120	39	6	4.78
	60-90	8.76	0.0532	126	13	6	7.43
	90-120	7.87	0.0997	172	45	15	5.70
	120-150	7.94	1.208	173	74	20	4.62
11	0-30	8.24	0.0723	51	85	30	1.22
	30-60	8.11	0.0364	64	12	5	3.82
	60-90	8.47	0.0836	242	5	6	17.50
	90-120	8.30	0.0972	320	13	7	17.69
	120-150	8.52	1.018	198	5	3	17.83
12	0-30	8.48	6.81	949	149	105	14.55
	30-60	8.07	3.84	692	84	32	16.33
	60-90	7.55	3.67	338	65	28	8.80
	90-120	7.94	3.44	279	85	47	6.05
	120-150	7.70	3.07	311	160	63	5.26

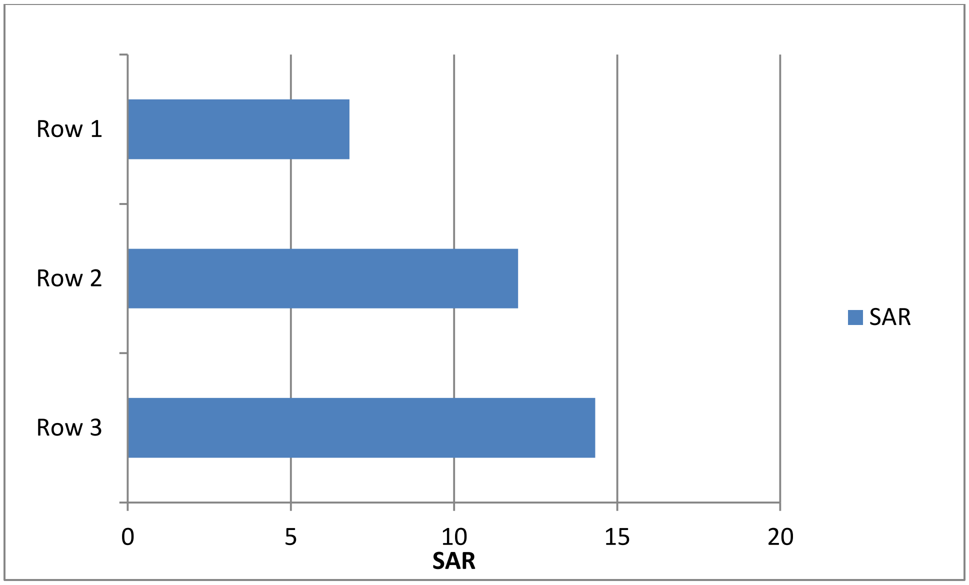


Figure 2. Mean SAR values by row of soil samples collected during the preliminary site sampling.

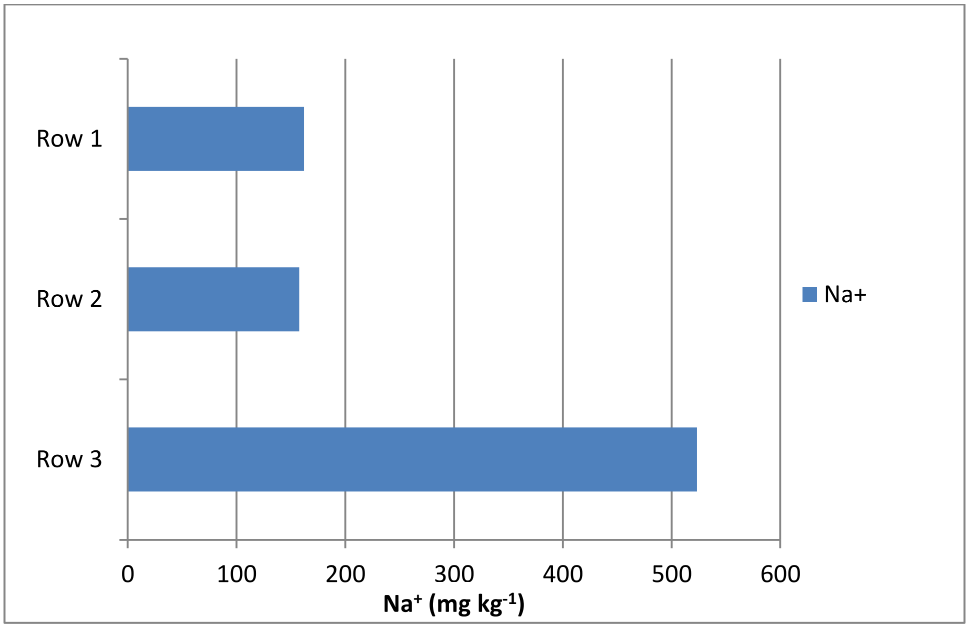


Figure 3. Mean Na^+ concentration by row of soil samples collected during the preliminary site sampling.

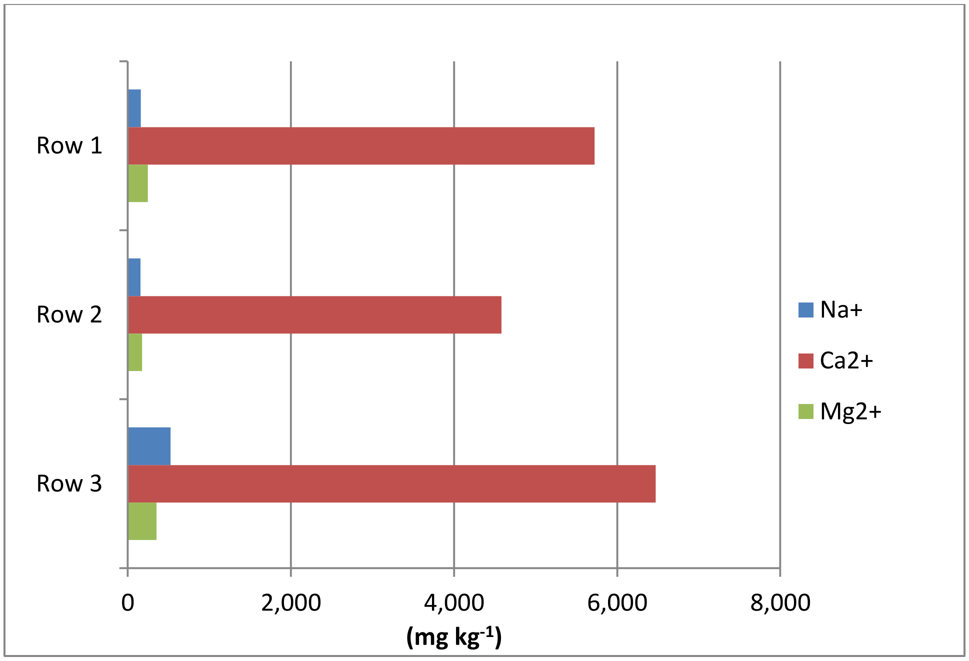


Figure 4. Mean Na^{+}, Ca^{2+}, and Mg^{2+} concentrations by row of soil samples collected during the preliminary site sampling.

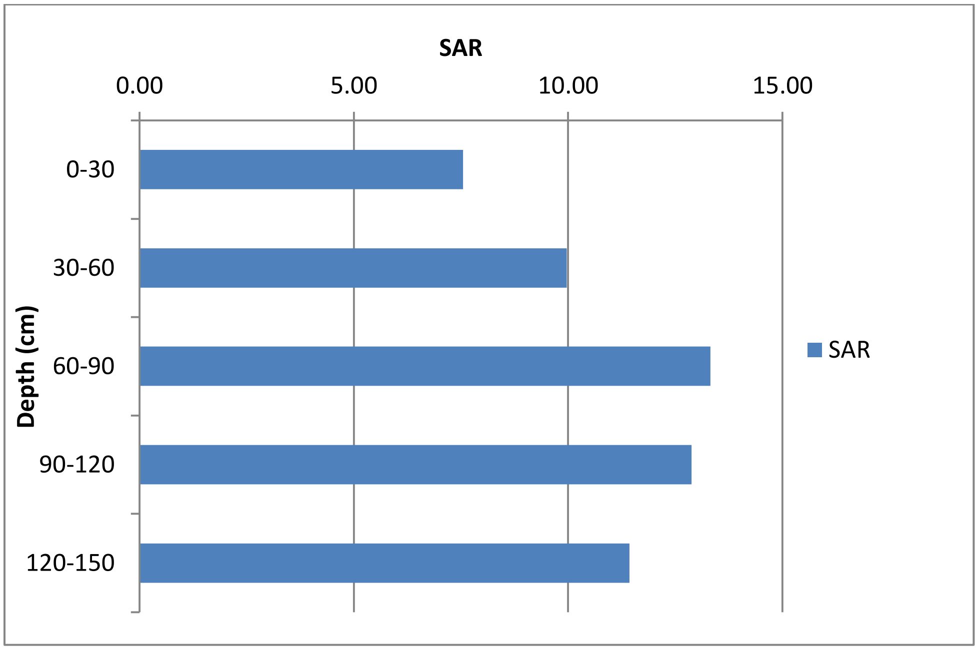


Figure 5. Mean SAR values of soil samples collected in 30 cm depth increments during the preliminary site sampling.

SAR values and water soluble Na^+ concentrations were the greatest in Row 3 (sample points 3, 6, 9, 12), which was in the closest proximity to Offat's Bayou (Figure 2 and 3). The SAR value indicates that Row 3 had the greatest ratio of Na^+ compared to Ca^{2+} and Mg^{2+} of the three rows. The same trend can be seen in the Inverse Distance Weighted (IDW) map (Figure 6) showing the gradient trends of SAR values as well as elevation of the surrounding area. Na^+, Ca^{2+}, and Mg^{2+} concentrations were the greatest in Row 3, but Ca^{2+} concentrations were found to exceed both Na^+ and Mg^{2+} (Figure 4). The gradient of SAR and Na+ concentrations was expected since Offat's Bayou is connected to Galveston Bay, and therefore the Gulf of Mexico, which is the Na^+ source.

Na^+, SAR, and pH values are variable throughout the site ranging from approximately 24.7 to 1959.1 mg kg^{-1}, 0.8 to 23.2, and 7.1 to 8.9, respectively. While a Na^+ value of 24.7 mg kg^{-1} Na^+, a SAR value of 0.8, and a pH value of 7.1 do not suggest sodium concern, the Na^+, SAR, and pH values of 1959.1, 23.2, and 8.9 could classify as sodic soils. Overall, the site could be classified as non-saline to slightly saline. The Na^+ concentrations found in the preliminary study were used to determine where to place the study plots on the site and to determine the gypsum application rate.

The highest SAR values occurred at a depth of 60 to 90 cm (figure 5). A possible explanation for this occurrence is that this is the region of the soil and groundwater interface. Preliminary sampling indicated that the water table of the site was variable with estimated depths ranging from 45 to 95 cm. The average water table depth to groundwater was approximately 70 cm below ground surface. The variability of the depth of the water table is problematic in that some areas of the site may be continuously contaminated with Na^+ as the water table rises. Because the area in which the site is located was inundated with brackish water from Galveston Bay during Hurricane Ike, salts were deposited onto the site. These deposited salts likely leached through the soil into the water table and may still impact the water table to this day.

Water tables close to the ocean may also be tidally influenced depending on the permeability and porosity of soils. Davis (1978) states that a water table has the capability of rising to the soil surface depending on several variables including; duration of the high tide, height of the tide, elevation of the site, and distance of the site from the tidal source. The tidal characteristics were not measured in this study, but the site has a low elevation and is located roughly only 150 m from Offat’s Bayou. The course, porous, texture of the soils onsite may also contribute to a tidal influence. A tidally influenced water table may be problematic for plant establishment because of repeated Na^+ exposure with each high tide. Plants which grow in these areas must be tolerant of elevated Na^+ concentrations.

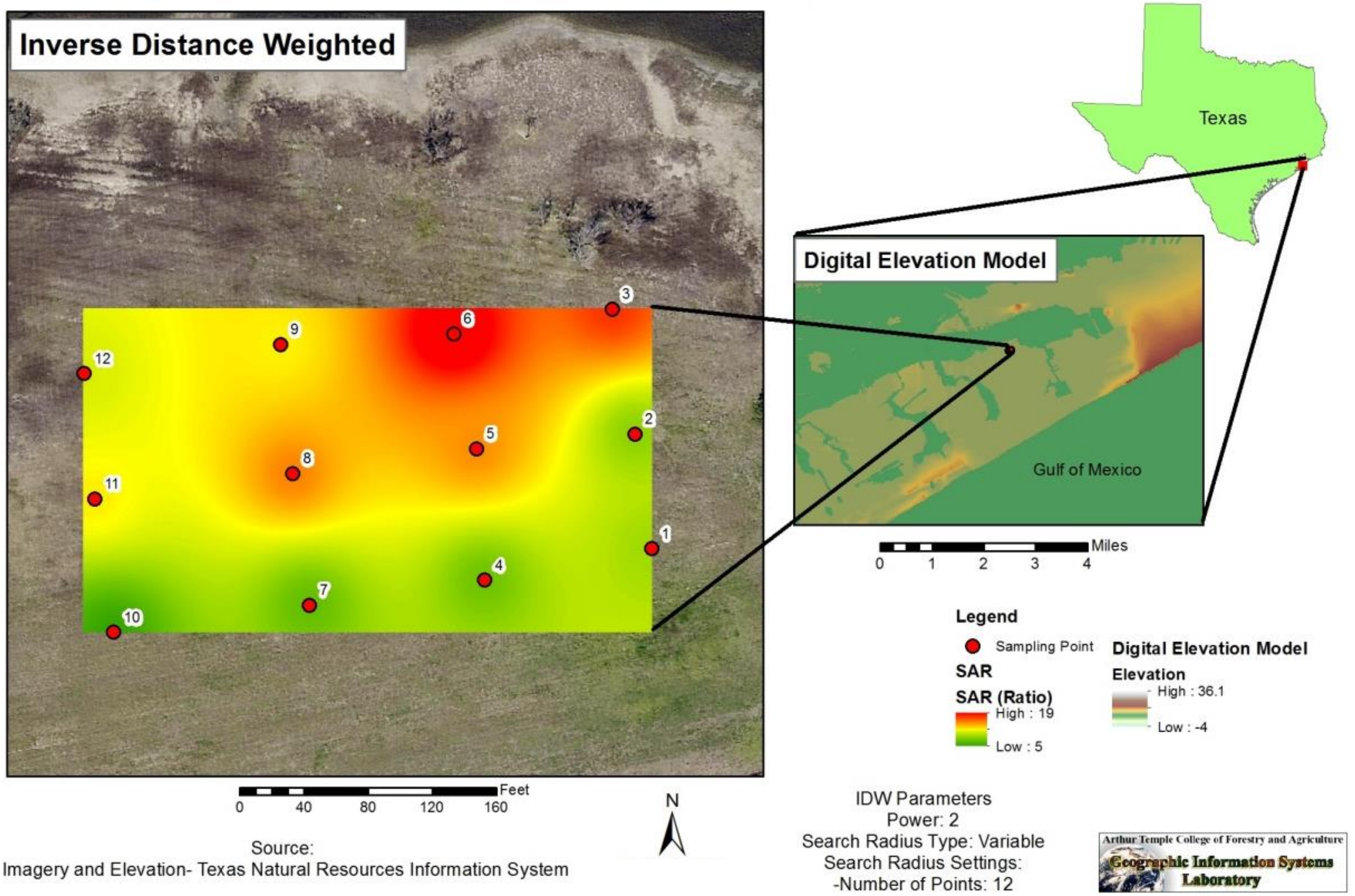


Figure 6. An Inverse Distance Weighted (IDW) map of the initial sampling showing the gradient of greater SAR values in proximity to Offat's Bayou and the elevation of the surrounding areas of Galveston, Texas.

1. Experimental Design

The project established two planting rows on the Moody Gardens property in close proximity (80 m) to Offat's Bayou of Galveston Bay. The specific placement of the planting rows was determined based on the gradient of elevated soil salinity concentrations, determined on preliminary testing of soil and groundwater samples. There were a total of 48 planting plots, 24 in each planting row, which had dimensions of approximately 4m long by 3m wide. There was also a 1.5m buffer between each of the plots within a row, and the two rows were placed approximately 1.25m apart (Figure 7). This spacing was utilized in order to allow space for walkways and also to minimize overlapping treatment effects between plots.

The experimental design contained seven soil management treatments and one control. Treatment plots consisted of constructed raised beds versus flat ground plots and received a treatment of incorporated pine bark mulch, ground gypsum ($CaSO_4 \cdot 2H_2O$), or a combination of mulch and gypsum. All treatment plots were then surface mulched. Plant seedlings were approximately one year old rooted cuttings planted in each of the plots after they were constructed. The three plant species that were evaluated in this study included live oak (*Quercus virginiana*), hybrid bald cypress (*Taxodium distichum var distichum* X *Taxodium distichum var mexicanum*), and yellow hibiscus (*Hibiscus hamabo*). The bald cypress, originally sourced from the Nanjing Botanical Garden in Nanjing, China, is a cross between bald cypress and Montezuma cypress (Zhou, 2012).

The specific treatments were control flat (CF), control bedded (CB), gypsum flat (GF), gypsum bedded (GB), mulch flat (MF), mulch bedded (MB), mulch and gypsum flat (MGF), and mulch and gypsum bedded (MGB). Each row contained six replications of each of the seven treatments and the control, yielding 48 plots in total (Figure 8). The placement of each treatment within the rows was determined by randomly drawn selection to avoid placement bias. A diagram illustrating the placement of each treatment within the plots is shown in Figure 7.

Raised beds were constructed of offsite sourced uncontaminated “bank sand” to an initial height of approximately 30 cm above the natural surface. Each of the plots receiving amendment treatments were tilled with a walk behind rototiller to incorporate the amendments. The control bedded and control flat plots were not tilled. The mulch treatment plots received an incorporation of approximately 8 cm of pine bark mulch to a depth of approximately 15 cm into the plot during the tillage process. The gypsum treatment plots received an application of ground gypsum, which was applied in a rate of approximately 907 kg per acre. This application rate equates to 5.1 kg of gypsum per planting plot and was calculated based off of a general application rate for slightly saline soils in the Agriculture Handbook No. 60 (USDA, 1954). In addition, approximately 8 cm of top mulch composed of woody on-site sourced materials was applied over the surface of all of the experimental plots.

Each plot contained two of each of the previously listed plants (live oak, a hybrid bald cypress, and yellow hibiscus) for a total of six plants which were randomly placed within each treatment plot. The plants were staked to avoid wind damage and laid out in an alternating pattern which provided a spacing of approximately 1m between each plant (Figure 7). Approximately 63 grams of 18-6-12 Osmocote™ fertilizer were spread around the base of each plant once planting was completed in March of 2016. A second application of approximately 32 grams of the fertilizer was applied two months later in May of 2016. The plants were irrigated for the duration of the first growing season with an above ground irrigation system using onsite reverse osmosis treated wastewater.

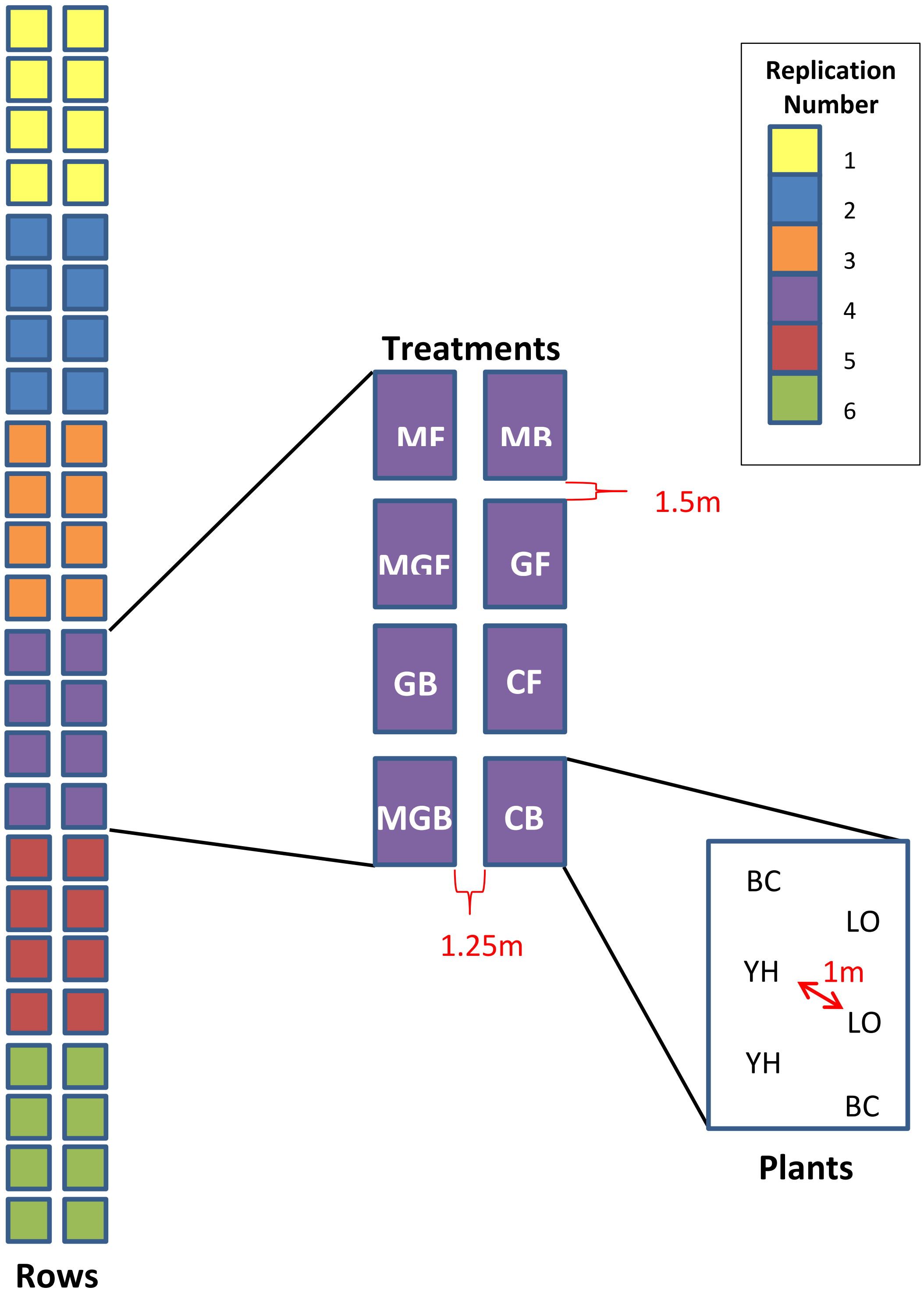


Figure 7. A diagram demonstrating the layout of the plants within a plot, treatments within a replication, and the replications within the two rows of plots at the study site located in the Moody Gardens property in Galveston, Texas. (BC - Hybrid bald cypress, YH - yellow hibiscus, LO - live oak)

Offat's Bayou

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Row 1	MF	GF	CB	GB	MGF	CF	MB	MF	MGB	GB	MGF	MF	MF	CB	MGB	CF	CB	CF	GF	MGB	GB	MGB	MGF	GF
	Replication 1				Replication 2				Replication 3				Replication 4				Replication 5				Replication 6			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Row 2	MGB	CF	MB	MGF	MGB	GB	CB	GF	CB	CF	GF	MB	GF	MGF	MB	GB	MF	GB	MGF	MB	MB	CF	MF	CB

CF = Control Flat
CB = Control Bedded
MF = Mulch Flat
MB = Mulch Bedded
GF = Gypsum Flat
GB = Gypsum Bedded
MGF = Mulch + Gypsum Flat
MGB = Mulch + Gypsum Bedded

Figure 8. A diagram of the placement of the eight implemented treatments, including combinations of mulch, gypsum, and bedded treatments, at the study site located in the Moody Gardens property in Galveston, Texas.

2. Soil Sampling Method

Soil samples were collected from the top 10cm of each plot using a soil sampler push probe. Several soil sample cores were collected randomly within each plot and composited into one sample which was of adequate size for analysis. Soil samples were taken to the Soil, Plant & Water Analysis Laboratory at Stephen F. Austin State University for analysis where they were air-dried and then analyzed. The measured soil parameters were pH, electrical conductivity, exchangeable sodium, calcium, magnesium, phosphorus, potassium, sulfur, boron, aluminum, arsenic, cadmium, copper, iron, mercury, manganese, lead, zinc, nickel, selenium, sodium adsorption ratio (SAR), total organic carbon, and total nitrogen.

3. Plant Measurement

Plant growth served as a means of monitoring plant response to the applied treatments. Ground line diameter and total height of each plant was measured three times, once immediately after planting in the spring of 2016, once during mid-summer (July) of 2016, and finally during the fall of 2016 (November) after plant growth ceased. The ground line stem diameter of each plant was measured utilizing a digital caliper at the base of the stem just above the root collar. Two ground line stem diameter measurements were taken, by rotating the caliper 90 degrees from the first measurement for the second measurement, and the two measurements were averaged. Total height was obtained by measuring from the top of the root collar to the tip of the dominant stem with a tape measure. Similar to diameter measurement, crown diameter was measured for the shrub used in the study, yellow hibiscus, by averaging two diameter measurements which were taken 90 degrees apart using a tape measure. Diameter, height growth, and crown diameter were calculated from the measurements.

