2012

Use of Expanded Shales, Clays and Slates-Light Weight Aggregate for Erosion Control and Grass Establishment on Un-vegetated Embankments

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USE OF EXPANDED SHALES, CLAYS AND SLATES - LIGHT WEIGHT AGGREGATE FOR EROSION CONTROL AND GRASS ESTABLISHMENT ON UN-VEGETATED EMBANKMENTS

A Thesis

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

in
The School of Plant, Environmental and Soil Sciences

by
Murilo de Santana Martins
B.A., Universidade Federal do Reconcavo da Bahia, 2008
December 2012

Acknowledgments

I would like to express my sincere appreciation to my major professor Dr. Jeff Beasley for his friendship, patience, supervision and direction throughout my graduate study at Louisiana State University, giving me the opportunity to pursue a master's degree. I would like to express my sincere appreciation to my graduate committee members Dr. Ron Strahan, and Dr. Charles Johnson. And with great gratitude to thank Dr. Maria Bavia and Dr. Gary Breitenbeck for affording me the opportunity to come to Louisiana State Univeristy, this would not have been possible without their support.

In addition, I would like to thank the Burden Research Center staff, the Louisiana State University Soil testing and plant analysis laboratory staff, the undergraduate student workers Ethan Eilers, Bret Sparks and Ryan Monk, fellow graduate students in special to Joseph Kraska, and all my friends who assisted and helped me throughout the good and bad moments of my trajectory during this project. In special I would like to thank my parents, sisters and brother, and the rest of my family for their love and support in every moment of my life.

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ABSTRACT

High salinity concentrations in soils used to renovation and construct levees adversely affect levee's performance due to increased susceptibility for erosion problems. Dispersion of the soil particles caused by salts and seal formation affect levee structure stabilization and vegetation establishment is impaired due to lower water infiltration capacity in levees; and high osmotic pressure exerted by salts reducing water availability for seed germination leaving levee surface prone to severe rilling and soil loss from runoff erosion. The objectives of this research were determine if expanded shales, clays, and slates-light weight aggregate (ESCS-LWA) over clay reduces erosion and evaluate how ESCS-LWA affects vegetation establishment from seed. Alternatives to soft armoring erosion protection such as concrete t-walls, concrete covering or rock applications are expensive and could limit levee expansion. The use of mulches such as ESCS-LWA can significantly reduce soil erosion and pollutant transfer as a transition to vegetation establishment. Aggregate particle reduce evaporation at the soil surface during wet periods by disrupting the soil-atmosphere continuum. The ability of ESCS-LWA to reduce erosion and increase water availability should allow for increased seed germination and plant growth. To test this hypothesis, four ESCS-LWA treatments (0, 50, 100, 150% ground coverage) were applied to bare soil and seeded with 75 kg PLS bermudagrass ha-1. Treatments were subjected to a rainfall simulation at 75 mm hr-1 at 30% slope for a 30-min runoff period in a greenhouse. Prior to simulation soil moisture was recorded with runoff volume and total solids (TS) collected during simulation. The ESCS-LWA increased the time until the onset of runoff and reduced TS losses >90% compared to bare soil. Increasing ESCS-LWA coverage resulted in higher soil moisture for 30 days post-rainfall simulation with 50% and 100% ground cover resulting in the highest bermudagrass coverage and biomass.

CHAPTER 1: LITERATURE REVIEW

IMPORTANCE OF LEVEES

The U.S. Army Corps of Engineers (USACE) (2000) defines levee as an embankment with the purpose of flood protection during seasonal high water and, is subjected to a long or short period of days to water loading. Other benefits provided by levees as a secondary function are recreational areas and habitats for different ecosystems.

The excavation of materials used for levee construction is made from borrow pits on the riverside of the levee. This reduces the expenses related to transport and environment impacts. However, the decision on using the material excavated is determined by soil properties and physiographic settings required in the standard procedures established by USACE. These standard procedures are required to avoid failure of levees as occurred when Hurricane Katrina hit New Orleans on 29 Aug 2005. Because of the destruction caused by Hurricane Katrina concerns about levee safety and flood risk management were brought in evidence, and the National Levee safety Act of 2007 under the Water Resources Development Act authorized USACE to develop a strategic implementation plan including an inventory and inspection of levees.

LEVEE CONSTRUCTION

Levees are built with different purposes, and the selection