4. Aerial Salt Collection

This study measured two paths of sea salt deposition including airborne (dry) sea salt deposition and precipitation (wet) deposition. A precipitation collector Model 301 (Aerochem Metrics Inc., Bushnell, FL) was placed in the field, near the planting site, to capture aerial salt input (Figure 9). The instrument collected both dry and wet deposition with a system of two pails. The dry pail remained uncovered during dry periods, while the wet pail was covered. The dry pail collected the airborne salts that are dispersed during dry weather conditions by sea spray. When a precipitation event occurred, a circuit on the instrument sensor was completed and the cover, which was formerly covering the wet pail, shifted to cover the dry pail. This allowed for the wet pail to collect the aerial salts contained in precipitation, while preventing aerial salts carried in precipitation from contaminating the dry sample. Pails were collected and replaced with another set of acid-washed pails every other week. The pails were then brought back to the laboratory for processing of the samples and further analysis. Sampling took place for a year from May of 2016 to May of 2017. Once sampling was completed, after approximately one year, the results of the analyses were used to characterize annual loading of salts from aerial deposition. Deposition was compared to average rainfall and wind gusts during the study duration for Galveston Island to help better understand periods of greater aerial salt deposition compared to weather patterns.

Figure 9. An image of the Precipitation Collector Model 301, in the dry fall sampling position, which was placed at the study site located in the Moody Gardens property in Galveston, Texas.

Dry Sample Processing

The dry sample pails received a rinse of ultra-pure deionized water down the sides of the pails to put deposited ions into solution for measurement. After rinsing, the volume of water in each pail was measured and then filtered through

Whatman 541 hardened, ashless filter paper. This process was repeated three times to ensure thorough rinsing of the pails.

Wet Sample Processing

The water samples were first agitated to collect precipitated ions from the sides of the pails. The total volume of the sample was measured for later calculation of concentration. A subsample was then filtered and collected for analysis. In cases where there was not a great enough volume of precipitation to form an adequate sample, the wet sample pail was processed in the same manner as is described in the dry sample process.

The resulting samples were taken to the Stephen F. Austin State University Soil, Plant & Water Analysis Laboratory for chemical analysis. The measured parameters included sodium, calcium, magnesium, chloride, electrical conductivity and pH. After the samples were analyzed, deposition concentrations were calculated to characterize the annual loading of salts from aerial deposition.

5. Statistical Analyses

A split plot ANOVA analysis was utilized to analyze the relationships between plant growth and the applied treatments with a significance level, or alpha, of 0.05. When the split plot ANOVA analysis indicated significant differences among the parameters, a Tukey test was also performed to determine mean separations. The data analyses for this paper were generated using SAS software. Copyright © 2019 SAS Institute Inc. SAS and all other SAS Institute

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6. Laboratory Analyses

Several different soil parameters were measured including pH, electrical conductivity, soluble and exchangeable sodium, calcium, and magnesium, sodium adsorption ratio (SAR), total organic carbon, and total nitrogen.

A Mehlich 3 extraction was utilized to quantify the concentrations of plant extractable nutrients. A Thermo Scientific iCAP 7400D Inductively Coupled Plasma Analyzer (ICP) was used to analyze the exchangeable salts (sodium, potassium, calcium, magnesium) from the Mehlich 3 soil test extraction. The Mehlich 3 soil test extraction procedure also was used for determination of phosphorus, sulfur, and boron concentrations (Mehlich, 1984).

Soil pH was determined utilizing a 1:2 soil to water ratio by volume saturated paste extract and a Thermo Electron Corporation Orion 3 Star Benchtop pH meter. Electrical conductivity (EC) and sodium adsorption ratio (SAR) were determined following the USDA Handbook 60 guidelines (United States Salinity Laboratory Staff, 1954). A SevenEasy Mettler Toledo conductivity meter was utilized to determine the EC. SAR calculations were applied using the soluble salts calcium, magnesium, and sodium concentrations measured using ICP.

Total N and total organic C were quantified with a carbon nitrogen combustion analyzer (Leco CN628) following SFASU Soil laboratory procedures.

The aerial salinity samples were characterized with a SFA soil laboratory standardized water test analysis which quantified a range of elements (this project focused on phosphorous, sodium, magnesium, calcium, and potassium) using the ICP. The standard water test analyses also included fluoride, chloride, nitrate, phosphate, and sulfate measured with an Ion Chromatograph (Dionex ICS-1000) using a Thermo Scientific 064141 separation column.

RESULTS AND DISCUSSION

Three parameters were measured in this study; select soil properties (soil chemical constituents), plant growth (plant height, stem diameter, crown diameter, and volume), and aerial salinity deposition. The analytical results of these measurements are presented and discussed in the following sections.

1. Soil

Soil samples were collected before treatment application (3/21/16) and approximately seven months later (10/27/16). Measured soil parameters included pH, NO_3^-, EC, CN Ratio, SAR, exchangeable and soluble Na^+, Ca^{2+}, and Mg^{2+}, P, K^+, S^{2-} , B^{3+} total organic C, and total N. Parameters of particular interest in this study included exchangeable and soluble Na^+, Ca^{2+}, and Mg^{2+}(Table 3) as well as pH, EC, and SAR (Table 4), but results of all measured parameters are provided in Appendix A.

Concentrations of soluble and exchangeable cations varied among the treatment plots. Soluble and exchangeable cations differed in how they are held in soils which in turn influences measurement. Soluble salts are those which are in the soil solution, while exchangeable cations are held on soil cation exchange sites and must first be displaced to be measured. Analytical results of the initial and final soil sampling events for soluble and exchangeable Na^+, Ca^{2+}, and Mg^{2+}, are presented in Table 3.

Table 3. The mean concentrations of soluble and exchangeable Na^+, Ca^{2+}, and Mg^{2+} (mg kg^{-1}) in soil samples by treatment collected before treatment application (3/21/16) and seven months after application (10/27/16) as well as the change in concentration between sampling events. Subscript letters indicate Tukey groupings among treatments within statistically significant soil parameters.

	Treatment	**Soluble**			**Exchangeable**		
		3/21/16	**10/27/16**	**Change**	**3/21/16**	**10/27/16**	**Change**
Na^+	CF	125.62_{A}	95.92	-29.71	202.89	207.32_{A}	4.42
	CB	26.71_{B}	60.57	33.87	134.59	139.53_{AB}	4.95
	MF	84.58_{AB}	70.24	-14.34	120.97	146.23_{B}	25.26
	MB	29.25_{B}	80.56	51.31	167.14	170.68_{AB}	3.54
	GF	94.93_{A}	74.87	-20.07	116.29	135.57_{B}	19.28
	GB	28.67_{B}	64.59	35.93	147.10	138.39_{B}	-8.71
	MGF	86.42_{AB}	75.14	-11.28	120.07	163.14_{AB}	43.07
	MGB	33.23_{B}	72.01	38.78	177.51	131.21_{B}	-46.31
Ca^{2+}	CF	65.55_{A}	76.97_{B}	11.41	2794.54	2389.76	-404.78
	CB	32.63_{B}	95.30_{AB}	62.67	2966.22	3099.76	133.54
	MF	91.16_{A}	88.93_{B}	-2.23	3219.69	2399.34	-820.36
	MB	33.04_{B}	92.37_{AB}	59.33	3442.76	2815.13	-627.63
	GF	69.65_{A}	97.13_{AB}	27.48	3626.91	2094.76	-1532.15
	GB	27.96_{B}	106.13_{AB}	78.17	3925.71	3551.84	-373.87
	MGF	67.65_{A}	96.20_{AB}	28.55	2944.39	2161.26	-783.12
	MGB	29.34_{B}	127.68_{A}	98.34	3841.46	3335.16	-506.30
Mg^{2+}	CF	28.32_{A}	30.15	1.84	424.69	497.77	73.08
	CB	11.35_{B}	25.60	14.25	327.09	382.76	55.67
	MF	35.56_{A}	27.96	-7.60	329.00	435.70	106.70
	MB	8.64_{B}	23.28	14.64	320.60	362.21	41.61
	GF	30.64_{A}	30.97	0.32	286.49	349.81	63.33
	GB	7.63_{B}	24.64	17.01	355.22	355.37	0.14
	MGF	29.52_{A}	28.12	-1.40	330.12	369.09	38.97
	MGB	7.62_{B}	29.06	21.44	378.44	308.32	-70.12

Quantifying Na^+, Ca^{2+}, and Mg^{2+} concentrations (before and during the study) aided in understanding salt movement in soils, but other soil properties were measured in order to better understand the soil treatment effects. Additional measured soil parameters included pH, EC, CN Ratio, and SAR. The measured mean pH, EC, total organic C, total N, CN ratio, and SAR are presented in Table 4.

Table 4. Mean values of pH, EC, total organic C, total N, CN ratio, and SAR for samples taken from different treatment plots located on the site near Scholes International Airport adjacent to Moody Gardens in Galveston, Texas.

	Treatment	**3/21/2016**	**10/27/2016**
pH	CF	8.62	8.40
	CB	8.33	8.25
	MF	8.51	8.47
	MB	8.30	8.37
	GF	8.42	8.20
	GB	8.29	8.36
	MGF	8.56	8.31
	MGB	8.40	8.29
EC (uS/cm)	CF	1923.67	1168.50
	CB	677.50	1031.50
	MF	1925.00	1060.00
	MB	735.83	1090.17
	GF	1859.17	1148.83
	GB	695.33	1103.67
	MGF	1713.33	1137.17
	MGB	735.17	1237.17
Total Organic C (uS/cm)	CF	18310.17	15837.00
	CB	6463.27	12616.17
	MF	16148.40	20027.17
	MB	8532.88	16259.50
	GF	13152.00	14817.00
	GB	6655.77	12831.83
	MGF	14816.20	21401.17
	MGB	6557.08	17845.00

Table 4. (continued).

Total N (uS/cm)	CF	2124.02	1909.63
	CB	988.63	1585.83
	MF	1873.17	1928.80
	MB	1171.82	1639.68
	GF	1607.30	1836.00
	GB	1032.12	1610.45
	MGF	1805.80	1985.25
	MGB	981.07	1705.07
CN Ratio	CF	8.55	8.27
	CB	6.55	7.92
	MF	8.28	10.43
	MB	7.10	9.86
	GF	8.18	8.07
	GB	6.45	7.96
	MGF	8.10	10.62
	MGB	6.70	10.46
SAR	CF	3.50	2.48
	CB	1.07	1.43
	MF	1.92	1.67
	MB	1.19	2.08
	GF	2.51	1.71
	GB	1.33	1.47
	MGF	2.28	1.87
	MGB	1.42	1.51

i. Statistical Analyses and Significant Soil Constituents

Statistical results of soil constituent concentrations across treatment types before (initial) and post treatment applications are presented in Table 5. Initially, there were not many statistically significant differences among treatments and blocks. No significant block differences were observed between treatment plots. The only statistical difference observed during the initial sampling was for soluble

Na^+, Ca^{2+}, and Mg^{2+}, which showed that there were differences in these constituent concentrations among treatment plots before treatment application.

Seven months later there were a greater number of significant differences in constituent concentrations. After treatment applications soluble Na^+ and Mg^{2+} concentrations no longer showed a significant statistical difference among treatments. Soluble Ca^{2+} concentrations, however, still showed statistically significant differences among treatment plots after treatment application. Exchangeable Na^+ also showed a significant treatment difference among treatment plots. Block differences were observed after treatment application for EC, soluble and exchangeable Na^+ and Mg^{2+}, K^+, P, B^{3+}, and S^{2-}. Statistically significant differences may have been observed between blocks post treatment due to varying concentrations of chemical constituents in the water table or could have been the result of inconsistent or excessive irrigation. Results of all of the statistical analyses performed on measured soil parameters are recorded in Appendix D.

Table 5. The results of an ANOVA statistical analysis to analyze the different soil constituent concentrations across treatment types before and after treatment applications with a significance level of 0.05.

		Initial		**Post Treatment**	
		Treatment	**Block**	**Treatment**	**Block**
SAR	--	0.1732	0.6065	0.1472	0.0309
EC	--	0.5494	0.8383	0.8263	0.0064
pH	--	0.3878	0.0650	0.2288	0.0362
Na$^+$	Soluble	<0.0001	0.1379	0.2366	0.0261
	Exchangeable	0.8824	0.8393	0.0121	0.0004
Ca^{2+}	Soluble	<0.0001	0.4896	0.0122	0.1872
	Exchangeable	0.6631	0.0366	0.5849	0.3980
Mg^{2+}	Soluble	<0.0001	0.1815	0.1468	0.0013
	Exchangeable	0.2191	0.1369	0.1253	0.0021
K$^+$	--	0.1856	0.4537	0.1569	0.0055
C	--	0.5229	0.7800	0.5598	0.1030
N	--	0.4223	0.9058	0.9293	0.2760
CN Ratio	--	0.8330	0.4911	0.3210	0.1495

Sodium (Na$^+$)

Preliminarily, there was a statistically significant difference among the treatment plot soluble Na$^+$ concentrations, but there was not a significant difference among the treatment blocks. This was likely due to the different soils used for the different treatment plots. Specifically, the constructed raised beds were constructed with offsite sourced uncontaminated soils while the flat ground plots were composed of native, salt contaminated soils. However, soluble Na$^+$ concentrations among post treatment collected soil samples were not statistically different, but as previously mentioned there was a significant difference among treatment blocks.

Greater changes in soil Na^+ concentrations were evident for soluble Na^+ than exchangeable Na^+ during the initial sampling. The constructed plots had consistently lower soluble Na^+ concentrations, initially, but concentrations increased by the final sampling (Figure 10). Soluble Na^+ concentrations may have increased in bedded treatments which were constructed with offsite sourced soils which were not initially contaminated, but may have had salts introduced from aerial salinity deposition, capillary rise of Na^+ contaminated groundwater, or both. Soluble Na^+ concentrations for flat ground plots were higher than that of the constructed raised bed plots, but decreased to concentrations more similar to constructed raised bed plots by the final sampling. However, the greatest concentrations of soluble Na^+ during the initial and final samplings were found in the flat ground control plots (CF) where no treatments were applied. A relatively light $CaSO_4$ treatment application (gypsum) slightly decreased the Na^+ concentrations of flat ground plots (GF and MGF). Application of a greater amount of gypsum could be considered to potentially help to further decrease the soil Na^+ concentration.

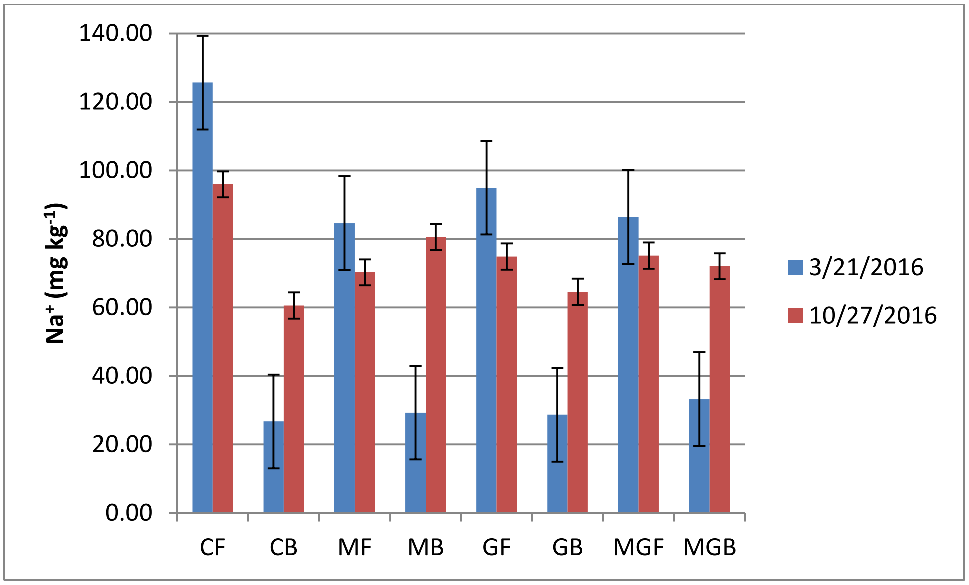

Figure 10. A comparison among the soluble Na^+ values of soil samples by treatment collected before treatment application (3/21/16) and seven months after application (10/27/16). n=6, standard deviation shown.

There was not a statistically significant difference for exchangeable Na^+ among treatments or blocks during the initial measurement. During the post treatment measurement, exchangeable Na^+ concentrations among soil treatment plots and blocks were statistically different. Exchangeable soil Na^+ concentrations had less variation between samplings compared to soluble Na^+ concentrations. In general, the observed trend was an increase in exchangeable Na^+ concentrations from the initial to final sampling for each treatment (Figure 11). Two treatments, the constructed raised bed plots with incorporated gypsum (GB) and with incorporated gypsum and mulch (MGB), were an exception to this trend with exchangeable Na^+ concentrations which trended lower, rather than increased. The trend of exchangeable Na^+ concentrations of GB and MGB plots may have been to decrease because gypsum was somewhat effective in aiding of displacement of exchangeable Na^+ in constructed raised bed plots. As with soluble Na^+, the greatest concentrations of exchangeable Na^+ were found in the flat ground control plots (CF).

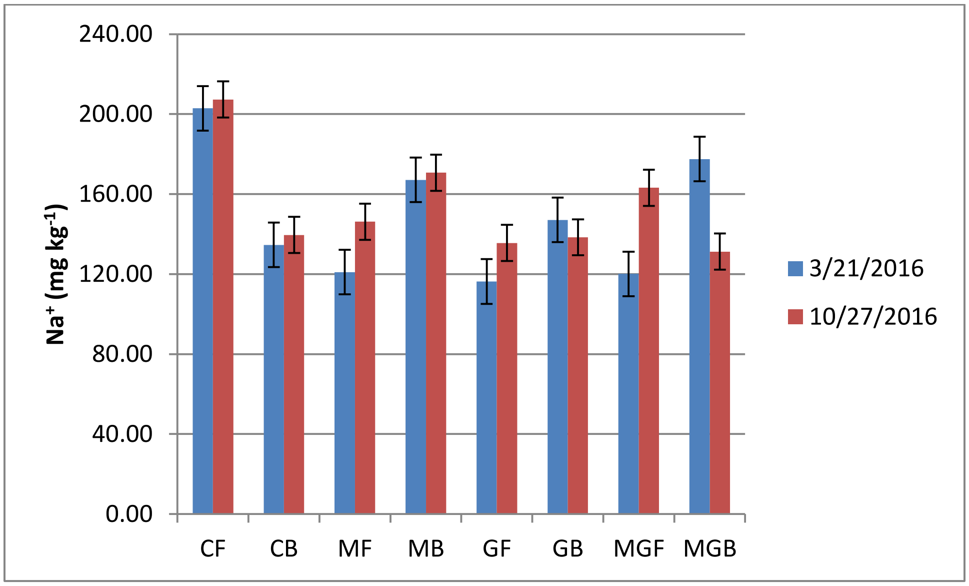

Figure 11. A comparison among the exchangeable Na^+ values of soil samples by treatment collected before treatment application (3/21/16) and seven months after application (10/27/16). n=6, standard deviation shown.

Calcium (Ca^{2+})

During the initial and post treatment measurements, a statistically significant difference in soluble Ca^{2+}concentrations was found among soil treatments. Statistically significant differences were not found among treatment blocks. Soluble Ca^{2+} concentrations were variable for the initial sampling, but flat ground plots had higher concentrations than constructed raised beds (Figure 12). Soluble Ca^{2+} concentrations increased for almost all treatments between the initial and final sampling events, with the exception of flat ground plots with incorporated mulch (MF) which slightly decreased. Ca^{2+} concentrations of all treatment plots could have potentially increased due to aerial deposition of salts from sea spray or from irrigation water. Constructed raised bed treatments generally had a greater increase in soluble Ca^{2+} concentrations compared to flat ground treatments. Notably, the constructed raised beds with incorporated mulch and gypsum (MGB) had an initial soluble Ca^{2+} concentration similar to those of the other raised beds, but had the greatest concentration for the final sampling. Plots with applied gypsum treatments generally had greater Ca^{2+} concentrations, which makes sense as gypsum is a source of Ca^{2+}. The applied $CaSO_4$ treatment (gypsum) was relatively light, but if more $CaSO_4 \cdot 2H_2O$ had been applied, Ca^{2+} concentrations would likely have been higher.

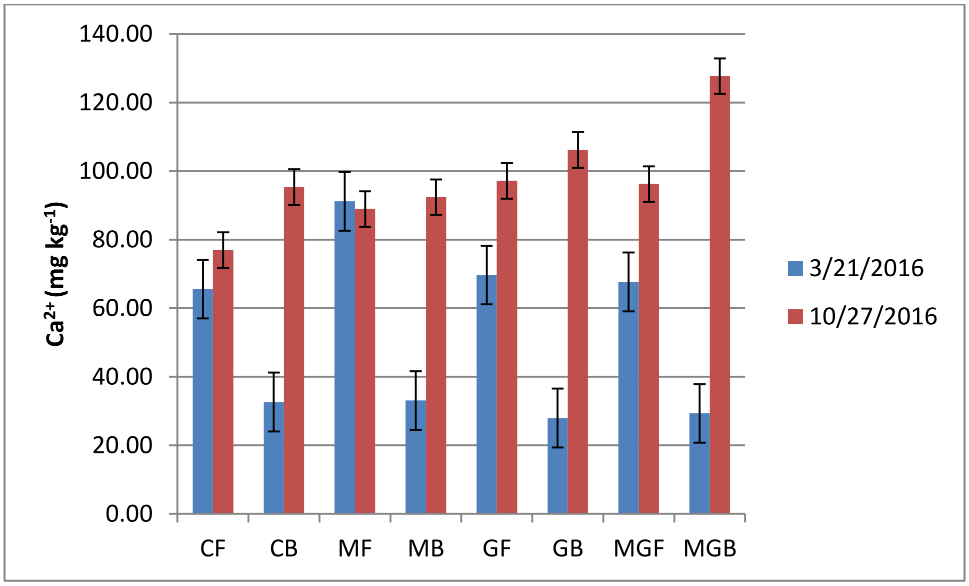

Figure 12. A comparison among the soluble Ca^{2+} values of soil samples by treatment collected before treatment application (3/21/16) and seven months after application (10/27/16). n=6, standard deviation shown.

Exchangeable Ca^{2+} concentrations were not statistically different among treatments or treatment blocks for the initial or post treatment sampling events. The general trend of exchangeable Ca^{2+} concentrations was a decrease between the initial and final measurement (Figure 13). Flat ground plots had lower exchangeable Ca^{2+} concentrations during the final measurement than the constructed raised beds. The greatest exchangeable Ca^{2+} concentrations were found in the constructed raised beds with incorporated gypsum (GB),

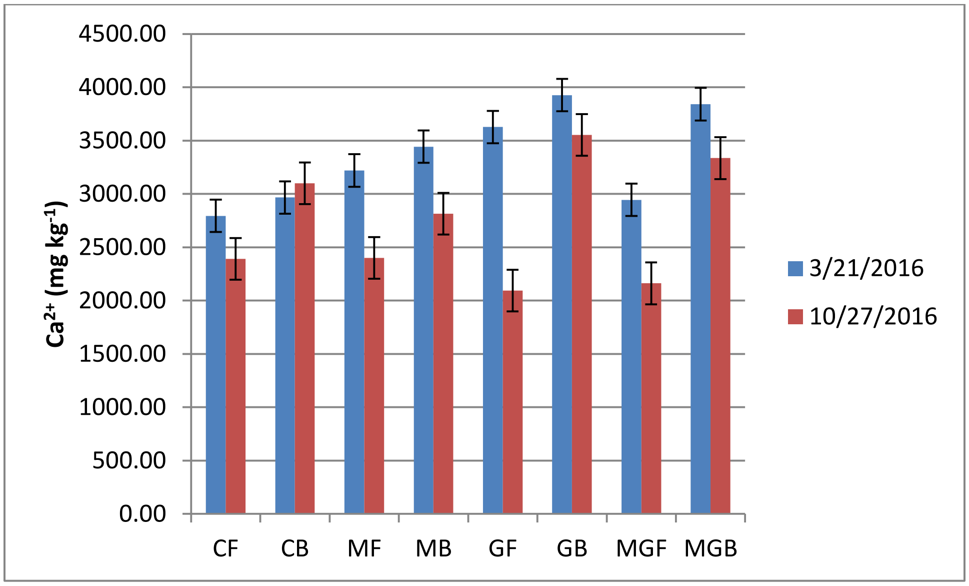

Figure 13. A comparison among the exchangeable Ca^{2+} values of soil samples by treatment collected before treatment application (3/21/16) and seven months after application (10/27/16). n=6, standard deviation shown.

ii. Other Notable Trends

Although the only soil constituents which showed significant differences among treatment plots after treatment application were exchangeable Na^+ and soluble Ca^{2+}, additional notable trends were observed. Notable trends were observed for Mg^{2+}, EC, and SAR.

Magnesium (Mg^{2+})

Soluble Mg^{2+} concentrations were found to be statistically different among soil treatments during the initial soil sampling. Initially, the constructed raised beds had lower soluble Mg^{2+} concentrations than the plots on flat ground (Figure 14). Although post treatment soluble Mg^{2+} concentrations did not show statistical difference among soil treatments after treatment application, a notable trend could be observed. The most notable trend was the increase in Mg^{2+} concentrations between the initial and final sampling of the constructed raised beds. The trend of soluble Mg^{2+} concentrations increasing might have been due to aerial deposition of salts from sea spray. Irrigation water may have also contributed to the Mg^{2+} concentrations.

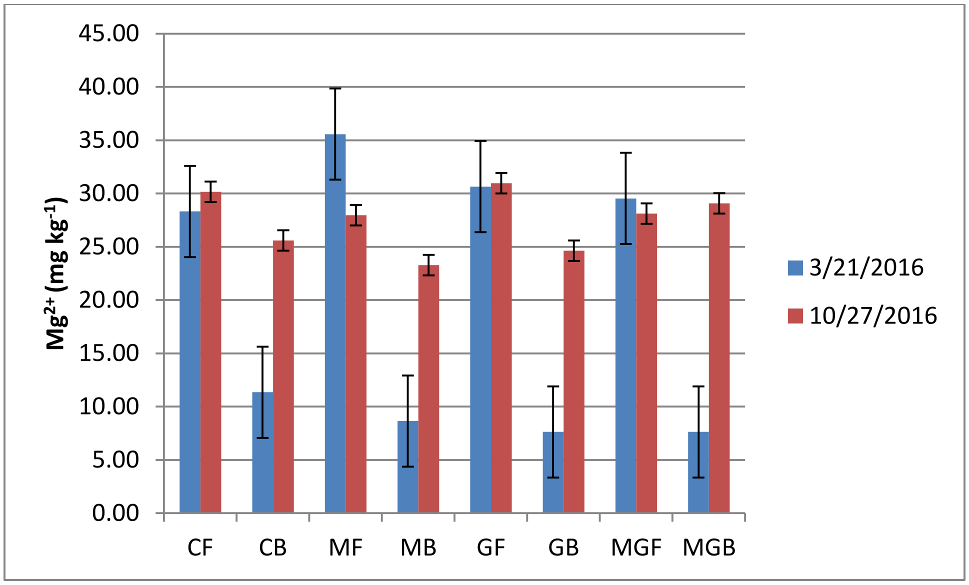

Figure 14. A comparison among the soluble Mg^{2+} values of soil samples by treatment collected before treatment application (3/21/16) and seven months after application (10/27/16). n=6, standard deviation shown.

Electrical Conductivity (EC)

A statistically significant difference was not found for EC values among the applied soil treatments during the initial and post treatment sampling events. Initially, the trend of EC values was to have values greater in samples collected from flat ground plots than the constructed beds. Constructed beds had a trend of lower EC values, initially, but the EC value trend for the second sampling stabilized to more similar values across all treatment types. The general trends were that the EC of flat ground plots decreased and the EC of constructed raised beds increased from the initial to final measurement just as the Na^+ concentrations had (Figure 15).

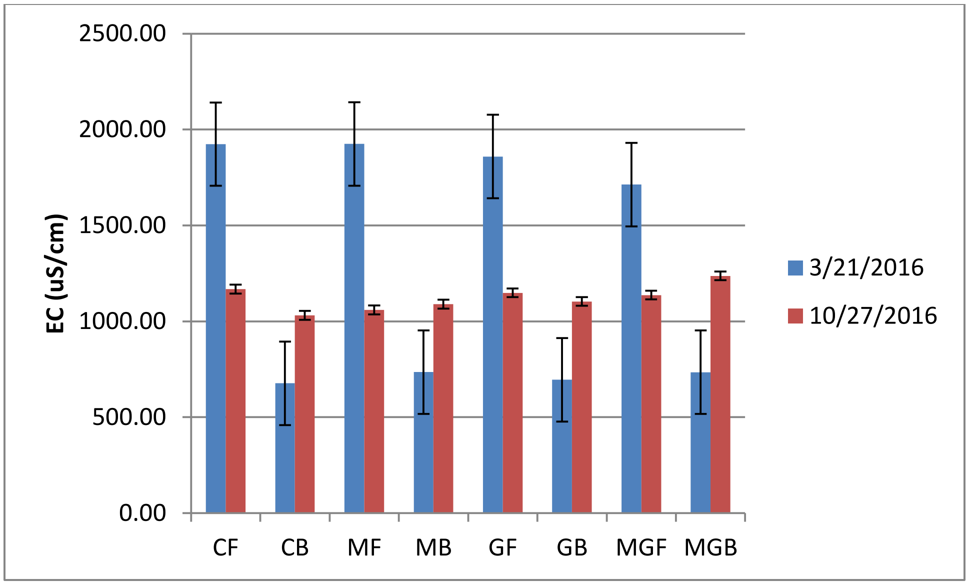

Figure 15. A comparison among the EC values of soil samples by treatment collected before treatment application (3/21/16) and seven months after application (10/27/16). n=6, standard deviation shown.

Sodium Adsorption Ratio (SAR)

Statistically significant differences in SAR values were not found among soil treatments following the initial or post treatment soil measurements. A notable trend was that SAR values decreased for flat ground plots and increased for constructed raised beds (Figure 16). The trend of SAR values of the flat ground plots decreasing could have been due to several factors including the applied treatments, irrigation, or plant uptake of salts, but the trends of the data collected in this study do not attribute the decrease to any one specific factor. The SAR values potentially had a trend of the constructed raised beds increasing due to exposure to salt sources on the site such as sea spray. Another possible reason for the SAR trend of increase in the raised beds could have been due to vegetation bringing Na^+ into foliage from deeper in the soil and subsequent deposition on the soil with leaf fall and decomposition.

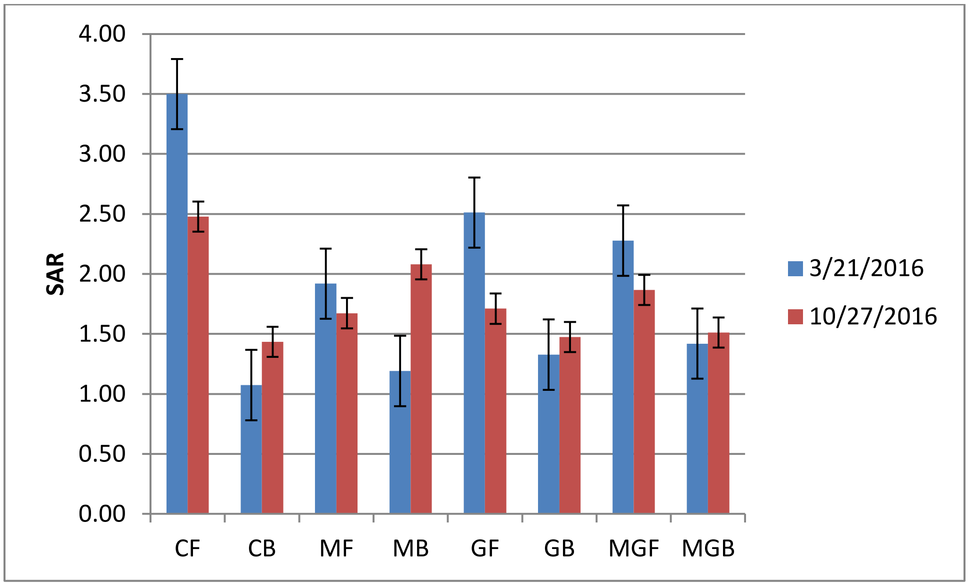

Figure 16. A comparison among the SAR values of soil samples by treatment collected before treatment application (3/21/16) and seven months after application (10/27/16). n=6, standard deviation shown.

Several factors may have impacted the study site soils. The applications of fertilizer in March and May of 2016 may have influenced the soil chemistry of the collected samples. Fertilizer provided for successful establishment of plants, but also increased ionic concentrations of chemical constituents including N, P, and K^+. Ions in the soils may have also served as nutrients for biological life such as the plants used in this study, for biota such as earthworms and insects, and for microbial populations. Biological life can influence nutrient concentrations such as that of C and N.

Unanticipated Enrichment and Influences

A notable trend of Na^+ enrichment during the study was observed in the constructed beds composed of off-site uncontaminated soil. This trend may have been due to capillary movement of Na^+ upward from contaminated soil and groundwater and/or aerial deposition, or both. Another factor which may have potentially influenced ionic soil concentrations were soil biota such as ants. There were a notable amount of fire ants which inhabited the constructed raised beds over time. Fire ants cycle soil from deeper depths to the soil surface and also from the soil surface to deeper depths. The noncompacted soils of the constructed raised beds were potentially favorable to fire ant inhabitation and colonization. Therefore, these beds may have become Na^+ enriched by contaminated soils which were carried by ants from greater depths and dispersed throughout the uncontaminated soils of the constructed raised beds.

2. Plant Survival and Growth

The height and stem diameter of the plants in this study were measured a total of three times during the first growing season to help determine the efficacy of the applied soil treatments on growth. The initial measurement immediately after planting took place on 3/15/16, the second measurement on 7/19/16, and the final measurement on 1/28/17. The mean heights, stem diameters, mean height growth, and mean stem diameter growth of live oak, hybrid bald cypress, and yellow hibiscus planted within each treatment are displayed for each measurement period in Tables 6 and 7. All of the recorded plant measurements can be found in Appendix B. The initial survival rate after planting was notable with mortality of only two out of the 288 planted plants after four weeks had passed. This high survival rate is probably attributable to the regular irrigation in the first growing season. However, the irrigation may have also masked potential treatment effects.

Statistical analyses of height and stem diameter growth for the initial and two subsequent measurement periods were conducted. Statistically significant differences were not found within each species for the initial measurements. Consequently, growth values shown in this section are based on the difference between the initial to second and the initial to final measurement.

Statistically significant differences were found among the plant species for both height and stem diameter growth between each of the measurement periods. Since different plant species with different growth rates were utilized in this study, statistical differences in growth were to be expected. Within each species, however, there were no statistically significant differences among the height and stem diameter growth by soil treatments. Results of the statistical analyses performed on plant height, diameter, and volume growth are recorded in Appendix E.

Table 6. The mean heights of live oak, hybrid bald cypress, and yellow hibiscus by soil treatments during the initial measurement (3/15/16), second measurement (7/19/16), and final measurement (1/28/17) along with the growth between the initial and second measurements and the initial and final measurements. (CF= Control Flat, CB= Control Bedded, MF= Mulch Flat, MB= Mulch Bedded, GF= Gypsum Flat, GB= Gypsum Bedded, MGF= Mulch, Gypsum, Flat, and MGB= Mulch, Gypsum, Bedded)

	Treatment	**Mean Height (cm)**			**Growth (cm)**	
		Initial (1)	**Second (2)**	**Final (3)**	**1 - 2**	**1 - 3**
Live Oak	CF	69.13	82.75	117.25	13.62	48.12
	CB	73.63	93.67	124.58	20.04	50.96
	MF	48.18	70.67	109.25	22.49	61.08
	MB	73.58	83.83	107.00	10.26	33.43
	GF	88.79	102.75	133.83	13.96	45.04
	GB	68.43	84.42	115.25	15.99	46.83
	MGF	78.34	101.92	133.33	23.58	54.99
	MGB	72.29	96.17	124.75	23.88	52.46
Hybrid Bald Cypress	CF	79.09	120.92	186.67	41.83	107.58
	CB	76.53	122.75	187.58	46.23	111.06
	MF	80.87	125.50	186.08	44.63	105.22
	MB	83.99	137.17	193.17	53.18	109.18
	GF	84.70	114.80	192.75	30.10	108.05
	GB	72.68	119.75	182.50	47.07	109.82
	MGF	74.34	118.83	176.75	44.50	102.41
	MGB	90.28	140.58	203.17	50.31	112.89
Yellow Hibiscus	CF	11.71	59.00	110.00	47.29	98.29
	CB	11.60	61.75	113.75	50.15	102.15
	MF	11.60	54.00	112.42	42.40	100.82
	MB	12.23	60.75	105.00	48.52	92.77
	GF	12.42	62.83	124.08	50.42	111.67
	GB	13.59	62.00	101.75	48.41	88.16
	MGF	11.33	64.18	117.18	52.85	105.85
	MGB	12.13	55.92	115.33	43.79	103.21

Table 7. The mean groundline stem diameters of live oak, hybrid bald cypress, and yellow hibiscus by soil treatment during the initial measurement (3/15/16), second measurement (7/19/16), and final measurement (1/28/17) along with the growth between the initial and second measurements and the initial and final measurements. (CF= Control Flat, CB= Control Bedded, MF= Mulch Flat, MB= Mulch Bedded, GF= Gypsum Flat, GB= Gypsum Bedded, MGF= Mulch, Gypsum, Flat, and MGB= Mulch, Gypsum, Bedded)

	Treatment	**Mean Diameter (mm)**			**Growth (mm)**	
		Initial (1)	**Second (2)**	**Final (3)**	**1 - 2**	**1 - 3**
Live Oak	CF	8.71	14.51	22.93	5.80	14.22
	CB	9.37	16.30	26.54	6.92	17.17
	MF	7.36	13.58	19.28	6.22	11.93
	MB	10.01	16.13	23.63	6.13	13.62
	GF	9.00	14.05	23.01	5.05	14.01
	GB	8.75	15.19	21.85	6.44	13.10
	MGF	8.31	14.95	22.97	6.63	14.65
	MGB	8.84	14.94	22.84	6.09	14.00
Hybrid Bald Cypress	CF	12.27	26.81	51.53	14.55	39.27
	CB	13.35	30.25	53.74	16.90	40.38
	MF	12.31	25.04	45.42	12.72	33.11
	MB	13.12	31.00	53.98	17.88	40.86
	GF	13.13	26.72	52.21	13.59	39.07
	GB	12.27	28.15	54.35	15.88	42.08
	MGF	12.18	23.51	46.49	11.33	34.31
	MGB	13.47	29.35	54.68	15.88	41.22
Yellow Hibiscus	CF	4.40	19.69	51.11	15.29	46.71
	CB	5.39	22.36	53.76	16.97	48.37
	MF	5.30	19.23	49.18	13.93	43.87
	MB	5.18	20.93	52.98	15.75	47.81
	GF	4.73	20.79	50.58	16.06	45.85
	GB	5.77	18.86	47.72	13.09	41.94
	MGF	5.13	19.65	55.00	14.52	49.87
	MGB	4.69	21.18	49.72	16.49	45.04

i. Height Growth

Hybrid bald cypress and yellow hibiscus had similar height growth between the initial and second measurement. The pattern of height growth among treatments was more uniform for yellow hibiscus than for hybrid bald cypress which had slightly more variation among treatments (Figure 17). The greatest height growth for this measurement period was with hybrid bald cypress in the (MB) raised bed with incorporated mulch treatment. The greatest height growth for yellow hibiscus was in (GF) flat plot with incorporated gypsum (Table 6). Live oak had the lowest height growth overall for each of the measurement periods. However, some unrequested pruning by Moody Garden Staff of the live oak and yellow hibiscus seedlings may have affected height growth measurements.

Hybrid bald cypress generally had the greatest height growth between the initial and final measurements, but the height growth of yellow hibiscus was only slightly less than that of hybrid bald cypress. During this measurement, height growth for hybrid bald cypress became more uniform across all treatments, while yellow hibiscus height growth still had more variation (Figure 18). The greatest height growth for this measurement period, and for hybrid bald cypress, was found in the treatment (MGB) composed of raised bed with incorporated mulch and gypsum. The flat treatment plot with incorporated gypsum (GF) yielded the greatest yellow hibiscus height growth (Table 6).

A statistically significant difference among plant species was found for height growth between the first and second measurement, however, a significant difference was not observed between the first and final measurement. These results may have been influenced by a lapse in communication, when the top portions of several plants (live oaks and yellow hibiscus) were removed by Moody Gardens staff just before the second measurement. Two height growth values were removed from the statistical analysis due to pruning which caused substantial negative growth values.

Since the tops of some of the plants were inadvertently pruned, stem diameter growth may serve as a more suitable indicator of plant growth. A significant difference was found between stem diameter growth for the first and second measurement periods, confirming that the plants had significant growth during the study, in spite of the undesired pruning.

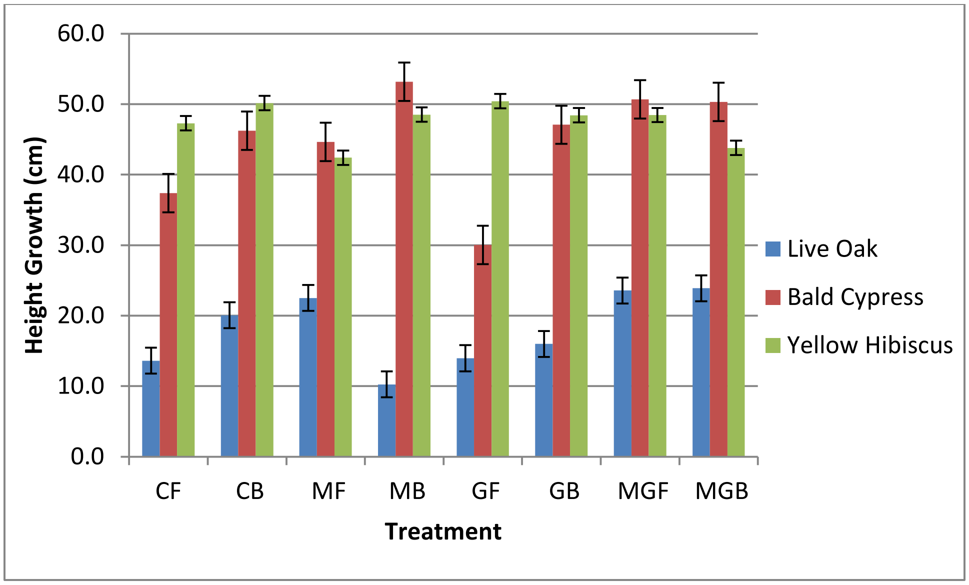

Figure 17. Mean total height growth by treatment between the initial and second measurement of live oak, hybrid bald cypress, and yellow hibiscus. n=6, standard deviation shown.

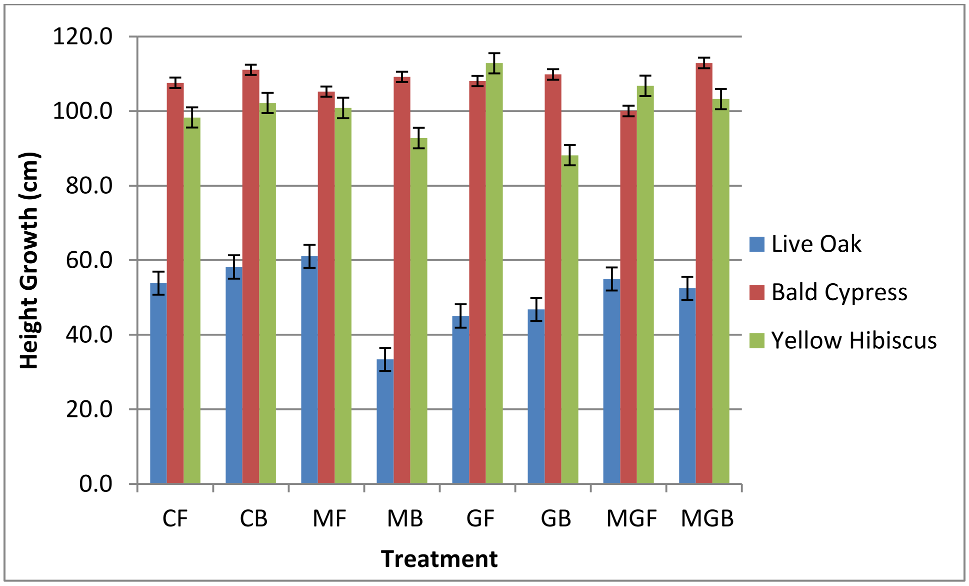

Figure 18. Mean total height growth by treatment between the initial and final measurement of live oak, hybrid bald cypress, and yellow hibiscus. n=6, standard deviation shown.

ii. **Stem Diameter Growth**

In general, yellow hibiscus showed greater stem diameter growth than hybrid bald cypress or live oak for both measurement periods. However, hybrid bald cypress had the greatest stem diameter growth recorded during the first measurement (Figure 19) with a treatment of a constructed raised bed and incorporated mulch (MB). Yellow hibiscus stem diameter growth was greatest with a raised bed treatment (CB). During the second measurement the greatest stem diameter growth (Figure 20), which was that of yellow hibiscus, occurred in a flat plot with incorporated mulch and gypsum (MGF). The raised bed with incorporated gypsum (GB) treatment yielded the greatest stem diameter growth for hybrid bald cypress. Measurements for yellow hibiscus and hybrid bald cypress were also more uniform across treatments during the second measurement period. Live oak had the least stem diameter growth for both measurement periods and maintained a somewhat standard stem diameter across all treatments.

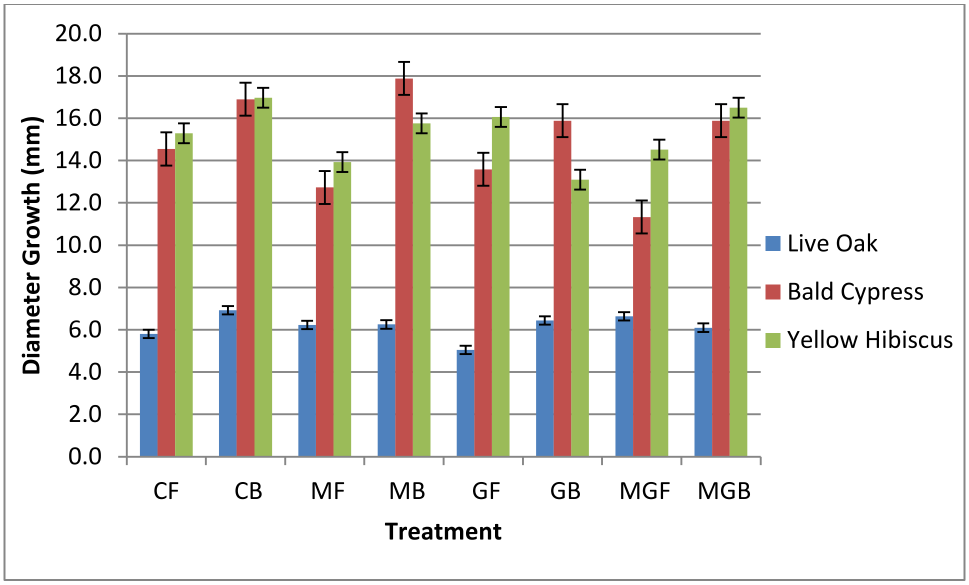

Figure 19. Mean groundline stem diameter growth by treatment between the initial and second measurement of live oak, hybrid bald cypress, and yellow hibiscus. n=6, standard deviation shown.

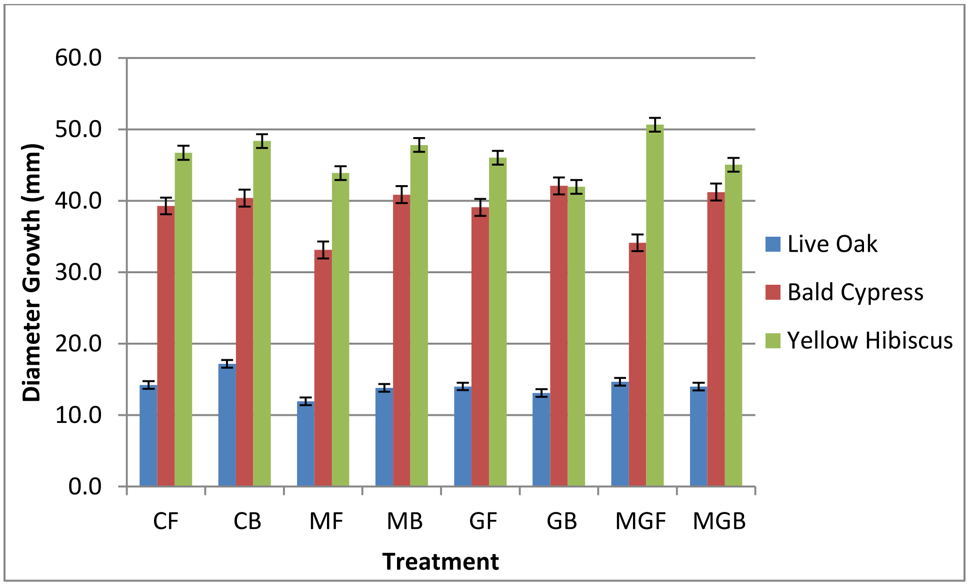

Figure 20. Mean groundline stem diameter growth by treatment between the initial and final measurement of live oak, hybrid bald cypress, and yellow hibiscus. n=6, standard deviation shown.

Construction of raised beds and incorporation of mulch were predicted to positively affect plant growth, but the results did not show this outcome. Raised beds were constructed to provide more volume of soil above the underlying salt impacted soils and water table, and providing more favorable conditions for plant establishment. Mulch was incorporated to improve soil structure, aeration, and water infiltration rates and to increase microbial activity. During this study there was no significant difference in height or stem diameter growth between the constructed raised beds and flat ground plots (Figure 21 and Figure 22). There also was not a significant difference in stem diameter or height growth between the control plots and those with incorporated mulch (Figure 23 and Figure 24).

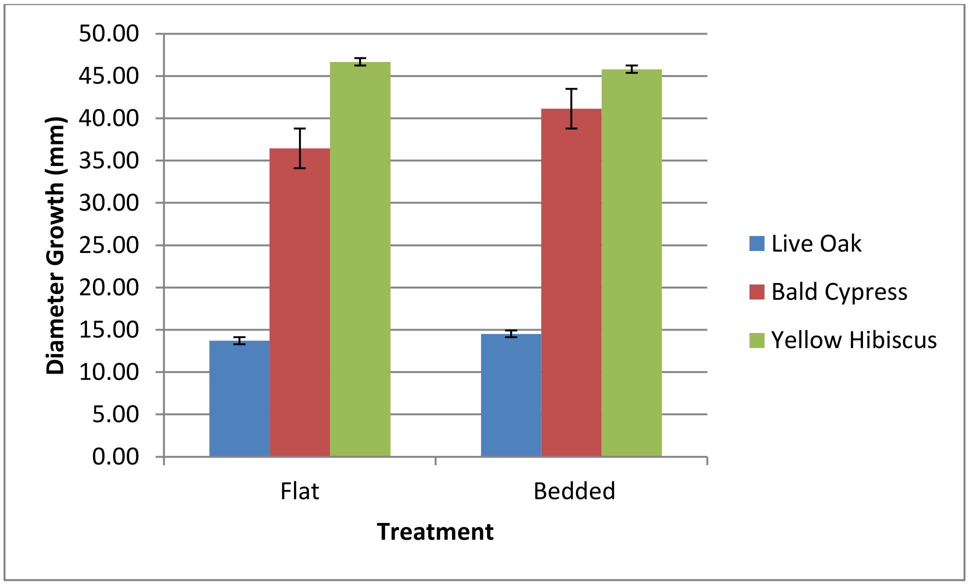

Figure 21. A comparison of mean groundline stem diameter growth of live oak, hybrid bald cypress, and yellow hibiscus between the initial and final measurement of the flat and bedded treatments. n=6, standard deviation shown.

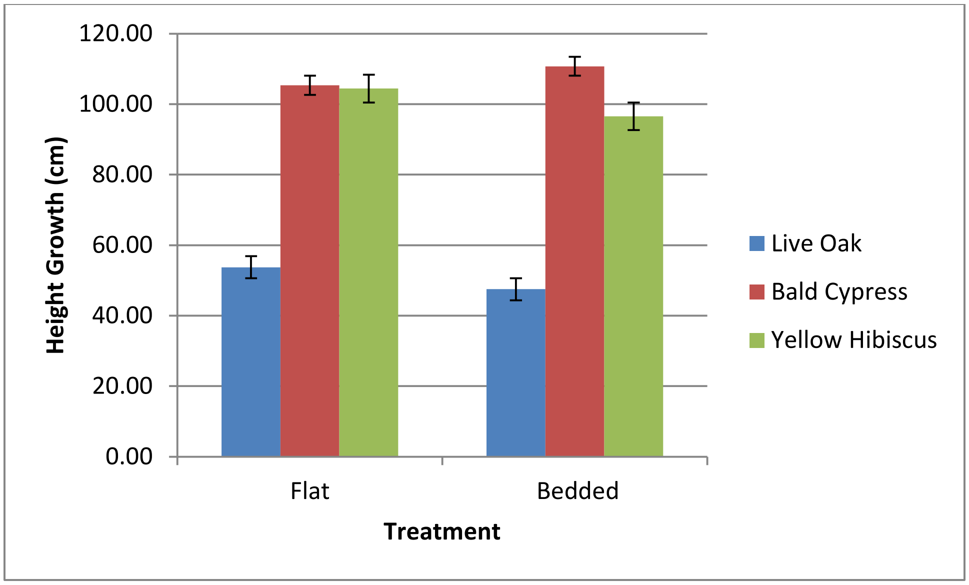

Figure 22. A comparison of mean total height growth of live oak, hybrid bald cypress, and yellow hibiscus between the initial and final measurement of the flat and bedded treatments. n=6, standard deviation shown.

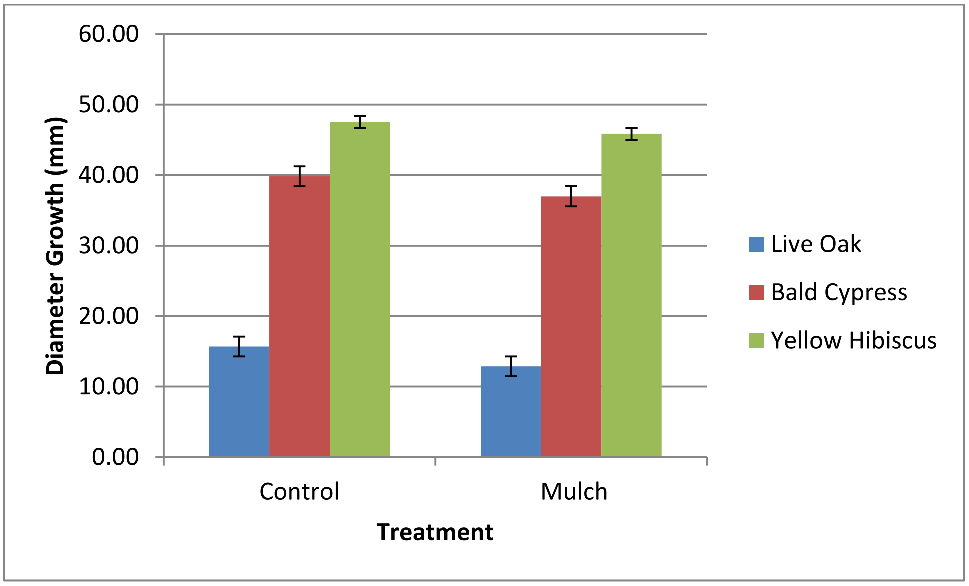

Figure 23. A comparison of mean groundline stem diameter growth of live oak, hybrid bald cypress, and yellow hibiscus between the initial and final measurement of the control and mulch treatments. n=6, standard deviation shown.

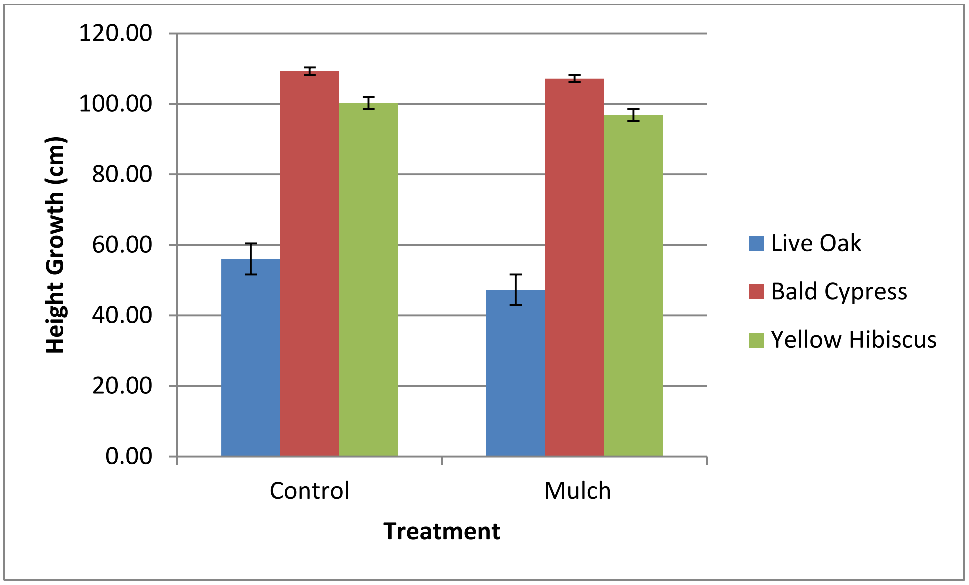

Figure 24. A comparison of mean total height growth of live oak, hybrid bald cypress, and yellow hibiscus between the initial and final measurement of the control and mulch treatments. n=6, standard deviation shown.

Incorporated mulch did not show a significant effect on plant height and stem diameter, but a companion study provided insight about the effect any of the applied treatments, including incorporated mulch, had on soil microbial communities. Fowler performed a study assessing and characterizing microbial communities of the salt affected soils. Fowler (2017) obtained soil samples from the plots built for this study to characterize and compare the differences in microbial communities present within plots which received the aforementioned treatments (gypsum, mulch, etc.). Her study found that there was not a significant statistical difference among microbial communities among the different treatments.

One factor that may have contributed to the lack of statistical differences among the plots was frequent irrigation. Irrigation was continued by Moody Gardens staff from when planting occurred, in March 2016, until January 2017. Frequent irrigation may have caused some leaching of salts deeper into soils, out of the plant rooting zone. In addition, the irrigation may have kept root system development shallower than it would have been without irrigation. If seedling roots had grown deeper they may have encountered higher salt concentrations at depth.

An additional observation was also made about yellow hibiscus. The yellow hibiscus was the smallest plant during the initial planting, but had a rapid growth rate throughout the study. For unknown reasons, yellow hibiscus was particularly susceptible to fire ant inhabitation. Ant colonization was prevalent on the stem of a great number of yellow hibiscus on the stem and soil interface. Additional studies would have to be performed to determine the relationship between and possible impact of ants inhabiting the yellow hibiscus.

iii. Crown Diameter Growth

Because the structure of yellow hibiscus was a shrub, compared to the tree structures of live oak and bald cypress, the crown diameter of the yellow hibiscus was also measured. Initially, yellow hibiscus had crown diameters ranging from approximately 5 to 10 cm. During the final tree measurement crown diameters were measured after significant growth had occurred. Mean crown diameter measurements for the final measurement are presented in Table 8.

Table 8. Mean measured crown diameter of yellow hibiscus during the final measurement period (1/28/17) by soil treatment. (CF= Control Flat, CB= Control Bedded, MF= Mulch Flat, MB= Mulch Bedded, GF= Gypsum Flat, GB= Gypsum Bedded, MGF= Mulch, Gypsum, Flat, and MGB= Mulch, Gypsum, Bedded)

Treatment	Mean Crown Diameter (cm)
CF	117.42
CB	117.50
MF	120.17
MB	113.67
GF	117.88
GB	116.17
MGF	131.00
MGB	122.67

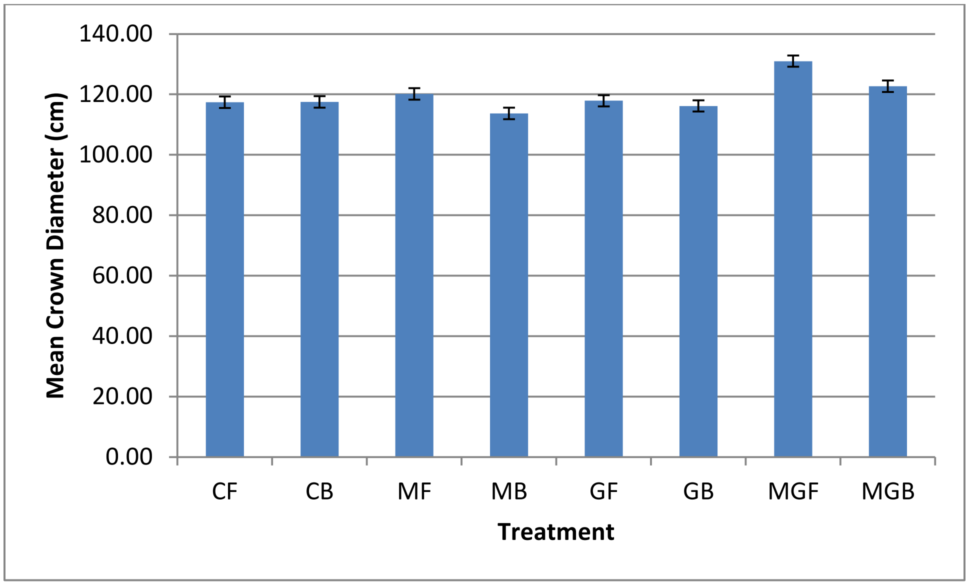

Figure 25. Mean measured crown diameter of yellow hibiscus during the final measurement period (1/28/17) by soil treatment. n=6, standard deviations shown.

Overall, there was not much variation among the measured crown diameters of yellow hibiscus with applied soil treatments (Figure 25). The greatest mean crown diameter was measured in a flat plot with incorporated mulch and gypsum (MGF). Unfortunately, before the final measurement, the yellow hibiscus were pruned by Moody Garden staff, severely affecting crown diameter measurements of the plants. Because crown diameter growth was so severely affected, statistical analyses were not performed.

iv. Volume Growth

Volume growth was also calculated to aid in determining the efficacy of the applied treatments in improving salt contaminated soils for plant growth. Volume growth was calculated using stem diameter growth and height growth with the equation: volume = stem diameter^2 x height (Table 9).

Table 9. The mean stem volume growth of live oak, hybrid bald cypress, and yellow hibiscus by soil treatment during the initial measurement (3/15/16), second measurement (7/19/16), and final measurement (1/28/17) along with the growth between the initial and second measurements and the initial and final measurements. (CF= Control Flat, CB= Control Bedded, MF= Mulch Flat, MB= Mulch Bedded, GF= Gypsum Flat, GB= Gypsum Bedded, MGF= Mulch, Gypsum, Flat, and MGB= Mulch, Gypsum, Bedded). Subscript letters indicate Tukey groupings among treatments within statistically significant soil parameters.

		Mean Stem Volume (cm^3)			**Growth**	
	Treatment	**Initial (1)**	**Second (2)**	**Final (3)**	**1 - 2**	**1 - 3**
Live Oak	CF	52.42	174.25	616.51	121.83	564.08
	CB	64.68	248.74	877.67	184.06	812.99
	MF	26.07	130.30	406.27	104.23	380.20
	MB	73.69	218.22	597.34	144.53	523.65
	GF	71.88	202.71	708.70	130.83	636.82
	GB	52.39	194.73	550.29	142.34	497.90
	MGF	54.15	227.70	703.37	173.54	649.21
	MGB	56.55	214.60	651.04	158.05	594.49
Bald Cypress	CF	118.99	869.28	4956.88	750.30	4837.89
	CB	136.46	1123.15	5416.63	986.68	5280.17
	MF	122.55	786.57	3839.35	664.02	3716.80
	MB	144.64	1318.46	5628.22	1173.81	5483.58
	GF	146.06	819.45	5253.30	673.38	5107.24
	GB	109.50	949.18	5390.83	839.68	5281.32
	MGF	110.27	656.79	3819.45	546.52	3709.18
	MGB	163.72	1210.84	6075.13	1047.12	5911.41
Yellow Hibiscus	CF	2.27	228.70	2873.64	226.44	2871.38
	CB	3.37	308.73	3287.38	305.36	3284.01
	MF	3.26	199.69	2718.81	196.42	2715.54
	MB	3.28	266.05	2947.55	262.77	2944.27
	GF	2.78	271.69	3174.26	268.91	3171.48
	GB	4.53	220.54	2316.64	216.01	2312.12
	MGF	2.98	247.75	3544.52	244.77	3541.54
	MGB	2.66	250.85	2851.42	248.18	2848.75

All plants had volume growth, but bald cypress and yellow hibiscus had substantial growth between the first and second measurement periods. Yellow hibiscus generally had the greatest mean volume growth between the initial and second measurements, followed closely by bald cypress. Bald cypress grown in constructed beds with incorporated mulch (MB) had the greatest mean volume growth (Figure 26). Between the initial and final measurements yellow hibiscus had the greatest volume growth over all applied treatments, with the exception of the constructed bed with incorporated gypsum treatment (GB) where bald cypress had the greatest volume growth (Figure 27). Live oak volume growth was notably lower than that of bald cypress or yellow hibiscus between the initial and second measurement and initial and final measurement.

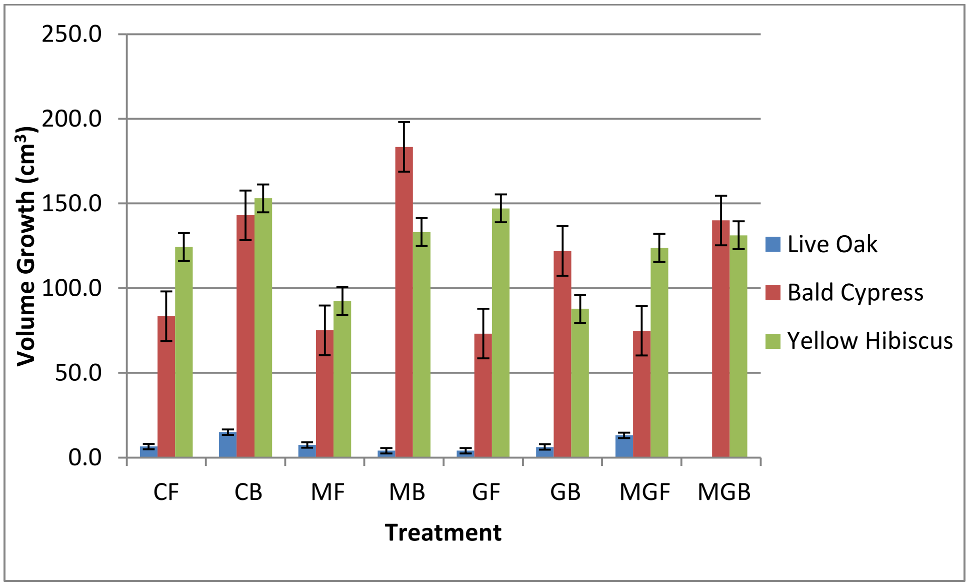

Figure 26. Mean volume growth by treatment between the initial and second measurement of live oak, hybrid bald cypress, and yellow hibiscus. n=6, standard deviation shown.

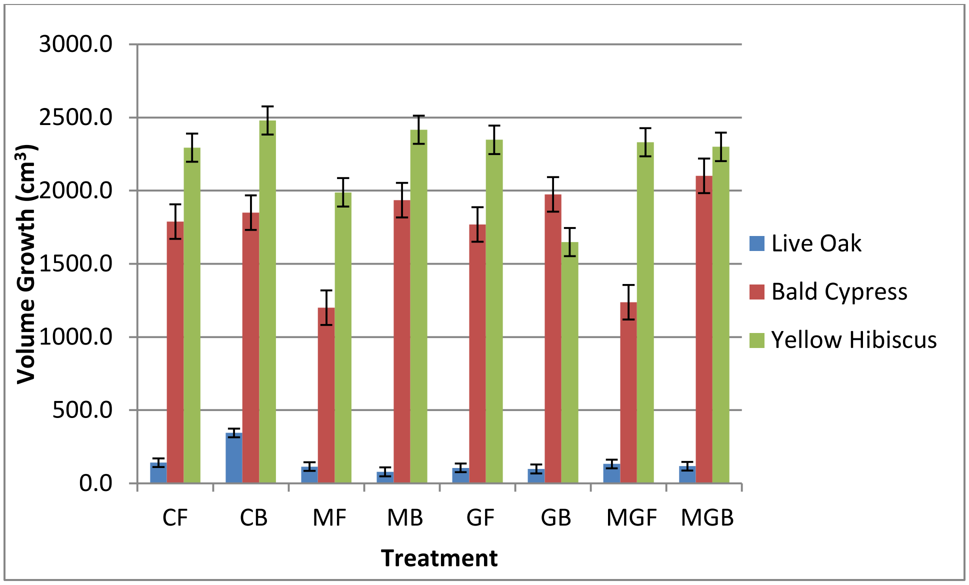

Figure 27. Mean volume growth by treatment between the initial and final measurement of live oak, hybrid bald cypress, and yellow hibiscus. n=6, standard deviation shown.

Between the initial and second measurement a statistically significant difference in volume growth was observed among applied treatments. There was a significant difference between the means of the flat ground plots with incorporated mulch (MF) compared to the constructed raised beds with incorporated mulch (MB) and also between the constructed raised beds with incorporated mulch (MF) compared to the flat ground plots with incorporated mulch and gypsum (MGF). The bedded treatments may have had a weak effect on volume growth between the initial and second measurement, but the same effect was not observed between the second and final measurement. A statistically significant difference was not observed between the second and final measurements. The lack of effect between the second and final measurement may have been due to the Na^+ enrichment of the constructed beds over time.

A significant difference was observed among species for both measurement periods. The significant difference in volume growth among species can be attributed to the variation of growth rates of different species. Volume growth between the initial and final measurement was also impacted by the unauthorized pruning of the live oak and yellow hibiscus. The removal of the tops of several trees would decrease the mean volume growth for the affected plants.

3. Aerial Salinity Deposition

Another factor to consider when characterizing the salt content of soils and the impact on above ground plots of plants is the continuous input of Na^+ and Cl^- from aerial deposition. This study sought to quantify the concentrations of deposited sea spray constituents, including Na^+ and Cl^-. Concentrations of PO_4^{3-}, SO_4^{2-}, P^{3-}, and K^+ were also quantified. Samples were collected over a one-year period from mid May of 2016 to mid May of 2017. During this time measurable amounts of salts were deposited.

No statistical tests were made on these data since only one sampling device was used. Deposition concentrations were highly variable among the 14 day sample collection periods. The sample collected from the 6/3/16 – 6/17/16 sampling does not include a dry fall deposition due to a missing collection pail which was taken from the precipitation collector by persons unknown. Measured aerial deposition ionic concentrations and rainfall amounts are recorded in Appendix C. Generally, a trend of greater ionic deposition being deposited during wet fall (precipitation events) than during dry fall events was observed (Table 10). Na^+, Cl^-, and Mg^{2+} had a greater percentage of deposition during wet fall than dry fall, but Ca^{2+} differed in that it had a greater percentage of deposition during dry fall. Cl^- had the greatest percentage of wet fall compared to dry fall, followed closely by Na^+.

Table 10. Percentages of dry and wet fall of total Na^+, Cl^-, Mg^{2+}, and Ca^{2+} deposition at Moody Gardens on Galveston Island from May 2016 to May 2017.

	% Wet Fall	**% Dry Fall**
Na^+	58.2	41.8
Cl^-	60.3	39.7
Mg^{2+}	53.1	46.9
Ca^{2+}	45.9	54.1

As can be seen in Figure 28 and 29, the greatest deposition for both Na^+ and Cl^- were collected from the sampling which took place from 12/2/16 to 12/16/16. The elevated Na^+ and Cl^- concentrations during this collection period can be attributed to Galveston Island receiving an above average amount of rainfall lasting from 12/2/16 – 12/5/16 (National Weather Service, 2016).

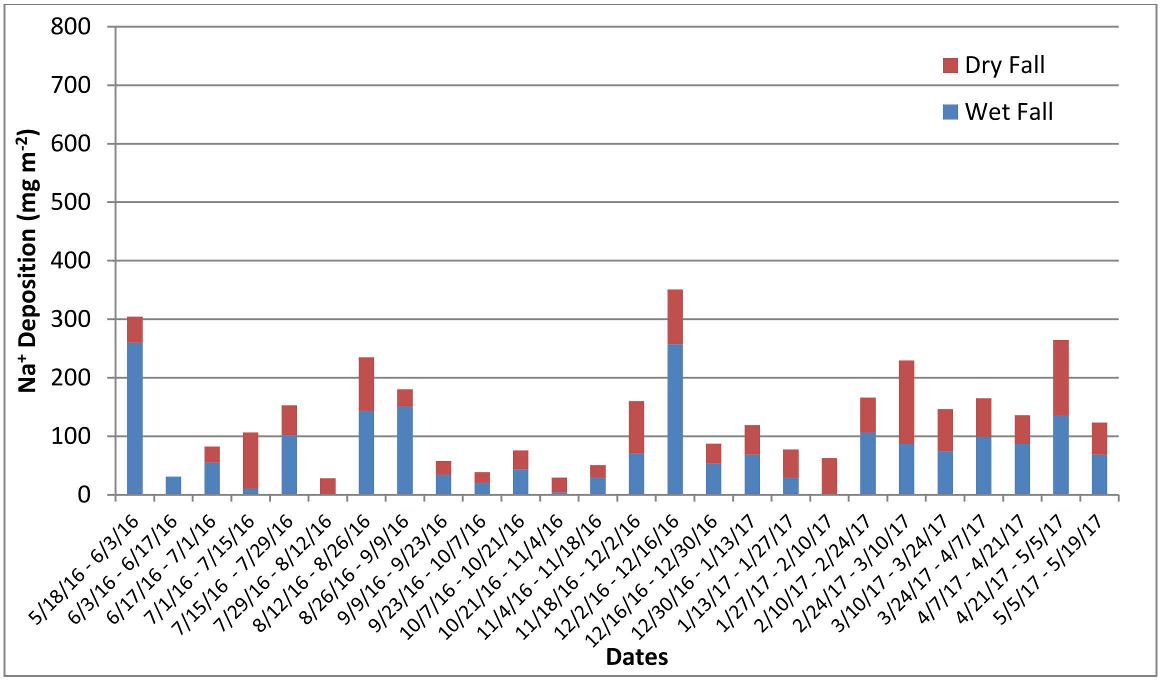

Figure 28. Na^+ deposition per m^2 at Moody Gardens on Galveston Island during 14 day sample collection periods from May 2016 to May 2017.

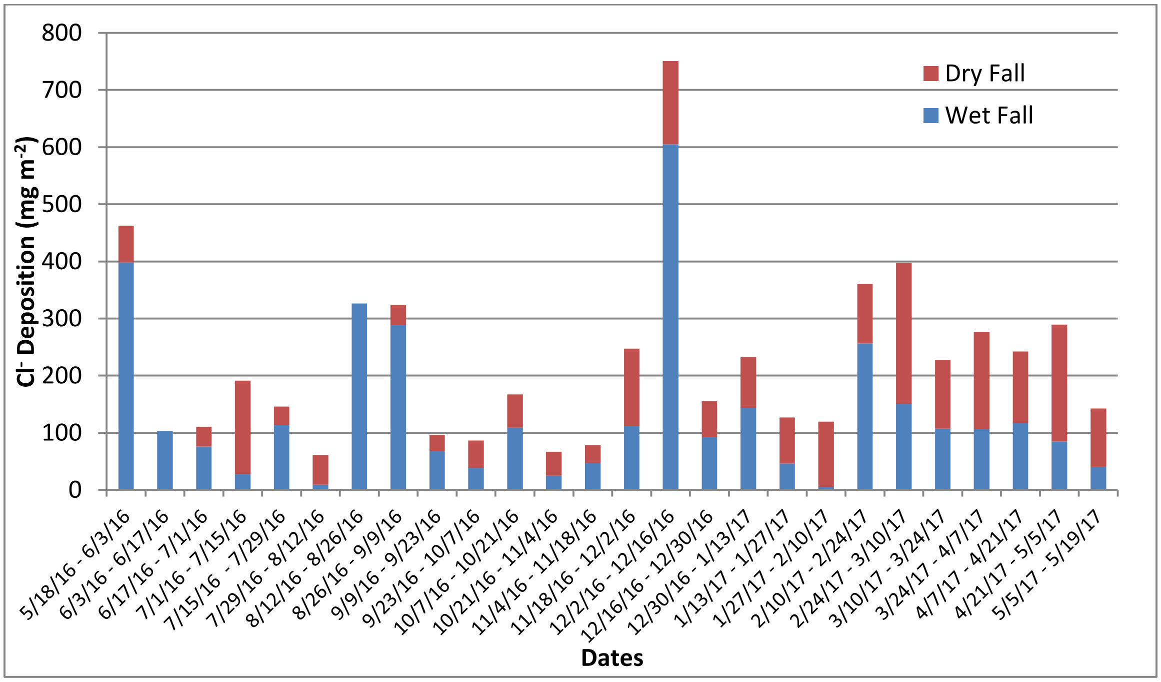

Figure 29. Cl^- deposition per m^2 at Moody Gardens on Galveston Island during 14 day sample collection periods from May 2016 to May 2017.

Smaller amounts of Mg^{2+} and Ca^{2+} deposition occurred compared to Na^{+} and Cl^{-}, but the same trend of variability between sampling events was followed. The same Na^{+} and Cl^{-} peak from the 12/2/16 to 12/16/16 sampling event was not observed. Instead, Mg^{2+} deposition peaked on the 4/21/17 to 5/5/17 sampling event with deposition of approximately 60 mg m^{-2} (Figure 30). Ca^{2+} deposition peaked at approximately 200 mg m^{-2} on the 7/29/16 to 8/12/16 sample (Figure 31). The peak Ca^{2+} deposition was different from the general trend of wet fall deposition exceeding dry fall deposition. The dry fall deposition of Ca^{2+}, approximately 160 mg m^{-2}, was about four times as much as the wet fall deposition of approximately 40 mg.

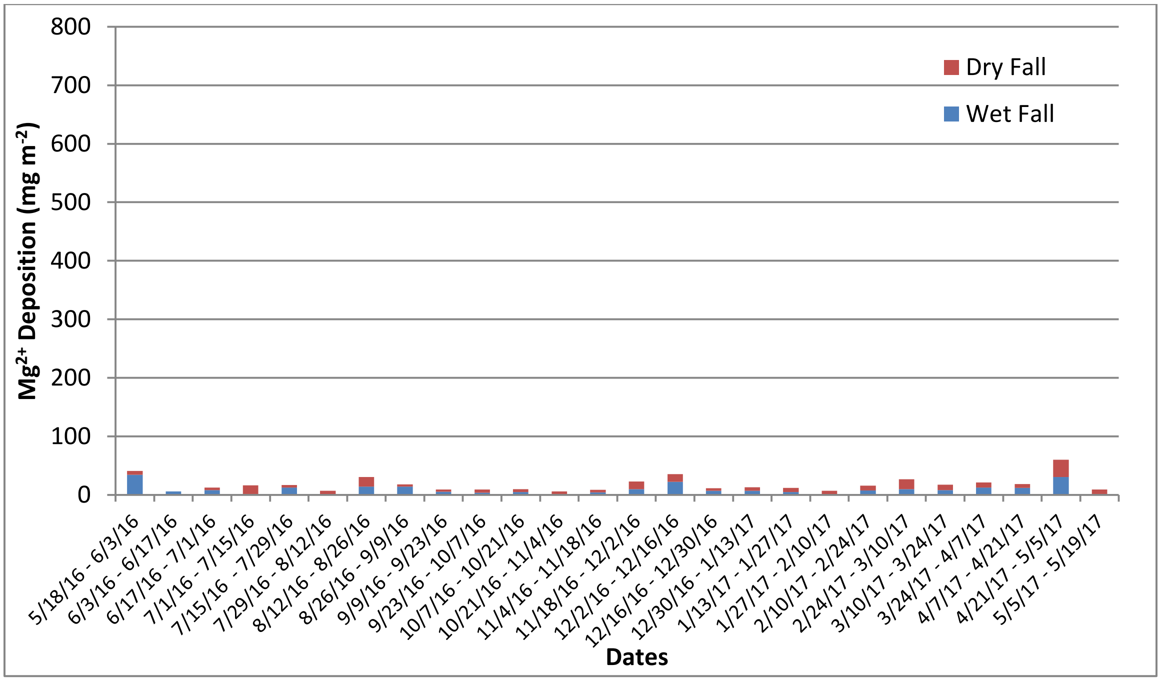

Figure 30. Mg^{2+} deposition per m^{2} at Moody Gardens on Galveston Island during 14 day sample collection periods from May 2016 to May 2017.

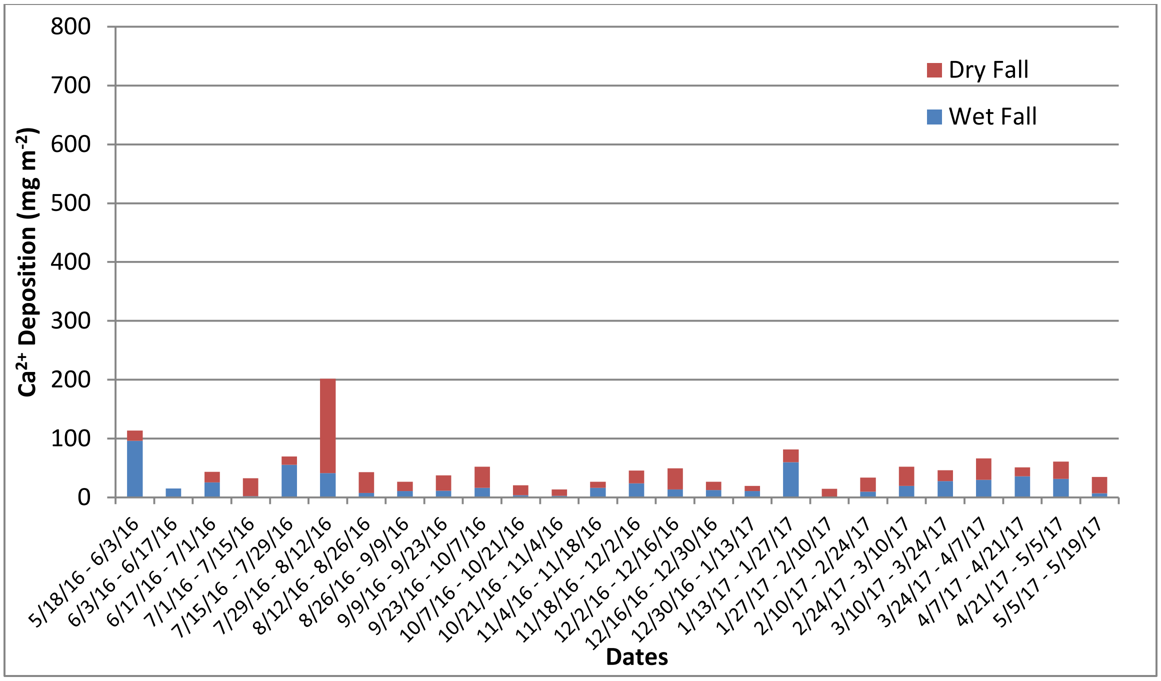

Figure 31. Ca^{2+} deposition per m^2 at Moody Gardens on Galveston Island during 14 day sample collection periods from May 2016 to May 2017.

Cl^- ions were deposited in the greatest concentration over the year of collection likely because Cl^- is a constituent of many salts including NaCl, $MgCl_2$, and $CaCl_2$. Na^+ was deposited in the next greatest concentration followed by SO_4^{2-}, $Ca^{2+,}$ and K^+. Concentrations of PO_4^{3-} and Mg^{2+} ions were deposited in the lowest concentrations (Figure 32).

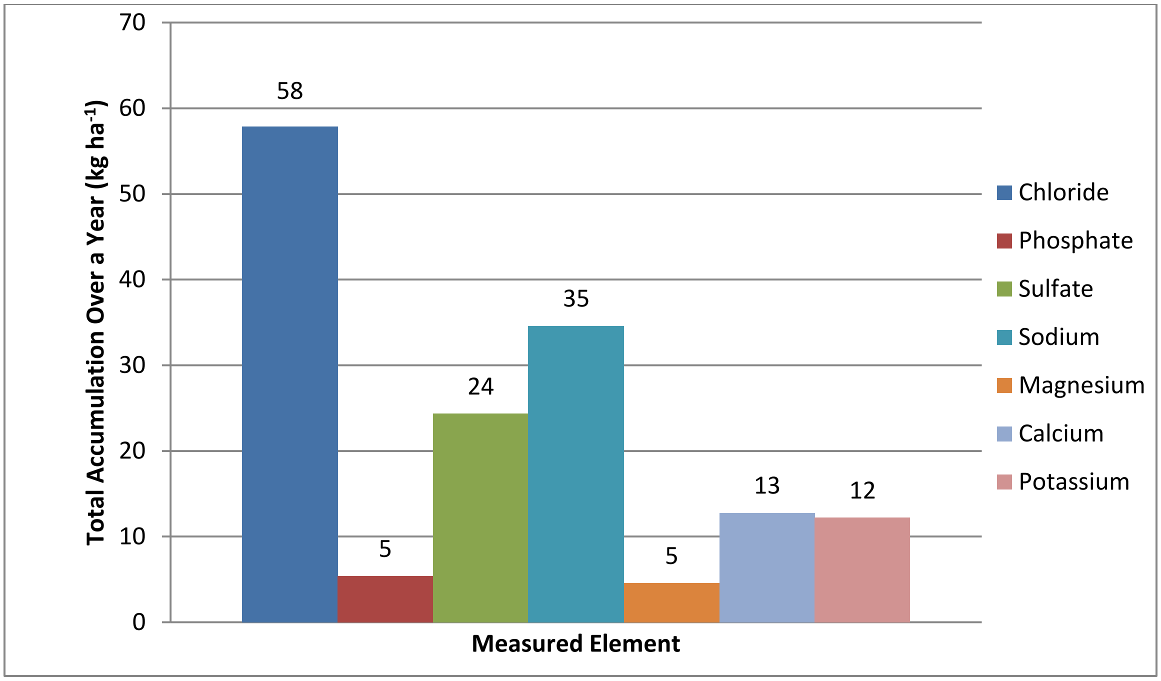

Figure 32. Total accumulation of Cl^- , PO_4^{3-}, SO_4^{2-}, Na^+, Mg^{2+}, Ca^{2+}, and K^+ on a per hectare basis deposited at the study location from May 2016 to May 2017.

Deposited ionic concentrations are dependent upon wind direction and velocity. Winds travel across a saline water body, such as an ocean, to mobilize aerial salts, so months characterized by winds from the south off of the Gulf of Mexico likely resulted in greater ionic deposition. Mc Williams and Sealy found that the greatest aerial salt deposition occurs during salt storm events, originating from the Gulf of Mexico, on Galveston Island in late spring to early summer (1987). As previously stated, higher wind speeds allow for increased mobilization of aerosolized oceanic salts (Edwards and Claxton, 1964). According to the National Oceanic and Atmospheric Administration (NOAA) the strongest wind gusts on Galveston Island from 2006 to 2012 took place during spring, late summer, and the month of December. September was characterized as having the strongest wind gust of approximately 70 knots (2017a).

A correlation between deposition concentrations and wind patterns cannot be distinguished in this study, but further studies and more frequent sampling might reveal a distinguishable pattern. Weather patterns vary from year to year and since sodium deposition concentrations are highly dependent on weather patterns, conditions from several years would be required to calculate accurate average deposition patterns. Installation of additional collection devices would provide a more representative sample and also aid in comparison of variation in deposition around Galveston Island. Samples in this study were collected every two weeks, but in order to better understand the rates of deposition and to more closely correlate deposition to weather patterns, more frequent sampling would be ideal. Samples collected daily, for instance, could be more accurately attributed to weather patterns for that specific day. Collecting samples more frequently would also aid in insuring that samples are not lost due to overflowing of wet fall buckets during heavy rain events.

In order to better understand the impact aerial Na^+ deposition may have on soil Na^+ concentrations, aerial deposition was compared to soil concentrations. Soil Na^+ concentrations for this comparison were taken from samples of the top 10 cm of soil, above groundwater influence. The amount of annual Na^+ deposition (0.0007 mg cm^{-2}) during the study was equivalent to 0.39% of the total amount of Na^+ quantified in the top 10 cm of soil (1.7798 mg cm^{-2}). Although the annual aerial input was only 0.39% of the total amount of Na^+ in the top 10 cm of soil, notable damage may occur in the form of foliar impact of vegetation from Na^+ buildup on leaf surfaces. This annual rate of deposition could also accumulate over time and could encourage persistence of elevated soil Na^+ concentrations.

4. Problems Encountered

Several obstacles were encountered during this study which may have affected results. The first was that due to a miscommunication, the tops of various plants were removed in order to reduce wind stress. Roughly seven live oak trees, along with several yellow hibiscus, were confirmed to have been pruned throughout random treatment plots.

Since it was not discovered that the plants would been pruned until after the pruning occurred, there was not a way to determine how much height was removed from each plant. This error negatively impacted the height measurements, and perhaps growth, of the affected plants. In some instances the removal of the plant tops caused negative growth values between measurements taken before and after the pruning.

The plants were staked to aid in resilience against wind stress. The addition of poles was also inconsistent due to different types of poles being added at different times. Installation of poles could have damaged plant roots and different types of poles were installed, which causes further inconsistencies.

Over-irrigation and inconsistent irrigation may have also impacted the study. Initially, the irrigation system was planned to be shut off after plant establishment in order to stress the plants to better observe the effect that the treatments had on the plants. However, the irrigation system remained on later in the season which may have aided in reducing Na^+ in the plant rooting zones and influenced treatment effectiveness.

Another point to take into consideration was that the study took place eight years after Hurricane Ike occurred. Therefore, the salt concentrations in the soil were not necessarily the same as the concentrations that were present just after the storm surge subsided. Over time some of the Na^+ ions probably had leached out of the system before the study occurred.

CONCLUSIONS

The three measured parameters in this study, select soil properties, plant growth, and aerial salinity deposition had unexpected results. Initially, during the initial soil sampling event, there were statistical differences observed for soluble Na^+, Ca^{2+}, and Mg^{2+}. Exchangeable Na^+ and soluble Ca^{2+} concentrations showed statistically significant differences among treatment plots after treatment application.

Soil amendment treatments did not significantly affect plant survival, height, or diameter growth for either measurement period during this first year of plant measurement. Constructed raised beds may have had a statistically significant, but weak, effect on plant volume growth between the first and second measurements, but the same effect was not observed between the second and final measurements.

In order to observe an effect from soil treatments, the plants may require further study over a greater period of time. For example, treatments such as gypsum, which is a slow release soil amendment, may require a greater amount of time than a year to become effective. Application of a greater amount of gypsum could also be considered to potentially help to further decrease the soil Na^+ concentration. Extended irrigation duration beyond the original planned duration may have contributed to the lack of soil amendment treatment effects.

Additionally, the unauthorized pruning of the trees may have also impacted potential plant growth that could have shown treatment effects**.**

Unsurprisingly, aerial deposition of sea spray constituents was highly variable throughout the sampling period. The general trend of aerial salinity was greater ionic deposition occurring during periods of precipitation opposed to during dry conditions. Cl^- ions, followed by Na^+, were found to be deposited in the greatest concentrations and could continually contribute to soil Na^+ concentrations.

At the conclusion of this study several noteworthy observations can be made. The first is that the amount of annual Na^+ deposition during the study was equivalent to 0.39% of the total amount of Na^+ quantified in the top 10 cm of soil above groundwater. This annual rate of deposition could accumulate over time and could contribute to persistence of elevated soil Na^+ concentrations.

An additional point of particular interest was that the constructed beds composed of off-site uncontaminated soil, became enriched with Na^+ and other ions during the study. Likely, this enrichment occurred because of capillary movement upward from contaminated soil and groundwater, transport of contaminated soils into the constructed beds by ants, and/or by aerial deposition, or a combination of all of these factors. In order to better understand the cycle of Na^+ accumulation an additional study characterizing the properties of the site’s water table and the role the water table might play in further Na^+ contamination would be beneficial.

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APPENDIX A: MEASURED SOIL PARAMETERS

Table a.1. SAR and soluble Na^+, Ca^{2+}, and Mg^{2+} (mg kg^{-1}) concentrations in soil samples by treatment collected before treatment application (3/21/16) and seven months after application (10/27/16).

Bed Number	Treatment	Na^+ (mg kg^{-1})		Ca^{2+} (mg kg^{-1})		Mg^{2+} (mg kg^{-1})		SAR	
		3/21	10/27	3/21	10/27	3/21	10/27	3/21	10/27
1	MF	43.72	54.84	93.96	61.45	33.77	17.74	0.98	1.59
2	GF	63.16	73.63	48.70	104.89	19.08	31.74	1.94	1.62
3	CB	33.16	53.98	22.87	102.75	6.88	23.11	1.56	1.25
4	GB	25.89	49.40	17.46	114.33	4.48	18.81	1.43	1.13
5	MGF	59.04	52.54	79.89	123.46	32.66	30.59	1.41	1.10
6	CF	68.87	75.18	66.86	65.46	26.66	27.32	1.80	1.97
7	MB	28.96	54.26	19.57	94.03	5.03	21.61	1.51	1.31
8	MF	92.05	71.11	95.40	100.65	30.51	27.43	2.10	1.62
9	MGB	35.50	65.67	22.05	157.55	6.62	34.13	1.70	1.24
10	GB	32.54	74.21	14.32	90.78	3.79	20.43	1.98	1.83
11	MGF	86.06	62.88	39.81	90.21	17.93	27.20	2.85	1.49
12	MF	75.62	55.64	98.46	73.41	35.18	22.67	1.66	1.46
13	MF	48.29	59.70	95.60	113.46	40.23	36.63	1.04	1.25
14	CB	32.34	51.80	28.72	90.81	6.70	22.34	1.41	1.26
15	MGB	24.10	70.15	21.83	102.16	4.45	22.23	1.23	1.64
16	CF	84.76	68.80	85.58	108.74	33.67	43.16	1.96	1.41
17	CB	31.89	60.39	34.29	117.14	8.56	31.80	1.26	1.28
18	CF	136.00	83.96	85.93	109.12	43.20	40.31	2.99	1.74
19	GF	223.30	111.46	51.60	93.66	24.78	32.26	6.39	2.53
20	MGB	31.49	113.32	32.40	115.69	8.66	32.97	1.27	2.39
21	GB	35.20	93.30	33.44	120.58	6.64	34.05	1.45	1.93

Table a.1. (continued).

22	MGB	45.46	69.12	34.19	136.64	9.31	30.91	1.78	1.39
23	MGF	55.42	60.09	43.12	88.22	30.28	30.58	1.58	1.41
24	GF	69.15	86.03	91.88	70.10	44.59	27.90	1.48	2.20
25	MGB	37.91	47.23	32.86	137.89	8.14	27.96	1.53	0.96
26	CF	148.70	129.96	40.52	46.87	18.12	20.34	4.88	3.99
27	MB	31.41	127.11	31.27	50.24	7.26	14.30	1.31	4.07
28	MGF	149.58	142.97	64.52	56.17	22.38	15.93	4.09	4.34
29	MGB	24.90	66.55	32.73	116.16	8.57	26.17	1.00	1.45
30	GB	24.43	57.53	23.57	76.95	6.80	21.01	1.14	1.50
31	CB	10.91	61.34	28.64	89.24	6.91	29.06	0.47	1.44
32	GF	80.34	73.33	72.36	107.81	28.66	32.91	2.02	1.59
33	CB	28.39	59.74	55.47	68.36	25.98	17.41	0.79	1.67
34	CF	106.29	81.67	71.66	50.22	29.16	19.05	2.67	2.49
35	GF	54.42	43.53	79.11	104.40	35.94	29.34	1.27	0.97
36	MB	42.62	65.42	58.13	105.86	12.78	23.27	1.32	1.50
37	GF	79.22	61.23	74.28	101.94	30.82	31.65	1.95	1.36
38	MGF	61.05	51.67	75.74	117.44	29.25	31.38	1.51	1.09
39	MB	23.88	52.74	25.22	129.92	8.21	35.21	1.06	1.06
40	GB	24.24	60.26	45.35	125.54	13.84	27.71	0.81	1.27
41	MF	116.14	91.23	85.28	94.00	35.79	30.33	2.66	2.09
42	GB	29.68	52.86	33.62	108.59	10.21	25.82	1.15	1.18
43	MGF	107.37	80.70	102.83	101.71	44.65	33.03	2.23	1.78
44	MB	21.57	59.40	27.38	85.18	7.97	23.14	0.93	1.47

Table a.1. (continued).

45	MB	27.08	124.45	36.69	88.99	10.60	22.14	1.01	3.06
46	CF	209.13	135.93	42.77	81.41	19.09	30.74	6.68	3.26
47	MF	131.64	88.91	78.24	90.62	37.91	32.95	3.06	2.03
48	CB	23.55	76.19	25.76	103.51	13.05	29.87	0.94	1.70

Table a.2. Exchangeable Na^+, Ca^{2+}, Mg^{2+}, and K^+ (mg kg^{-1}) concentrations in soil samples by treatment collected before treatment application (3/21/16) and seven months after application (10/27/16).

SAMPLE ID	**Treatment**	**Na^+ (mg kg^{-1})**		**Ca^{2+} (mg kg $^{-1}$)**		**Mg^{2+} (mg kg^{-1})**		**K^+ (mg kg^{-1})**	
		3/21	**10/27**	**3/21**	**10/27**	**3/21**	**10/27**	**3/21**	**10/27**
1	MF	91.4	146.7	2789.2	2800.4	358.7	553.6	202.6	313.6
2	GF	135.5	115.6	2249.6	1686.4	303.0	353.0	160.8	190.1
3	CB	104.6	114.2	6724.7	3504.5	303.4	326.8	46.2	148.9
4	GB	111.1	120.9	4154.1	3069.9	278.9	261.3	71.2	142.8
5	MGF	99.5	105.8	1970.1	1995.4	331.0	302.5	173.1	194.4
6	CF	238.7	165.3	4344.6	1848.7	583.5	505.3	359.1	269.8
7	MB	159.9	114.1	8465.3	2634.8	448.2	281.9	107.7	126.6
8	MF	303.1	135.6	4654.2	3080.2	603.7	388.1	287.6	204.0
9	MGB	190.1	120.0	7018.8	3538.1	419.8	296.4	106.7	153.3
10	GB	178.8	166.6	8588.9	5167.3	431.2	372.1	112.1	174.9
11	MGF	184.6	111.6	3573.1	1923.9	524.0	327.6	284.4	168.5
12	MF	98.4	108.4	2368.4	2343.4	381.0	367.1	183.7	211.9
13	MF	97.1	96.6	4106.9	1719.1	244.7	321.1	77.4	179.1
14	CB	88.1	100.4	3529.8	2417.1	221.8	329.1	78.3	162.0
15	MGB	151.6	122.1	3774.6	2725.6	435.5	267.5	191.8	137.9
16	CF	63.4	128.4	2026.9	2725.9	175.9	430.4	55.0	221.8
17	CB	224.9	103.0	2639.9	2917.7	505.5	297.7	265.4	129.5
18	CF	481.2	124.6	3937.6	1997.5	626.8	347.1	333.5	182.2
19	GF	114.7	178.2	3755.9	3072.3	247.0	386.4	78.9	224.5
20	MGB	116.6	158.9	5521.8	2241.5	287.1	314.1	90.8	130.9
21	GB	138.1	136.9	5031.4	3223.2	299.1	299.0	88.0	138.5
22	MGB	130.8	90.7	1188.5	2211.0	427.3	232.7	254.2	99.7
23	MGF	177.1	78.8	2712.9	1019.1	433.8	198.4	234.6	125.6
24	GF	114.9	132.2	5075.1	1318.1	286.8	277.9	80.3	154.8
25	MGB	383.5	115.5	2136.5	5444.3	493.7	316.9	283.1	174.4
26	CF	61.4	267.4	2571.3	1769.7	160.2	457.8	40.7	273.8
27	MB	173.2	292.4	1283.5	2824.5	275.4	396.8	158.1	216.7
28	MGF	74.9	411.3	2556.3	3424.4	186.9	520.9	48.8	350.1
29	MGB	92.4	180.1	3408.6	3850.5	207.3	422.3	54.8	299.6
30	GB	53.8	152.5	976.7	3413.6	122.8	394.5	39.8	244.1
31	CB	116.2	173.4	1369.0	2359.8	268.7	472.6	147.1	260.9
32	GF	85.3	180.2	4377.8	2821.5	223.1	419.6	44.0	261.8
33	CB	185.4	184.5	1548.8	4203.0	360.3	460.0	192.8	217.4
34	CF	124.5	277.0	1730.7	3175.7	464.3	694.9	244.3	400.3

Table a.2. (continued).

35	GF	91.5	111.7	3424.2	2401.2	212.7	373.3	56.9	245.7
36	MB	140.5	127.5	1693.9	2730.9	372.8	285.5	191.4	119.8
37	GF	155.8	95.6	2878.8	1269.2	446.2	288.7	246.5	166.1
38	MGF	110.2	116.4	3715.9	2290.9	270.7	396.8	66.3	214.2
39	MB	126.4	134.4	4205.3	2993.2	268.4	418.2	82.8	191.6
40	GB	194.8	116.3	1955.0	2841.6	470.7	327.1	269.8	140.9
41	MF	72.2	167.8	3478.2	2148.8	218.6	467.7	47.1	235.8
42	GB	206.0	137.2	2848.2	3595.5	528.6	478.1	286.4	205.6
43	MGF	74.1	154.9	3138.1	2313.9	234.4	468.4	62.5	226.5
44	MB	71.3	126.3	2946.9	2236.4	175.1	374.9	49.6	141.2
45	MB	331.5	229.3	2061.7	3470.8	383.7	416.0	168.9	167.0
46	CF	248.2	281.3	2156.1	2821.0	537.4	551.2	250.6	250.4
47	MF	63.6	222.2	1921.2	2304.2	167.2	516.5	57.2	268.8
48	CB	88.4	161.7	1985.0	3196.4	302.9	410.4	85.8	174.8

Table a.3. pH, E.C., and NO_3^- concentrations in soil samples by treatment collected before treatment application (3/21/16) and seven months after application (10/27/16).

SAMPLE ID	Treatment	pH		E.C. (uS/cm)		NO_3^- (mg/kg^{-1})	
		3/21	10/27	3/21	10/27	3/21	10/27
1	MF	8.6	8.6	1576	775	10	21
2	GF	8.8	8.4	1258	1055	12	6
3	CB	8.4	8.3	633	949	1	16
4	GB	8.2	8.3	580	994	1	4
5	MGF	8.7	8.4	1595	1146	7	1
6	CF	8.7	8.5	1506	950	6	6
7	MB	8.4	8.3	609	949	1	3
8	MF	8.7	8.5	1890	1097	12	9
9	MGB	8.3	8.1	630	1417	1	16
10	GB	8.2	8.5	586	1029	1	3
11	MGF	8.6	8.4	1305	1013	14	5
12	MF	8.6	8.5	1844	871	1	6
13	MF	8.5	8.3	1800	1195	2	1
14	CB	8.4	8.4	753	964	1	3
15	MGB	8.3	8.4	596	1059	1	1
16	CF	8.6	8.2	1903	1346	1	2
17	CB	8.5	8.2	784	1203	1	6
18	CF	8.5	8.2	2380	1436	7	3
19	GF	8.7	8.4	2540	1386	1	1
20	MGB	8.4	8.3	778	1399	1	5
21	GB	8.5	8.2	887	1441	1	1
22	MGB	8.5	8.3	878	1201	1	1
23	MGF	8.5	7.7	1424	1099	4	1
24	GF	8.1	7.6	2190	1185	3	1
25	MGB	8.5	8.1	827	1199	1	1
26	CF	8.7	8.5	1757	1091	6	14
27	MB	8.4	8.7	735	1093	1	4
28	MGF	8.8	8.7	2050	1229	9	4
29	MGB	8.4	8.5	702	1148	1	4
30	GB	8.4	8.5	602	915	1	4
31	CB	8.4	7.9	565	1058	1	2
32	GF	8.2	8.2	1656	1173	16	6
33	CB	8.3	8.4	755	811	1	4
34	CF	8.5	8.5	1796	835	6	5
35	GF	8.3	8.4	1804	1021	8	5

Table a.3. (continued).

36	MB	8.4	8.4	1132	1077	1	7
37	GF	8.4	8.2	1707	1073	2	2
38	MGF	8.4	8.3	1606	1160	1	1
39	MB	8.1	8.0	612	1288	1	1
40	GB	8.3	8.3	805	1191	1	33
41	MF	8.4	8.6	2250	1203	3	4
42	GB	8.2	8.4	712	1052	1	10
43	MGF	8.3	8.4	2300	1176	5	6
44	MB	8.3	8.4	627	934	1	6
45	MB	8.2	8.5	700	1200	1	15
46	CF	8.8	8.4	2200	1353	4	2
47	MF	8.3	8.3	2190	1219	2	4
48	CB	8.0	8.3	575	1204	1	3

Table a.4. P, B^{3+}, and S^{2-} concentrations in soil samples by treatment collected before treatment application (3/21/16) and seven months after application (10/27/16).

SAMPLE ID	Treatment	P (mg kg^{-1})		B^{3+} (mg kg^{-1})		S^{2-} (mg kg^{-1})	
		3/21	10/27	3/21	10/27	3/21	10/27
1	MF	5.3	3.8	0.2	1.0	10.7	9.5
2	GF	7.9	6.4	0.3	0.8	12.0	9.9
3	CB	7.1	5.9	-0.8	0.3	11.4	7.8
4	GB	9.7	5.5	-0.9	0.2	10.4	17.2
5	MGF	4.9	5.7	-0.3	0.3	8.6	9.6
6	CF	8.3	6.2	-0.2	0.2	18.8	11.0
7	MB	9.6	5.3	-1.1	0.0	16.1	3.6
8	MF	10.3	4.7	0.2	0.2	60.1	6.5
9	MGB	9.0	5.8	-1.1	0.2	18.3	13.6
10	GB	13.0	5.6	-1.2	0.0	21.6	9.5
11	MGF	7.3	5.7	0.8	0.0	13.6	4.6
12	MF	5.2	5.9	0.7	0.1	9.6	4.8
13	MF	7.2	5.1	-0.2	0.0	5.8	4.2
14	CB	4.2	5.0	-0.2	-0.2	4.2	3.4
15	MGB	4.6	7.3	2.2	-0.1	18.2	7.0
16	CF	2.8	5.4	0.3	0.2	3.1	8.0
17	CB	7.3	7.5	1.9	-0.4	14.9	4.6
18	CF	4.5	5.7	2.5	0.1	37.3	5.6
19	GF	4.4	5.9	0.2	0.6	6.7	20.2
20	MGB	4.9	6.2	0.2	-0.1	8.8	10.0
21	GB	5.5	6.0	0.2	0.6	10.4	17.2
22	MGB	8.4	5.6	0.6	0.0	10.0	4.4
23	MGF	12.0	5.9	1.2	-0.6	17.6	4.1
24	GF	4.4	9.4	-0.1	-0.3	6.6	10.5
25	MGB	7.9	10.3	0.7	-0.5	17.5	10.7
26	CF	3.3	7.0	0.3	-0.4	3.7	15.4
27	MB	4.0	7.9	0.9	0.0	8.5	16.4
28	MGF	5.0	6.8	0.2	0.2	5.8	33.8
29	MGB	4.5	8.3	0.1	0.0	6.2	17.0
30	GB	6.0	7.1	0.0	0.5	3.2	19.2
31	CB	5.2	7.6	0.3	-0.7	7.5	15.2
32	GF	2.6	8.1	0.0	-0.3	3.6	18.6
33	CB	4.4	7.8	0.5	-0.4	8.1	12.0
34	CF	6.2	7.1	0.6	0.0	8.3	18.2
35	GF	4.6	7.6	0.0	0.2	7.5	17.7

Table a.4. (continued).

36	MB	6.3	5.2	0.8	0.8	9.6	6.7
37	GF	7.7	6.7	1.1	0.9	12.1	9.8
38	MGF	4.1	4.1	-0.1	0.8	6.7	13.5
39	MB	4.7	4.3	-0.2	0.5	6.8	16.7
40	GB	4.8	4.6	0.7	0.6	8.8	14.0
41	MF	2.0	6.9	-0.1	0.8	4.0	22.4
42	GB	6.7	6.4	1.0	0.7	16.9	19.5
43	MGF	3.9	5.4	-0.2	0.8	4.9	21.8
44	MB	3.6	4.6	-0.2	0.5	4.7	9.7
45	MB	4.2	5.5	1.2	0.6	18.1	13.5
46	CF	6.7	6.2	1.6	1.2	16.7	20.2
47	MF	5.1	6.2	-0.2	1.6	3.9	13.1
48	CB	0.7	8.6	-0.2	1.1	6.1	9.7

Table a.5. C, N, and CN Ratio concentrations in soil samples by treatment collected before treatment application (3/21/16) and seven months after application (10/27/16).

SAMPLE ID	Treatment	C (mg kg^{-1})		N (mg kg^{-1})		CN RATIO	
		3/21	10/27	3/21	10/27	3/21	10/27
1	MF	15620.0	16893.0	1950.1	1784.6	8.0	9.5
2	GF	18871.0	26121.0	2258.5	2414.6	8.4	10.8
3	CB	6910.8	12343.0	935.6	1542.3	7.4	8.0
4	GB	6256.0	11395.0	1034.6	1485.8	6.0	7.7
5	MGF	14623.0	29479.0	1684.8	2193.8	8.7	13.4
6	CF	14862.0	19477.0	1823.3	2012.0	8.2	9.7
7	MB	6372.0	21672.0	1017.5	1758.5	6.3	12.3
8	MF	13103.0	22613.0	1672.3	1720.9	7.8	13.1
9	MGB	6783.5	20862.0	1010.4	1789.5	6.7	11.7
10	GB	6570.4	12964.0	1027.3	1648.3	6.4	7.9
11	MGF	17248.0	18461.0	2115.9	1894.4	8.2	9.7
12	MF	20058.0	21111.0	2173.2	2026.1	9.2	10.4
13	MF	15872.0	17677.0	1885.6	1852.0	8.4	9.5
14	CB	6371.5	10403.0	991.7	1413.4	6.4	7.4
15	MGB	5975.0	14264.0	1018.0	1708.4	5.9	8.3
16	CF	18556.0	13125.0	2045.6	1725.9	9.1	7.6
17	CB	6754.6	15079.0	1041.2	1668.7	6.5	9.0
18	CF	19959.0	16810.0	2308.6	2069.1	8.6	8.1
19	GF	27409.0	14528.0	2580.1	1942.8	10.6	7.5
20	MGB	6327.9	20292.0	984.6	1879.8	6.4	10.8
21	GB	6992.2	14457.0	1002.1	1651.3	7.0	8.8
22	MGB	7624.1	16313.0	1022.3	1689.2	7.5	9.7
23	MGF	16839.0	14207.0	1943.3	1575.8	8.7	9.0
24	GF	27038.0	12599.0	2813.7	1661.4	9.6	7.6
25	MGB	6858.6	16289.0	893.2	1542.8	7.7	10.6
26	CF	13208.0	15367.0	1778.3	1968.2	7.4	7.8
27	MB	6033.5	12236.0	1004.4	1411.7	6.0	8.7
28	MGF	15052.0	17013.0	1933.4	1833.7	7.8	9.3
29	MGB	5773.4	19050.0	957.9	1620.7	6.0	11.8
30	GB	6068.5	11415.0	1011.7	1489.7	6.0	7.7
31	CB	5476.3	10218.0	958.4	1528.7	5.7	6.7
32	GF	17825.0	11720.0	2162.4	1614.1	8.2	7.3
33	CB	7485.7	15350.0	975.8	1737.1	7.7	8.8
34	CF	18347.0	14192.0	2171.4	1797.8	8.4	7.9
35	GF	18548.0	13652.0	2197.6	1871.8	8.4	7.3

Table a.5. (continued).

36	MB	11554.0	16536.0	1215.4	1700.7	9.5	9.7
37	GF	13152.0	14817.0	1607.3	1836.0	8.2	8.1
38	MGF	17841.0	22328.0	2054.1	2074.7	8.7	10.8
39	MB	6270.4	14783.0	995.8	1560.6	6.3	9.5
40	GB	7585.9	12504.0	1083.0	1657.6	7.0	7.5
41	MF	26285.0	21747.0	2523.7	2141.4	10.4	10.2
42	GB	6461.6	14256.0	1034.0	1730.0	6.2	8.2
43	MGF	7294.2	26919.0	1103.3	2339.1	6.6	11.5
44	MB	6567.4	16431.0	1030.1	1715.1	6.4	9.6
45	MB	14400.0	15899.0	1767.7	1691.5	8.1	9.4
46	CF	24929.0	16051.0	2616.9	1884.8	9.5	8.5
47	MF	5952.4	20122.0	1034.1	2047.8	5.8	9.8
48	CB	5780.7	12304.0	1029.1	1624.8	5.6	7.6

APPENDIX B: MEASURED PLANT PARAMETERS

Table b.1. Measured diameters of live oak, hybrid bald cypress, and yellow hibiscus by soil treatments during the initial measurement (3/15/16), second measurement (7/19/16), and final measurement (1/28/17) along with the growth between the initial and second measurements and the initial and final measurements. * -Trees which had to be replaced during the course of the study

Bed Number	Treatment	ID Number	Species	Diameter (mm)			Growth 1 (mm)	Growth 2 (mm)
				3/15/2016	7/19/2016	1/28/2017		
1	MF	1	LO	6.16	10.73	19.08	4.57	12.92
		2	BC	16.66	26.49	51.11	9.84	34.46
		3	HH	9.98	19.84	56.09	9.87	46.11
		4	HH	8.70	17.80	55.14	9.10	46.45
		5	LO	8.31	10.20	21.70	1.89	13.40
		6	BC	10.27	22.79	45.89	12.52	35.62
2	GF	7*	HH	5.155	25.495	48.945	20.34	43.79
		8	LO	10.54	15.42	23.33	4.88	12.79
		92	LO	11.66	15.58	21.83	3.93	10.17
		10	BC	10.13	19.14	48.98	9.02	38.86
		11	HH	4.10	16.37	44.49	12.27	40.39
		12	BC	20.16	24.72	36.04	4.57	15.89
3	CB	13	BC	5.88	18.57	47.98	12.69	42.10
		14	HH	5.34	23.45	48.29	18.11	42.95
		15	HH	4.94	22.26	54.72	17.33	49.78
		16	LO	10.44	13.93	16.26	3.49	5.82
		17	BC	14.11	19.02	42.88	4.91	28.77
		18	LO	6.92	15.54	23.59	8.62	16.67

Table b.1. (continued).

4	GB	19	HH	8.98	18.49	43.94	9.52	34.96
		20	HH	5.70	18.81	57.09	13.11	51.40
		21	BC	15.96	31.30	58.62	15.34	42.67
		22	LO	6.44	12.41	19.27	5.97	12.83
		23	BC	15.84	31.63	57.13	15.79	41.29
		24	LO	9.01	16.45	19.87	7.44	10.86
5	MGF	25*	HH	5.31	18.77	45.49	13.46	40.18
		26	HH	6.94	23.05	52.90	16.11	45.97
		27	BC	9.80	15.39	35.84	5.59	26.04
		28	BC	12.50	28.02	50.52	15.52	38.02
		29	LO	10.01	16.84	21.18	6.84	11.17
		30	LO	10.79	19.18	29.79	8.39	19.00
6	CF	31	HH	5.18	17.47	47.46	12.29	42.28
		32	BC	15.13	37.46	66.23	22.33	51.11
		33	HH	4.92	12.97	40.91	8.06	35.99
		34	BC	11.86	21.38	45.81	9.52	33.95
		35	LO	10.24	14.58	27.68	4.34	17.44
		36	LO	9.57	16.27	25.61	6.70	16.05
7	MB	37	LO	9.54	17.97	24.37	8.43	14.83
		38	HH	5.40	26.82	64.15	21.43	58.75
		39	HH	4.86	31.78	60.68	26.92	55.83
		40	BC	9.31	16.85	35.46	7.54	26.15
		41	BC	11.24	31.72	51.71	20.48	40.47
		42	LO	9.13	14.58	18.94	5.45	9.81

Table b.1. (continued).

8	MF	43	HH	5.44	18.39	48.67	12.95	43.23
		44	BC	10.91	27.99	45.30	17.08	34.39
		45	HH	5.75	11.83	38.46	6.08	32.71
		46	BC	13.86	24.65	44.18	10.79	30.32
		47	LO	2.38	5.95	11.26	3.57	8.88
		48	LO	6.39	13.98	20.76	7.59	14.37
9	MGB	49	LO	8.12	15.85	21.50	7.74	13.38
		50	HH	5.26	23.42	46.14	18.16	40.88
		51	BC	15.35	26.83	53.97	11.48	38.63
		52	HH	4.17	14.50	31.12	10.33	26.96
		53	LO	7.66	16.64	22.41	8.98	14.75
		54	BC	12.22	26.16	44.76	13.95	32.54
10	GB	55	HH	5.67	21.17	48.02	15.50	42.36
		56	HH	8.39	16.60	34.80	8.22	26.42
		57	BC	14.62	32.42	63.17	17.80	48.55
		58	LO	10.24	14.89	18.95	4.66	8.72
		59	LO	11.38	18.33	24.30	6.96	12.93
		60	BC	16.90	36.03	66.41	19.13	49.51
11	MGF	61	HH	5.98	24.05	60.16	18.07	54.18
		62	BC	11.36	23.28	50.01	11.92	38.65
		63	LO	9.07	14.22	18.70	5.15	9.63
		64	BC	17.73	24.62	54.68	6.89	36.95
		65	LO	10.46	15.25	19.97	4.79	9.51
		66	HH	4.85	20.39	59.88	15.55	55.03

Table b.1. (continued).

12	MF	67	HH	4.42	21.23	48.70	16.81	44.28
		68	LO	8.17	12.66	17.23	4.50	9.07
		69	BC	10.74	27.32	47.91	16.59	37.17
		70	LO	8.36	14.77	22.74	6.41	14.38
		71	BC	14.80	30.09	48.43	15.30	33.63
		72	HH	4.58	24.99	57.90	20.41	53.32
13	MF	73	HH	5.29	21.26	48.75	15.97	43.46
		74	LO	5.69	17.53	15.10	11.84	9.41
		75	BC	13.17	24.80	39.09	11.64	25.92
		76	LO	10.83	15.59	21.17	4.76	10.34
		77	HH	4.16	17.27	45.21	13.11	41.05
		78	BC	10.71	19.49	39.64	8.79	28.94
14	CB	79	LO	7.66	17.17	24.79	9.51	17.13
		80	LO	10.48	21.73	31.57	11.26	21.10
		81	BC	10.98	32.38	52.21	21.40	41.23
		82	BC	18.21	35.02	59.90	16.81	41.69
		83	HH	5.25	20.54	46.52	15.29	41.27
		84	HH	6.27	20.84	52.10	14.57	45.83
15	MGB	85	LO	11.55	17.24	25.28	5.69	13.73
		86	HH	5.07	28.82	52.65	23.75	47.58
		87	HH	3.36	18.98	43.90	15.62	40.54
		88	LO	9.41	15.03	23.39	5.63	13.99
		89	BC	19.82	33.90	59.60	14.09	39.79
		90	BC	13.72	29.35	58.21	15.63	44.49

Table b.1. (continued).

16	CF	91	LO	6.61	14.17	21.99	7.56	15.38
		92	LO	7.60	12.13	16.83	4.53	9.23
		93	HH	5.55	25.96	56.43	20.41	50.88
		94	BC	12.65	29.85	52.02	17.20	39.37
		95	BC	19.89	27.01	47.74	7.12	27.86
		96	HH	3.76	20.24	48.26	16.48	44.50
17	CB	97	HH	6.32	25.79	62.72	19.48	56.40
		98	LO	13.07	15.06	24.91	1.99	11.85
		99	LO	9.41	15.72	22.14	6.31	12.73
		100	BC	16.05	35.61	50.38	19.56	34.33
		101	HH	5.98	21.40	50.21	15.43	44.23
		102	BC	11.64	33.01	62.92	21.37	51.28
18	CF	103	LO	8.83	18.13	32.90	9.30	24.07
		104	LO	10.69	13.74	19.55	3.05	8.86
		105	BC	10.40	32.13	61.35	21.73	50.95
		106	BC	5.56	18.52	46.39	12.96	40.83
		107	HH	3.65	20.12	48.48	16.48	44.84
		108	HH	4.39	19.59	56.85	15.20	52.47
19	GF	109	HH	4.69	17.84	54.54	13.16	49.85
		110	LO	9.34	13.84	19.60	4.50	10.26
		111	LO	4.37	9.09	15.76	4.73	11.40
		112	BC	7.39	24.39	50.55	17.00	43.16
		113	BC	12.26	28.22	55.15	15.96	42.89
		114	HH	4.79	22.04	50.16	17.25	45.37

Table b.1. (continued).

20	MGB	115	LO	10.67	17.07	26.15	6.41	15.49
		116	BC	18.34	35.02	54.21	16.68	35.87
		117	HH	5.94	22.00	57.49	16.07	51.56
		118	HH	4.09	16.80	39.65	12.72	35.57
		119	BC	7.38	31.19	53.15	23.81	45.77
		120	LO	7.72	11.58	15.91	3.86	8.20
21	GB	121	LO	9.10	14.12	22.30	5.02	13.20
		122	BC	13.01	28.80	62.00	15.79	48.99
		123	LO	9.89	19.24	28.96	9.35	19.07
		124	HH	5.47	19.82	46.48	14.35	41.01
		125	HH	5.06	17.60	43.94	12.54	38.88
		126	BC	7.21	24.92	49.00	17.72	41.79
22	MGB	127	LO	4.96	12.09	24.83	7.13	19.88
		128	LO	11.21	15.65	26.07	4.44	14.87
		129	HH	4.79	19.13	45.04	14.34	40.25
		130	BC	18.03	32.80	62.21	14.77	44.18
		131	HH	4.37	21.88	53.40	17.52	49.04
		132	BC	10.75	30.55	72.64	19.80	61.89
23	MGF	133	LO	5.43	11.25	22.52	5.82	17.10
		134*	BC	15.22	19.525	51.66	4.305	36.44
		135	HH	3.34	18.56	55.24	15.22	51.90
		136	BC	8.89	21.18	52.42	12.29	43.54
		137	HH	5.50	19.07	50.49	13.58	45.00
		138	LO	5.23	14.25	27.55	9.03	22.33

Table b.1. (continued).

24	GF	139	LO	8.15	14.53	29.72	6.38	21.57
		140	LO	5.52	12.34	23.58	6.82	18.06
		141	HH	4.80	19.90	52.53	15.10	47.73
		142	BC	20.13	34.45	69.66	14.32	49.53
		143	BC	8.81	23.70	44.81	14.89	36.00
		144	HH	4.51	20.37	30.89	15.86	26.38
25	MGB	145	LO	5.80	8.47	15.39	2.67	9.59
		146	BC	7.81	23.67	47.43	15.86	39.62
		147	HH	5.76	31.63	71.82	25.87	66.07
		148	HH	4.57	18.11	42.58	13.54	38.01
		149	LO	9.08	16.06	22.31	6.98	13.23
		150	BC	14.16	33.10	58.03	18.94	43.87
26	CF	151	BC	11.77	27.20	54.24	15.43	42.48
		152	BC	8.98	21.22	44.78	12.24	35.80
		153	LO	7.55	10.84	18.75	3.29	11.20
		154	LO	9.65	15.17	19.43	5.53	9.79
		155	HH	5.27	18.61	52.29	13.34	47.02
		156	HH	4.07	17.12	41.34	13.05	37.27
27	MB	157	LO	7.56	11.48	16.53	3.92	8.97
		158	HH	7.48	20.45	72.07	12.97	64.59
		159	BC	17.09	30.35	57.83	13.26	40.74
		160	BC	11.33	28.43	50.26	17.10	38.93
		161	HH	4.79	22.52	56.43	17.73	51.64
		162	LO	8.78	14.82	24.67	6.04	15.89

Table b.1. (continued).

28	MGF	163	LO	9.20	15.53	23.94	6.33	14.74
		164	HH	6.48	18.97	47.50	12.49	41.02
		165	HH	4.62	17.34	48.88	12.72	44.26
		166	BC	14.29	21.17	29.29	6.88	15.00
		167	BC	7.63	28.26	49.23	20.64	41.60
		168	LO	8.89	14.78	23.54	5.89	14.65
29	MGB	169	LO	11.06	16.19	25.99	5.13	14.93
		170	LO	8.94	17.43	24.93	8.49	15.99
		171	BC	11.78	18.97	34.70	7.20	22.93
		172	HH	4.36	19.33	53.27	14.98	48.91
		173	HH	4.55	19.59	59.64	15.05	55.09
		174	BC	12.28	30.67	57.31	18.39	45.04
30	GB	175	LO	6.56	9.61	13.99	3.05	7.43
		176	BC	7.87	23.74	50.42	15.88	42.56
		177	LO	5.77	14.19	23.43	8.42	17.66
		178	HH	4.00	22.95	60.13	18.96	56.13
		179	HH	4.57	16.87	45.81	12.30	41.24
		180	BC	9.73	19.18	41.95	9.45	32.22
31	CB	181	LO	9.76	16.84	24.03	7.08	14.27
		182	HH	5.70	23.06	51.72	17.36	46.02
		183	BC	14.80	26.29	50.95	11.49	36.15
		184	LO	6.61	14.92	22.52	8.32	15.92
		185	BC	17.22	29.70	47.92	12.49	30.70
		186	HH	4.54	30.35	56.85	25.81	52.31

Table b.1. (continued).

32	GF	187	LO	9.90	14.56	23.08	4.66	13.18
		188	BC	17.59	32.35	59.42	14.76	41.83
		189	HH	4.37	26.32	58.03	21.95	53.66
		190	LO	13.14	19.43	27.98	6.29	14.84
		191	BC	16.04	26.41	45.09	10.37	29.05
		192	HH	4.49	13.56	37.11	9.07	32.62
33	CB	193	LO	13.32	16.07	17.22	2.75	3.90
		194	LO	7.51	14.95	25.28	7.44	17.77
		195	HH	4.00	14.07	42.16	10.07	38.16
		196	BC	14.65	37.00	62.51	22.35	47.86
		197	BC	15.58	33.68	63.00	18.10	47.42
		198	HH	4.60	19.06	67.10	14.47	62.50
34	CF	199	LO	5.46	12.37	22.07	6.91	16.61
		200	BC	15.00	28.53	54.90	13.53	39.90
		201	HH	2.89	20.95	57.49	18.06	54.60
		202	BC	11.73	27.22	49.97	15.50	38.25
		203	HH	3.65	24.58	63.28	20.94	59.64
		204	LO	5.03	12.75	22.70	7.72	17.67
35	GF	205	LO	8.76	11.77	22.43	3.01	13.67
		206	BC	11.37	29.64	56.94	18.27	45.57
		207	HH	4.57	21.57	51.60	17.00	47.03
		208	LO	10.72	15.84	26.33	5.12	15.62
		209	HH	5.87	19.53	58.00	13.67	52.13
		210	BC	10.54	23.78	51.60	13.24	41.06

Table b.1. (continued).

36	MB	211	LO	9.31	16.32	22.57	7.01	13.27
		212	BC	9.83	35.23	59.24	25.41	49.41
		213	LO	10.78	14.47	22.45	3.70	11.67
		214	BC	13.89	34.43	53.34	20.54	39.45
		215	HH	5.35	22.76	67.48	17.41	62.13
		216	HH	4.46	21.28	51.93	16.82	47.48
37	GF	217	HH	3.94	22.89	66.17	18.95	62.23
		218	BC	16.12	31.22	58.69	15.11	42.58
		219	LO	6.58	13.26	20.51	6.68	13.93
		220	LO	9.32	12.92	22.02	3.60	12.70
		221	HH	5.53	23.67	54.50	18.15	48.98
		222	BC	7.07	22.61	49.57	15.54	42.50
38	MGF	223	HH	5.52	21.98	64.43	16.46	58.92
		224	LO	4.94	13.36	23.83	8.42	18.89
		225	LO	9.14	15.15	21.17	6.01	12.03
		226	BC	12.14	30.34	49.71	18.20	37.57
		227	BC	14.02	26.18	52.75	12.16	38.73
		228	HH	4.15	21.09	48.23	16.94	44.08
39	MB	229	LO	7.01	17.31	28.95	10.30	21.94
		230	HH	4.80	20.01	51.41	15.22	46.61
		231	BC	13.05	28.09	54.27	15.04	41.22
		232	HH	4.25	16.27	40.25	12.03	36.01
		233	LO	7.01	12.67	21.87	5.67	14.87
		234	BC	16.17	37.44	65.98	21.27	49.81

Table b.1. (continued).

40	GB	235	LO	10.33	14.83	26.25	4.50	15.92
		236	LO	9.58	12.88	21.91	3.31	12.33
		237	HH	3.92	17.67	43.29	13.75	39.37
		238	BC	11.78	26.97	39.86	15.20	28.09
		239	HH	5.85	19.25	50.27	13.40	44.42
		240	BC	18.38	32.32	61.20	13.94	42.82
41	MF	241	LO	8.16	13.58	22.01	5.42	13.85
		242	BC	13.36	27.52	51.27	14.16	37.91
		243	HH	4.13	18.12	47.33	14.00	43.21
		244	LO	9.29	15.19	20.72	5.90	11.43
		245	BC	13.48	29.41	47.28	15.93	33.80
		246	HH	3.37	21.26	46.51	17.90	43.14
42	GB	247	LO	9.97	15.25	21.88	5.29	11.91
		248	HH	4.73	18.72	53.38	13.99	48.66
		249	LO	6.76	20.07	21.14	13.31	14.38
		250	BC	6.60	22.01	48.15	15.41	41.55
		251	HH	6.96	18.41	45.47	11.45	38.51
		252	BC	9.42	28.54	54.30	19.13	44.88
43	MGF	253	BC	8.09	25.03	51.00	16.95	42.92
		254*	HH	3.21	--	--	--	--
		255	HH	5.69	26.80	71.80	21.11	66.11
		256	LO	9.41	17.30	24.16	7.89	14.75
		257	BC	14.50	19.14	30.75	4.64	16.25
		258	LO	7.23	12.28	19.31	5.06	12.08

Table b.1. (continued).

44	MB	259	BC	11.54	29.30	53.03	17.76	41.49
		260	BC	9.85	31.30	52.19	21.45	42.34
		261	LO	10.51	14.66	23.97	4.15	13.46
		262	HH	4.17	17.67	40.65	13.50	36.48
		263	LO	6.99	11.56	15.76	4.57	8.77
		264	HH	5.45	14.72	43.74	9.27	38.30
45	MB	265	HH	5.75	17.10	44.30	11.35	38.55
		266	LO	10.71	17.76	25.69	7.05	14.98
		267	BC	16.53	32.55	55.84	16.02	39.32
		268	LO	11.83	20.57	29.10	8.74	17.27
		269	HH	5.38	19.78	42.74	14.41	37.36
		270	BC	17.67	36.39	58.62	18.72	40.96
46	CF	271	LO	8.82	15.38	21.14	6.56	12.32
		272	HH	5.31	18.15	47.84	12.84	42.54
		273	BC	11.18	28.60	52.55	17.42	41.37
		274	HH	4.20	20.53	52.74	16.34	48.55
		275	LO	14.46	18.63	26.54	4.17	12.08
		276	BC	13.06	22.67	42.42	9.61	29.36
47	MF	277	BC	7.61	18.19	41.35	10.58	33.74
		278	HH	4.55	19.43	52.96	14.89	48.41
		279	BC	12.19	21.70	43.66	9.51	31.47
		280	LO	5.26	17.12	7.97	11.86	2.72
		281	HH	3.32	19.37	44.45	16.05	41.13
		282	LO	9.31	15.69	31.69	6.38	22.38

Table b.1. (continued).

48	CB	283	BC	12.24	32.96	53.47	20.72	41.23
		284	LO	10.06	17.53	60.42	7.47	50.36
		285	LO	7.27	16.13	25.81	8.86	18.54
		286	BC	8.91	29.77	50.75	20.87	41.85
		287	HH	6.15	21.93	55.78	15.78	49.63
		288	HH	5.65	25.60	56.98	19.95	51.34

Table b.2. Measured heights of live oak, hybrid bald cypress, and yellow hibiscus by soil treatments during the initial measurement (3/15/16), second measurement (7/19/16), and final measurement (1/28/17) along with the growth between the initial and second measurements and the initial and final measurements. * -Trees which had to be replaced during the course of the study

Bed Number	Treatment	ID Number	Species	Height (cm) 3/15/2016	7/19/2016	1/28/2017	Growth 1 (cm)	Growth 2 (cm)
1	MF	1	LO	64.0	65.0	105.0	1.0	41.0
		2	BC	106.0	146.0	205.0	40.0	99.0
		3	HH	11.0	41.0	115.0	30.0	104.0
		4	HH	13.0	52.0	117.0	39.0	104.0
		5	LO	36.0	67.0	128.0	31.0	92.0
		6	BC	63.0	145.0	227.0	82.0	164.0
2	GF	7*	HH	11.0	57.0	110.0	46.0	99.0
		8	LO	101.0	109.0	132.0	8.0	31.0
		9	LO	115.0	143.0	172.0	28.0	57.0
		10	BC	86.0	84.0	195.0	-2.0	109.0
		11	HH	16.0	53.0	125.0	37.0	109.0
		12	BC	83.0	72.0	160.0	-11.0	77.0
3	CB	13	BC	25.5	94.0	185.0	68.5	159.5
		14	HH	15.0	42.0	87.0	27.0	72.0
		15	HH	14.0	52.0	127.0	38.0	113.0
		16	LO	94.5	67.0	66.0	-27.5	-28.5
		17	BC	63.0	117.0	180.0	54.0	117.0
		18	LO	85.0	114.0	144.0	29.0	59.0

Table b.2. (continued).

4	GB	19	HH	14.0	57.0	103.0	43.0	89.0
		20	HH	14.0	66.0	124.0	52.0	110.0
		21	BC	80.0	130.0	180.0	50.0	100.0
		22	LO	62.0	78.0	98.0	16.0	36.0
		23	BC	109.0	136.0	210.0	27.0	101.0
		24	LO	82.0	100.0	105.0	18.0	23.0
5	MGF	25*	HH	8.0	67.0	105.0	59.0	97.0
		26	HH	12.0	65.0	140.0	53.0	128.0
		27	BC	69.5	102.0	192.0	32.5	122.5
		28	BC	63.0	110.0	203.0	47.0	140.0
		29	LO	100.0	132.0	193.0	32.0	93.0
		30	LO	97.5	150.0	141.0	52.5	43.5
6	CF	31	HH	12.5	50.0	88.0	37.5	75.5
		32	BC	87.0	146.0	219.0	59.0	132.0
		33	HH	13.5	45.0	82.0	31.5	68.5
		34	BC	53.0	104.0	161.0	51.0	108.0
		35	LO	95.0	116.0	148.0	21.0	53.0
		36	LO	89.5	100.0	149.0	10.5	59.5
7	MB	37	LO	112.0	87.0	106.0	-25.0	-6.0
		38	HH	18.0	87.0	148.0	69.0	130.0
		39	HH	15.0	59.0	94.0	44.0	79.0
		40	BC	65.0	118.0	142.0	53.0	77.0
		41	BC	67.0	122.0	198.0	55.0	131.0
		42	LO	36.0	80.0	90.0	44.0	54.0

Table b.2. (continued)

8	MF	43	HH	12.0	55.0	130.0	43.0	118.0
		44	BC	87.0	144.0	181.0	57.0	94.0
		45	HH	13.0	52.0	100.0	39.0	87.0
		46	BC	87.0	144.0	170.0	57.0	83.0
		47	LO	7.0	41.0	66.0	34.0	59.0
		48	LO	51.0	88.0	120.0	37.0	69.0
9	MGB	49	LO	49.0	85.0	128.0	36.0	79.0
		50	HH	13.0	50.0	117.0	37.0	104.0
		51	BC	78.0	117.0	200.0	39.0	122.0
		52	HH	12.0	40.0	82.0	28.0	70.0
		53	LO	64.0	78.0	101.0	14.0	37.0
		54	BC	110.0	150.0	232.0	40.0	122.0
10	GB	55	HH	17.0	67.0	131.0	50.0	114.0
		56	HH	16.5	68.0	110.0	51.5	93.5
		57	BC	101.0	132.0	226.0	31.0	125.0
		58	LO	93.0	93.0	103.0	0.0	10.0
		59	LO	98.0	100.0	154.0	2.0	56.0
		60	BC	94.0	154.0	196.0	60.0	102.0
11	MGF	61	HH	10.0	63.0	110.0	53.0	100.0
		62	BC	98.0	141.0	202.0	43.0	104.0
		63	LO	85.0	86.0	114.0	1.0	29.0
		64	BC	108.0	135.0	176.0	27.0	68.0
		65	LO	105.0	137.0	153.0	32.0	48.0
		66	HH	14.0	75.0	150.0	61.0	136.0

Table b.2. (continued).

12	MF	67	HH	8.0	63.0	130.0	55.0	122.0
		68	LO	50.5	50.0	109.0	-0.5	58.5
		69	BC	90.0	131.0	226.0	41.0	136.0
		70	LO	56.0	78.0	97.0	22.0	41.0
		71	BC	84.0	119.0	180.0	35.0	96.0
		72	HH	12.0	56.0	118.0	44.0	106.0
13	MF	73	HH	11.0	52.0	114.0	41.0	103.0
		74	LO	56.0	64.0	112.0	8.0	56.0
		75	BC	108.0	131.0	148.0	23.0	40.0
		76	LO	53.0	91.0	186.0	38.0	133.0
		77	HH	13.0	56.0	115.0	43.0	102.0
		78	BC	60.0	118.0	167.0	58.0	107.0
14	CB	79	LO	71.0	129.0	178.0	58.0	107.0
		80	LO	67.0	95.0	170.0	28.0	103.0
		81	BC	73.5	114.0	178.0	40.5	104.5
		82	BC	113.5	154.0	190.0	40.5	76.5
		83	HH	14.0	63.0	120.0	49.0	106.0
		84	HH	10.0	72.0	124.0	62.0	114.0
15	MGB	85	LO	85.5	112.0	128.0	26.5	42.5
		86	HH	8.5	50.0	125.0	41.5	116.5
		87	HH	9.0	50.0	118.0	41.0	109.0
		88	LO	102.0	109.0	140.0	7.0	38.0
		89	BC	116.0	169.0	244.0	53.0	128.0
		90	BC	92.0	139.0	208.0	47.0	116.0

Table b.2. (continued).

16	CF	91	LO	46.5	48.0	85.0	1.5	38.5
		92	LO	53.0	60.0	79.0	7.0	26.0
		93	HH	11.0	55.0	128.0	44.0	117.0
		94	BC	105.0	147.0	210.0	42.0	105.0
		95	BC	130.0	125.0	190.0	-5.0	60.0
		96	HH	12.0	70.0	116.0	58.0	104.0
17	CB	97	HH	11.0	70.0	100.0	59.0	89.0
		98	LO	70.0	80.0	114.0	10.0	44.0
		99	LO	56.0	72.0	96.0	16.0	40.0
		100	BC	65.0	113.0	178.0	48.0	113.0
		101	HH	13.5	65.0	78.0	51.5	64.5
		102	BC	85.0	125.0	156.0	40.0	71.0
18	CF	103	LO	61.5	95.0	158.0	33.5	96.5
		104	LO	95.0	89.0	102.0	-6.0	7.0
		105	BC	63.5	105.0	210.0	41.5	146.5
		106	BC	50.5	102.0	166.0	51.5	115.5
		107	HH	11.5	60.0	126.0	48.5	114.5
		108	HH	12.0	68.0	110.0	56.0	98.0
19	GF	109	HH	12.5	65.0	140.0	52.5	127.5
		110	LO	59.0	80.0	76.0	21.0	17.0
		111	LO	68.5	85.0	102.0	16.5	33.5
		112	BC	57.0	98.0	191.0	41.0	134.0
		113	BC	106.0	130.0	195.0	24.0	89.0
		114	HH	11.0	57.0	140.0	46.0	129.0

Table b.2. (continued).

20	MGB	115	LO	63.0	100.0	155.0	37.0	92.0
		116	BC	99.0	146.0	204.0	47.0	105.0
		117	HH	13.0	67.0	126.0	54.0	113.0
		118	HH	12.5	55.0	100.0	42.5	87.5
		119	BC	66.5	113.0	169.0	46.5	102.5
		120	LO	53.5	75.0	99.0	21.5	45.5
21	GB	121	LO	59.0	70.0	132.0	11.0	73.0
		122	BC	90.0	115.0	196.0	25.0	106.0
		123	LO	80.0	125.0	153.0	45.0	73.0
		124	HH	15.0	57.0	75.0	42.0	60.0
		125	HH	9.0	70.0	117.0	61.0	108.0
		126	BC	65.5	120.0	196.0	54.5	130.5
22	MGB	127	LO	55.0	70.0	137.0	15.0	82.0
		128	LO	58.5	100.0	141.0	41.5	82.5
		129	HH	12.0	50.0	103.0	38.0	91.0
		130	BC	106.5	165.0	215.0	58.5	108.5
		131	HH	12.5	50.0	89.0	37.5	76.5
		132	BC	65.0	142.0	219.0	77.0	154.0
23	MGF	133	LO	55.5	62.0	157.0	6.5	101.5
		134*	BC	--	115.0	203.0	115.0	--
		135	HH	12.0	45.0	100.0	33.0	88.0
		136	BC	39.0	125.0	180.0	86.0	141.0
		137	HH	11.0	45.0	113.0	34.0	102.0
		138	LO	59.0	78.0	123.0	19.0	64.0

Table b.2. (continued).

24	GF	139	LO	91.5	116.0	164.0	24.5	72.5
		140	LO	50.0	72.0	145.0	22.0	95.0
		141	HH	12.5	70.0	155.0	57.5	142.5
		142	BC	97.0	136.0	205.0	39.0	108.0
		143	BC	75.5	102.0	170.0	26.5	94.5
		144	HH	14.5	57.0	100.0	42.5	85.5
25	MGB	145	LO	65.0	83.0	82.0	18.0	17.0
		146	BC	60.8	123.0	170.0	62.2	109.2
		147	HH	13.5	68.0	137.0	54.5	123.5
		148	HH	15.6	60.0	125.0	44.4	109.4
		149	LO	98.0	113.0	131.0	15.0	33.0
		150	BC	93.0	141.0	197.0	48.0	104.0
26	CF	151	BC	101.0	127.0	204.0	26.0	103.0
		152	BC	57.0	107.0	173.0	50.0	116.0
		153	LO	78.0	74.0	103.0	-4.0	25.0
		154	LO	99.6	100.0	85.0	0.4	-14.6
		155	HH	12.0	56.0	110.0	44.0	98.0
		156	HH	11.0	45.0	94.0	34.0	83.0
27	MB	157	LO	70.7	72.0	69.0	1.3	-1.7
		158	HH	6.5	65.0	136.0	58.5	129.5
		159	BC	100.0	141.0	180.0	41.0	80.0
		160	BC	102.2	155.0	176.0	52.8	73.8
		161	HH	12.0	56.0	116.0	44.0	104.0
		162	LO	59.9	85.0	102.0	25.1	42.1

Table b.2. (continued).

28	MGF	163	LO	97.5	105.0	115.0	7.5	17.5
		164	HH	9.6	60.0	112.0	50.4	102.4
		165	HH	7.0	65.0	105.0	58.0	98.0
		166	BC	81.0	99.0	125.0	18.0	44.0
		167	BC	57.7	102.0	190.0	44.3	132.3
		168	LO	108.0	112.0	121.0	4.0	13.0
29	MGB	169	LO	87.0	109.0	129.0	22.0	42.0
		170	LO	87.0	120.0	126.0	33.0	39.0
		171	BC	103.5	142.0	182.0	38.5	78.5
		172	HH	12.7	81.0	122.0	68.3	109.3
		173	HH	11.2	50.0	140.0	38.8	128.8
		174	BC	93.0	140.0	198.0	47.0	105.0
30	GB	175	LO	37.7	40.0	65.0	2.3	27.3
		176	BC	67.5	112.0	177.0	44.5	109.5
		177	LO	44.7	57.0	120.0	12.3	75.3
		178	HH	11.0	66.0	128.0	55.0	117.0
		179	HH	11.4	60.0	108.0	48.6	96.6
		180	BC	30.2	88.0	163.0	57.8	132.8
31	CB	181	LO	113.0	115.0	127.0	2.0	14.0
		182	HH	7.0	54.0	104.0	47.0	97.0
		183	BC	80.5	114.0	188.0	33.5	107.5
		184	LO	54.0	83.0	118.0	29.0	64.0
		185	BC	96.3	133.0	182.0	36.7	85.7
		186	HH	7.7	60.0	121.0	52.3	113.3

Table b.2. (continued).

32	GF	187	LO	94.1	117.0	156.0	22.9	61.9
		188	BC	102.5	152.0	217.0	49.5	114.5
		189	HH	14.0	100.0	116.0	86.0	102.0
		190	LO	147.2	130.0	139.0	-17.2	-8.2
		191	BC	86.0	119.0	210.0	33.0	124.0
		192	HH	9.0	45.0	90.0	36.0	81.0
33	CB	193	LO	67.0	84.0	83.0	17.0	16.0
		194	LO	81.5	116.0	153.0	34.5	71.5
		195	HH	11.0	45.0	114.0	34.0	103.0
		196	BC	86.5	133.0	206.0	46.5	119.5
		197	BC	88.0	126.0	204.0	38.0	116.0
		198	HH	10.0	70.0	132.0	60.0	122.0
34	CF	199	LO	32.0	68.0	125.0	36.0	93.0
		200	BC	89.3	139.0	225.0	49.7	135.7
		201	HH	10.5	77.0	113.0	66.5	102.5
		202	BC	49.4	118.0	154.0	68.6	104.6
		203	HH	12.5	74.0	155.0	61.5	142.5
		204	LO	42.0	53.0	121.0	11.0	79.0
35	GF	205	LO	128.5	107.0	134.0	-21.5	5.5
		206	BC	58.5	117.0	191.0	58.5	132.5
		207	HH	11.5	70.0	129.0	58.5	117.5
		208	LO	116.0	128.0	170.0	12.0	54.0
		209	HH	12.1	47.0	126.0	34.9	113.9
		210	BC	90.0	116.0	181.0	26.0	91.0

Table b.2. (continued).

36	MB	211	LO	75.0	89.0	147.0	14.0	72.0
		212	BC	72.0	145.0	231.0	73.0	159.0
		213	LO	78.5	98.0	115.0	19.5	36.5
		214	BC	90.0	128.0	182.0	38.0	92.0
		215	HH	12.0	51.0	125.0	39.0	113.0
		216	HH	11.5	70.0	114.0	58.5	102.5
37	GF	217	HH	11.6	78.0	123.0	66.4	111.4
		218	BC	108.0	139.0	200.0	31.0	92.0
		219	LO	41.7	66.0	96.0	24.3	54.3
		220	LO	53.0	80.0	120.0	27.0	67.0
		221	HH	13.3	55.0	135.0	41.7	121.7
		222	BC	67.0	112.0	198.0	45.0	131.0
38	MGF	223	HH	12.5	70.0	122.0	57.5	109.5
		224	LO	46.0	84.0	109.0	38.0	63.0
		225	LO	83.6	104.0	136.0	20.4	52.4
		226	BC	88.5	122.0	147.0	33.5	58.5
		227	BC	92.0	130.0	156.0	38.0	64.0
		228	HH	14.5	73.0	120.0	58.5	105.5
39	MB	229	LO	57.3	67.0	106.0	9.7	48.7
		230	HH	15.0	64.0	120.0	49.0	105.0
		231	BC	76.2	130.0	188.0	53.8	111.8
		232	HH	15.3	54.0	67.0	38.7	51.7
		233	LO	46.2	72.0	95.0	25.8	48.8
		234	BC	93.5	142.0	216.0	48.5	122.5

Table b.2. (continued).

40	GB	235	LO	62.0	111.0	107.0	49.0	45.0
		236	LO	73.7	90.0	150.0	16.3	76.3
		237	HH	16.0	66.0	80.0	50.0	64.0
		238	BC	38.0	88.0	145.0	50.0	107.0
		239	HH	10.0	55.0	80.0	45.0	70.0
		240	BC	98.0	137.0	174.0	39.0	76.0
41	MF	241	LO	50.1	60.0	63.0	9.9	12.9
		242	BC	90.0	126.0	193.0	36.0	103.0
		243	HH	12.1	56.0	107.0	43.9	94.9
		244	LO	35.0	66.0	97.0	31.0	62.0
		245	BC	71.7	109.0	183.0	37.3	111.3
		246	HH	9.0	65.0	80.0	56.0	71.0
42	GB	247	LO	53.0	80.0	83.0	27.0	30.0
		248	HH	14.0	65.0	97.0	51.0	83.0
		249	LO	76.0	69.0	113.0	-7.0	37.0
		250	BC	48.0	117.0	160.0	69.0	112.0
		251	HH	15.2	47.0	68.0	31.8	52.8
		252	BC	51.0	108.0	167.0	57.0	116.0
43	MGF	253	BC	56.0	116.0	187.0	60.0	131.0
		254*	HH	--	--	--	--	--
		255	HH	14.0	78.0	112.0	64.0	98.0
		256	LO	40.0	103.0	130.0	63.0	90.0
		257	BC	65.0	129.0	160.0	64.0	95.0
		258	LO	63.0	70.0	108.0	7.0	45.0

Table b.2. (continued).

44	MB	259	BC	77.7	150.0	214.0	72.3	136.3
		260	BC	80.5	119.0	208.0	38.5	127.5
		261	LO	70.0	74.0	80.0	4.0	10.0
		262	HH	10.0	50.0	90.0	40.0	80.0
		263	LO	80.5	60.0	83.0	-20.5	2.5
		264	HH	12.5	50.0	90.0	37.5	77.5
45	MB	265	HH	5.0	67.0	88.0	62.0	83.0
		266	LO	110.5	112.0	143.0	1.5	32.5
		267	BC	89.2	150.0	183.0	60.8	93.8
		268	LO	86.3	110.0	148.0	23.7	61.7
		269	HH	14.0	56.0	72.0	42.0	58.0
		270	BC	94.6	146.0	200.0	51.4	105.4
46	CF	271	LO	68.0	90.0	123.0	22.0	55.0
		272	HH	13.0	52.0	85.0	39.0	72.0
		273	BC	82.0	114.0	140.0	32.0	58.0
		274	HH	9.0	56.0	113.0	47.0	104.0
		275	LO	69.5	100.0	129.0	30.5	59.5
		276	BC	81.4	117.0	188.0	35.6	106.6
47	MF	277	BC	57.0	64.0	143.0	7.0	86.0
		278	HH	11.4	50.0	127.0	38.6	115.6
		279	BC	66.7	129.0	210.0	62.3	143.3
		280	LO	62.5	58.0	68.0	-4.5	5.5
		281	HH	13.7	50.0	96.0	36.3	82.3
		282	LO	57.0	120.0	160.0	63.0	103.0

Table b.2. (continued).

48	CB	283	BC	90.5	157.0	205.0	66.5	114.5
		284	LO	54.0	96.0	156.0	42.0	102.0
		285	LO	70.5	73.0	90.0	2.5	19.5
		286	BC	51.0	93.0	199.0	42.0	148.0
		287	HH	15.0	78.0	131.0	63.0	116.0
		288	HH	11.0	70.0	127.0	59.0	116.0

Table b.3. Measured crown diameters of yellow hibiscus by soil treatments during the second measurement (7/19/16) and final measurement (1/28/17) along with the growth between the second and final measurements. * -Trees which had to be replaced during the course of the study

Bed Number	Treatment	ID Number	Crown Diameter 1 (cm)	Crown Diameter 2 (cm)	Crown Diameter Growth (cm)
1	MF	3	126	119	-7
		4	120	115	-5
2	GF	7*	120	120	0
		11	139	140	1
3	CB	14	91	64	-27
		15	110	112	2
4	GB	19	143	123	-20
		20	142	143	1
5	MGF	25*	141	153	12
		26	136	100	-36
6	CF	31	114	100	-14
		33	130	116	-14
7	MB	38	170	150	-20
		39	110	124	14
8	MF	43	110	120	10
		45	123	102	-21
9	MGB	50	167	135	-32
		52	68	66	-2
10	GB	55	170	101	-69
		56	110	102	-8
11	MGF	61	155	150	-5
		66	150	180	30
12	MF	67	134	109	-25
		72	120	130	10
13	MF	73	100	182	82
		77	140	107	-33
14	CB	83	124	139	15
		84	100	166	66
15	MGB	86	113	114	1
		87	150	163	13
16	CF	93	140	125	-15
		96	70	127	57

Table b.3. (continued).

17	CB	97	123	136	13
		101	103	110	7
18	CF	107	110	166	56
		108	100	50	-50
19	GF	109	100	72	-28
		114	100	140	40
20	MGB	117	124	172	48
		118	75	60	-15
21	GB	124	124	128	4
		125	114	107	-7
22	MGB	129	110	113	3
		131	140	136	-4
23	MGF	135	115	86	-29
		137	97	106	9
24	GF	141	149	140	-9
		144	92	87	-5
25	MGB	147	114	120	6
		148	159	120	-39
26	CF	155	162	135	-27
		156	90	125	35
27	MB	158	115	111	-4
		161	139	128	-11
28	MGF	164	156	109	-47
		165	126	82	-44
29	MGB	172	148	157	9
		173	130	90	-40
30	GB	178	151	167	16
		179	97	103	6
31	CB	182	106	153	47
		186	134	152	18
32	GF	189	151	132	-19
		192	84	84	0
33	CB	195	110	134	24
		198	65	90	25
34	CF	201	96	146	50
		203	142	147	5
35	GF	207	174	124	-50
		209	120	95	-25

Table b.3. (continued).

36	MB	215	156	120	-36
		216	96	85	-11
37	GF	217	114	117	3
		221	110	125	15
38	MGF	223	100	129	29
		228	130	132	2
39	MB	230	102	140	38
		232	97	114	17
40	GB	237	90	105	15
		239	64	55	-9
41	MF	243	138	150	12
		246	69	125	56
42	GB	248	155	107	-48
		252	90	97	7
43	MGF	254*	--	--	--
		255	169	180	11
44	MB	262	36	113	77
		264	95	75	-20
45	MB	265	102	123	21
		269	98	129	31
46	CF	272	73	123	50
		274	106	125	19
47	MF	278	122	157	35
		281	69	97	28
48	CB	287	130	114	-16
		288	99	155	56

APPENDIX C: MEASURED AERIAL DEPOSITION PARAMETERS

Table c.1. Cl^-, NO_3^-, PO_4^{3-}, SO_4^{2-}, P, Na^+, Mg^{2+}, Ca^{2+}, K^+ deposition from wet and dry fall samples collected at Moody Gardens on Galveston Island during 14 day sample collection periods from May 2016 to May 2017. The 6/3/16 – 6/17/16 sampling does not include a dry fall deposition due to a missing collection pail which was taken from the precipitation collector by persons unknown.

Dates	Sample Type	Days Sampled	Volume (L)	Cl^-		NO_3^-		PO_4^{3-}			SO_4^{2-}		P		Na^+			Mg^{2+}		Ca^{2+}		K^+	
				(mg/L)	(mg/m^2)	(mg/L)	(mg/m^2)	(mg/L)	(mg)	(mg/m^2)	(mg/L)	(mg/m^2)	(mg/L)	(mg/m^2)	(mg/L)	(mg)	(mg/m^2)	(mg/L)	(mg/m^2)	(mg/L)	(mg/m^2)	(mg/L)	(mg/m^2)
5/18/16 - 6/3/16	Wet	17	7.0	2.2	397.8	1.5	273.0	-	-	-	0.8	150.3	0.1	18.7	1.4	9.9	259.8	0.2	34.2	0.5	96.1	0.9	169.3
	Dry	17	0.5	5.0	64.5	0.7	9.0	-	-	-	0.9	12.1	0.1	1.1	3.4	1.7	44.4	0.5	6.4	1.3	17.4	0.5	6.4
6/3/16 - 6/17/16	Wet	15	2.5	1.6	103.1	0.9	56.3	0.9	2.3	61.3	0.5	32.0	0.3	16.7	0.5	1.2	31.0	0.1	5.8	0.2	15.0	0.6	39.0
	Dry	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
6/17/16 - 7/1/16	Wet	15	1.4	2.1	75.8	1.3	47.9	0.2	0.3	8.6	1.1	40.2	0.2	5.5	1.5	2.1	54.6	0.2	8.2	0.7	25.6	0.4	15.1
	Dry	15	0.5	2.4	34.8	1.4	19.8	0.5	0.3	7.4	0.6	9.2	0.4	5.5	1.9	1.1	27.9	0.3	4.2	1.2	17.8	1.9	26.8
7/1/16 - 7/15/16	Wet	15	0.4	2.3	27.3	0.6	7.2	-	-	-	0.3	3.5	0.2	2.2	0.9	0.4	10.6	0.1	1.5	0.2	2.1	0.0	0.4
	Dry	15	0.4	14.1	163.9	0.9	10.1	0.2	0.1	2.1	2.2	25.9	0.4	4.5	8.2	3.6	95.8	1.3	14.6	2.6	30.4	2.2	26.1
7/15/16 - 7/29/16	Wet	15	3.7	1.2	113.6	1.2	110.6	-	-	-	0.5	45.1	0.1	6.7	1.1	3.9	101.6	0.1	12.6	0.6	55.7	-	-
	Dry	15	0.5	2.5	32.4	1.2	15.6	0.7	0.4	9.3	0.8	10.4	1.7	21.3	4.0	1.9	51.3	0.3	4.3	1.1	13.8	1.8	23.0
7/29/16 - 8/12/16	Wet	15	0.3	1.0	9.2	0.6	5.5	0.2	0.1	2.1	0.2	1.9	0.1	1.2	-	-	-	0.0	0.4	4.5	41.4	1.3	11.6
	Dry	15	0.4	4.9	51.6	0.1	1.0	0.2	0.1	1.9	1.4	14.6	0.1	1.3	2.7	1.1	28.4	0.6	6.5	15.3	160.4	2.0	20.6
8/12/16 - 8/26/16	Wet	15	5.4	2.3	326.0	0.6	81.1	-	-	-	0.6	78.3	0.0	2.6	1.0	5.4	143.0	0.1	14.2	0.1	7.5	0.5	70.8
	Dry	15	0.5	-	-	1.2	14.7	0.3	0.2	4.3	2.9	36.3	0.1	1.0	7.4	3.5	92.3	1.3	15.9	2.8	35.3	0.7	8.7
8/26/16 - 9/9/16	Wet	15	2.3	4.8	288.0	1.1	65.9	2.7	6.1	160.5	0.8	50.1	0.4	26.7	2.5	5.7	151.0	0.2	14.0	0.2	11.1	3.1	187.8
	Dry	15	0.5	2.8	36.0	1.7	22.0	0.2	0.1	3.0	1.0	12.2	0.1	0.8	2.3	1.1	29.2	0.3	3.9	1.2	15.3	0.7	8.9
9/9/16 - 9/23/16	Wet	15	1.5	1.7	68.1	0.8	31.1	0.4	0.7	17.3	0.8	30.4	0.1	2.4	0.8	1.3	33.9	0.1	5.1	0.3	11.6	1.5	62.6
	Dry	15	0.5	2.3	28.3	2.1	25.4	0.4	0.2	4.9	1.1	13.5	0.1	1.5	2.0	0.9	23.7	0.3	4.1	2.1	25.9	1.4	17.6
9/23/16 - 10/7/16	Wet	15	0.3	4.9	37.9	6.7	51.8	1.9	0.6	14.6	3.1	23.7	0.5	3.6	2.6	0.8	19.8	0.5	3.9	2.1	16.4	0.6	4.6
	Dry	15	0.5	3.8	48.5	3.5	45.9	1.6	0.8	20.3	2.6	34.1	0.4	4.8	1.5	0.7	19.0	0.4	5.1	2.8	35.7	1.7	22.0
10/7/16 - 10/21/16	Wet	15	1.7	2.4	108.7	2.1	92.4	1.0	1.8	46.3	1.6	70.0	0.1	6.6	1.0	1.6	43.3	0.1	4.6	0.1	3.8	0.5	22.7
	Dry	15	0.5	4.6	58.3	2.5	32.1	1.1	0.5	13.2	3.2	40.3	0.2	2.0	2.6	1.2	32.4	0.4	5.0	1.3	16.6	0.7	9.0
10/21/16 - 11/4/16	Wet	15	0.5	1.9	24.7	0.7	9.3	-	-	-	0.3	4.0	0.6	7.4	0.3	0.2	4.1	0.1	1.4	0.2	3.0	0.7	8.9
	Dry	15	0.5	3.5	41.9	1.4	16.9	0.4	0.2	5.0	1.3	15.8	0.6	6.9	2.1	0.9	24.9	0.4	4.4	0.9	10.5	1.0	12.3

Table c.1. (continued).

11/4/16 - 11/18/16	Wet	15	0.3	5.4	46.5	2.2	18.4	-	-	-	2.3	19.4	0.6	4.9	3.3	1.1	28.6	0.5	4.4	1.9	16.2	1.5	12.8
	Dry	15	0.5	2.6	32.2	4.1	51.5	0.1	0.1	1.6	2.9	36.5	0.6	7.4	1.8	0.8	22.0	0.3	4.2	0.8	10.3	1.1	13.9
11/18/16 - 12/2/16	Wet	15	0.4	11.1	112.3	2.5	24.8	0.4	0.1	3.6	3.6	36.3	0.7	7.4	6.9	2.7	70.4	1.0	9.6	2.4	23.9	1.2	12.1
	Dry	15	0.5	10.3	135.2	1.4	18.1	0.3	0.1	3.8	2.6	34.5	0.6	8.1	6.8	3.4	89.7	1.0	13.2	1.7	21.9	2.3	30.4
12/2/16 - 12/16/16	Wet	15	7.4	3.1	604.7	1.9	367.4	-	-	-	2.0	385.8	0.1	19.6	1.3	9.8	257.6	0.1	22.5	0.1	13.6	0.4	73.9
	Dry	15	0.4	13.5	145.8	15.4	166.3	1.6	0.6	16.8	4.6	49.6	0.4	4.4	8.7	3.5	93.4	1.2	12.8	3.3	35.6	2.1	23.1
12/16/16 - 12/30/16	Wet	15	0.5	7.7	92.1	3.1	37.2	-	-	-	3.4	40.7	0.2	1.8	4.4	2.0	52.9	0.6	6.8	1.1	12.8	1.1	13.1
	Dry	15	0.5	5.2	63.4	2.9	34.9	-	-	-	2.5	30.2	0.1	1.4	2.8	1.3	34.4	0.4	4.5	1.1	14.0	0.5	5.5
12/30/16 - 1/13/17	Wet	15	1.5	3.6	142.7	2.0	82.2	-	-	-	2.1	82.4	0.1	4.4	1.7	2.6	67.9	0.2	7.1	0.3	10.6	0.3	11.6
	Dry	15	0.5	7.5	89.8	2.4	28.1	-	-	-	2.5	30.1	0.1	1.3	4.3	1.9	50.9	0.5	5.8	0.8	9.0	0.4	4.4
1/13/17 - 1/27/17	Wet	15	0.2	11.7	46.1	11.3	44.5	1.6	0.2	6.3	8.5	33.5	0.4	1.6	7.3	1.1	28.7	1.2	4.8	15.1	59.6	1.1	4.2
	Dry	15	0.5	6.7	80.5	3.2	38.4	-	-	-	3.0	35.5	0.1	1.7	4.1	1.9	48.7	0.6	6.8	1.9	22.2	0.7	7.9
1/27/17 - 2/10/17	Wet	15	0.1	1.5	5.3	1.8	6.4	-	-	-	1.4	5.0	0.1	0.3	0.3	0.0	0.9	0.0	0.1	0.0	0.1	0.3	1.0
	Dry	15	0.5	9.1	114.3	3.5	43.4	1.9	0.9	24.2	3.8	47.1	0.5	6.7	5.0	2.4	62.0	0.5	6.8	1.2	14.6	2.3	28.6
2/10/17 - 2/24/17	Wet	15	3.6	2.7	256.4	1.9	175.0	-	-	-	1.7	161.1	0.1	11.4	1.1	4.0	106.5	0.1	7.7	0.1	9.9	0.2	21.2
	Dry	15	0.5	7.3	104.3	3.7	53.4	-	-	-	2.9	42.2	0.1	2.0	4.1	2.3	59.4	0.5	7.8	1.7	23.7	0.6	8.4
2/24/17 - 3/10/17	Wet	15	0.5	12.0	150.2	2.3	28.5	-	-	-	2.9	36.2	0.1	1.6	6.9	3.3	86.7	0.8	9.7	1.6	19.4	0.5	6.7
	Dry	15	0.5	20.8	247.6	3.4	40.6	-	-	-	4.7	55.5	0.2	2.0	12.0	5.4	143.1	1.4	16.7	2.8	32.9	1.4	16.3
3/10/17 - 3/24/17	Wet	15	0.5	8.0	107.2	3.1	41.0	2.7	1.4	36.4	3.2	42.1	0.9	11.4	5.6	2.8	74.3	0.6	8.1	2.1	27.7	1.8	24.0
	Dry	15	0.5	9.8	119.8	3.3	40.2	1.1	0.5	12.9	8.9	108.9	0.1	1.8	5.9	2.7	72.1	0.8	9.2	1.5	18.8	0.7	8.1
3/24/17 - 4/7/17	Wet	15	0.5	9.0	106.5	2.3	27.2	-	-	-	2.7	31.6	0.2	1.8	8.3	3.8	98.9	1.1	12.5	2.5	29.7	0.8	9.8
	Dry	15	0.4	15.1	169.8	3.4	37.9	-	-	-	3.9	43.9	0.4	4.4	5.9	2.5	66.2	0.8	8.8	3.3	36.9	1.7	19.1
4/7/17 - 4/21/17	Wet	15	0.5	8.9	117.3	21.9	288.4	1.6	0.8	21.7	3.7	48.4	0.2	2.0	6.6	3.3	86.6	0.9	12.0	2.7	35.8	0.7	8.8
	Dry	15	0.4	12.5	125.1	3.2	32.0	-	-	-	3.2	31.7	0.1	1.1	4.9	1.9	49.4	0.7	6.6	1.5	15.4	0.5	4.9
4/21/17 - 5/5/17	Wet	15	0.4	8.7	84.4	3.9	38.2	-	-	-	4.2	40.9	0.6	5.5	13.9	5.1	135.2	3.1	30.6	3.3	31.8	3.2	30.9
	Dry	15	0.4	22.2	204.8	3.0	27.6	2.0	0.7	18.3	13.6	125.2	0.6	5.3	14.1	4.9	129.5	3.2	29.2	3.2	29.3	3.2	29.3
5/5/17 - 5/19/17	Wet	15	0.4	3.8	40.2	2.1	22.5	1.2	0.5	12.4	1.9	20.2	0.1	1.1	6.5	2.6	68.3	0.1	1.3	0.7	7.2	0.4	3.8
	Dry	15	0.4	10.7	101.9	1.6	14.9	-	-	-	2.7	26.2	0.2	1.5	5.8	2.1	55.0	0.8	7.7	2.9	27.6	1.4	13.3

APPENDIX D: SOIL STATISTICAL ANALYSES RESULTS

Table d.1. Statistical results of ANOVA test run on measured soluble soil Na^+ concentrations from soil samples collected before treatment application (3/21/16) and seven months after application (10/27/16).

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	7	118.8940	16.9849	8.3500	<0.0001
Block	5	18.3346	3.6669	1.8000	0.1379

Table d.2. Statistical results of ANOVA test run on measured exchangeable soil Na^+ concentrations from soil samples collected before treatment application (3/21/16) and seven months after application (10/27/16).

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	7	26001.4196	3714.4885	0.4200	0.8824
Block	5	18027.4525	3605.4905	0.4100	0.8393

Table d.3. Statistical results of ANOVA test run on measured soluble soil Ca^{2+} concentrations from soil samples collected before treatment application (3/21/16) and seven months after application (10/27/16).

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	7	61.2471	8.7496	15.4600	<0.0001
Block	5	2.5578	0.5116	0.9000	0.4896

Table d.4. Statistical results of ANOVA test run on measured exchangeable soil Ca^{2+} concentrations from soil samples collected before treatment application (3/21/16) and seven months after application (10/27/16).

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	7	13226663.4000	1889523.3400	0.7100	0.6631
Block	5	35827562.6600	7165512.5300	2.7000	0.0366

Table d.5. Statistical results of ANOVA test run on measured soluble soil Mg^{2+} concentrations from soil samples collected before treatment application (3/21/16) and seven months after application (10/27/16).

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	7	41.6792	5.9542	21.9000	<0.0001
Block	5	2.1966	0.4393	1.6200	0.1815

Table d.6. Statistical results of ANOVA test run on measured exchangeable soil Mg^{2+} concentrations from soil samples collected before treatment application (3/21/16) and seven months after application (10/27/16).

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	7	148911.1575	21273.0225	1.4500	0.2191
Block	5	133064.2273	26612.8455	1.8100	0.1369

Table d.7. Statistical results of ANOVA test run on measured SAR values from soil samples collected before treatment application (3/21/16) and seven months after application (10/27/16).

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	7	17.1567	2.4510	1.5800	0.1732
Block	5	5.6458	1.1292	0.7300	0.6065

Table d.8. Statistical results of ANOVA test run on measured EC values from soil samples collected before treatment application (3/21/16) and seven months after application (10/27/16).

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	7	2627666.9170	375380.9880	0.8600	0.5494
Block	5	898963.0000	179792.7500	0.4100	0.8383

Table d.9. Statistical results of ANOVA test run on measured soil pH values from soil samples collected before treatment application (3/21/16) and seven months after application (10/27/16).

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	7	0.2307	0.0330	1.0900	0.3878
Block	5	0.3476	0.0695	2.3100	0.0650

Table d.10. Statistical results of ANOVA test run on measured soil K^+ concentrations from soil samples collected before treatment application (3/21/16).

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	7	87338.5887	12476.9412	1.5400	0.1856
Block	5	38947.6177	7789.5236	0.9600	0.4537

Table d.11. Statistical results of ANOVA test run on measured soil CN Ratio values from soil samples collected before treatment application (3/21/16).

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	7	6.5203	0.9315	0.4900	0.8330
Block	5	8.5131	1.7026	0.9000	0.4911

Table d.12. Statistical results of ANOVA test run on measured soil total organic C concentrations from soil samples collected before treatment application (3/21/16).

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	7	292028090.0000	41718298.6000	0.8900	0.5229
Block	5	114976964.0000	22995392.8000	0.4900	0.7800

Table d.13. Statistical results of ANOVA test run on measured soil total N concentrations from soil samples collected before treatment application (3/21/16).

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	7	2686774.8550	383824.9790	1.0400	0.4223
Block	5	565654.3790	113130.8760	0.3100	0.9058

Table d.14. Statistical results of ANOVA test run on measured soil P concentrations from soil samples collected before treatment application (3/21/16).

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	7	54.7961	7.8280	1.7200	0.1359
Block	5	76.1362	15.2272	3.3500	0.0141

Table d.15. Statistical results of ANOVA test run on measured soil S^{2-} concentrations from soil samples collected before treatment application (3/21/16).

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	7	269.6902	38.5272	0.4000	0.8929
Block	5	717.2466	143.4493	1.5100	0.2128

Table d.16. Statistical results of ANOVA test run on measured soil B^{3+} concentrations from soil samples collected before treatment application (3/21/16).

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	7	2.5648	0.3664	0.6200	0.7385
Block	5	5.4990	1.0998	1.8500	0.1284

Table d.17. Statistical results of ANOVA test run on measured soluble soil Na^+ concentrations from soil samples collected seven months after treatment application (10/27/16).

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	7	9.2187	1.3170	1.4000	0.2366
Block	5	13.7699	2.7540	2.9300	0.0261

Table d.18. Statistical results of ANOVA test run on measured exchangeable soil Na^+ concentrations from soil samples collected seven months after treatment application (10/27/16).

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	7	47294.7828	6756.3975	3.0900	0.0121
Block	5	66783.7217	13356.7443	6.1100	0.0004

Table d.19. Statistical results of ANOVA test run on measured soluble soil Ca^{2+} concentrations from soil samples collected seven months after treatment application (10/27/16).

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	7	22.6072	3.2296	3.0900	0.0122
Block	5	8.3485	1.6697	1.6000	0.1872

Table d.20. Statistical results of ANOVA test run on measured exchangeable soil Ca^{2+} concentrations from soil samples collected seven months after treatment application (10/27/16).

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	7	4455372.6080	636481.8010	0.8100	0.5879
Block	5	4170837.5590	834167.5120	1.0600	0.3980

Table d.21. Statistical results of ANOVA test run on measured soluble soil Mg^{2+} concentrations from soil samples collected seven months after treatment application (10/27/16).

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	7	2.1007	0.3001	1.6800	0.1468
Block	5	4.5631	0.9126	5.1000	0.0013

Table d.22. Statistical results of ANOVA test run on measured exchangeable soil Mg^{2+} concentrations from soil samples collected seven months after treatment application (10/27/16).

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	7	76539.7864	10934.2552	1.7700	0.1253
Block	5	145926.6331	29185.3266	4.7200	0.0021

Table d.23. Statistical results of ANOVA test run on measured SAR values from soil samples collected seven months after treatment application (10/27/16).

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	7	5.6360	0.8051	1.6800	0.1472
Block	5	6.7543	1.3509	2.8100	0.0309

Table d.24. Statistical results of ANOVA test run on measured EC values from soil samples collected seven months after treatment application (10/27/16).

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	7	77111.9167	11015.9881	0.5000	0.8263
Block	5	428605.0000	85721.0000	3.9100	0.0064

Table d.25. Statistical results of ANOVA test run on measured pH values from soil samples collected seven months after treatment application (10/27/16).

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	7	0.3603	0.0515	1.4200	0.2288
Block	5	0.4903	0.0981	2.7000	0.0362

Table d.26. Statistical results of ANOVA test run on measured soil K^+ concentrations from soil samples collected seven months after treatment application (10/27/16).

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	7	32437.2891	4633.8984	1.6400	0.1569
Block	5	56729.6543	11345.9309	4.0100	0.0055

Table d.27. Statistical results of ANOVA test run on measured soil CN Ratio values from soil samples collected seven months after treatment application (10/27/16).

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	7	19.8922	2.8417	1.2100	0.3210
Block	5	20.4507	4.0901	1.7500	0.1495

Table d.28. Statistical results of ANOVA test run on measured soil total organic C concentrations from soil samples collected seven months after treatment application (10/27/16).

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	7	103342182.0000	14763168.9000	0.8400	0.5598
Block	5	175052973.7000	35010594.7000	2.0000	0.1030

Table d.29. Statistical results of ANOVA test run on measured soil total N concentrations from soil samples collected seven months after treatment application (10/27/16).

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	7	129728.4292	18532.6327	0.3400	0.9293
Block	5	360203.9742	72040.7948	1.3300	0.2760

Table d.30. Statistical results of ANOVA test run on measured soil P concentrations from soil samples collected seven months after treatment application (10/27/16).

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	7	8.7852	1.2550	0.9300	0.4967
Block	5	29.7423	5.9485	4.4000	0.0033

Table d.31. Statistical results of ANOVA test run on measured soil S^{2-} concentrations from soil samples collected seven months after treatment application (10/27/16).

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	7	302.9203	43.2743	1.9200	0.0953
Block	5	781.8310	156.3662	6.9500	0.0001

Table d.32. Statistical results of ANOVA test run on measured soil B^{3+} concentrations from soil samples collected seven months after treatment application (10/27/16).

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	7	1.0123	0.1446	1.1000	0.3826
Block	5	6.0389	1.2078	9.2200	<0.0001

APPENDIX E: PLANT STATISTICAL ANALYSES RESULTS

Table e.1. Statistical results of split plot analysis run on measured plant height growth between the initial (3/15/16) and second (7/19/16) tree measurements.

Effect	Num DF	Den DF	F Value	Pr > F
Treatment	7	35	0.96	0.4738
Species	2	10	114.15	<0.0001
Treatment*Species	14	70	1.36	0.1941

Table e.2. Statistical results of split plot analysis run on measured plant height growth between the second (7/19/16) and final (1/28/17) tree measurements.

Effect	Num DF	Den DF	F Value	Pr > F
Treatment	7	35	0.90	0.5168
Species	2	10	148.19	<0.0001
Treatment*Species	14	70	0.79	0.6733

Table e.3. Statistical results of split plot analysis run on measured plant diameter growth between the initial (3/15/16) and second (7/19/16) tree measurements.

Effect	Num DF	Den DF	F Value	Pr > F
Treatment	7	35	2.66	0.0255
Species	2	10	206.97	<0.0001
Treatment*Species	14	70	1.63	0.0922

Table e.4. Statistical results of split plot analysis run on measured plant diameter growth between the second (7/19/16) and final (1/28/17) tree measurements.

Effect	Num DF	Den DF	F Value	Pr > F
Treatment	7	35	1.87	0.1051
Species	2	10	522.57	<0.0001
Treatment*Species	14	70	1.40	0.1746

Table e.5. Statistical results of split plot analysis run on measured plant volume growth between the initial (3/15/16) and second (7/19/16) tree measurements.

Effect	**Num DF**	**Den DF**	**F Value**	**Pr > F**
Treatment	7	35	4.38	0.0014
Species	2	10	275.96	<0.0001
Treatment*Species	14	70	3.22	0.0006

Table e.6. Statistical results of split plot analysis run on measured plant volume growth between the second (7/19/16) and final (1/28/17) tree measurements.

Effect	**Num DF**	**Den DF**	**F Value**	**Pr > F**
Treatment	7	35	2.17	0.0618
Species	2	10	259.46	<0.0001
Treatment*Species	14	70	2.01	0.0294

VITA

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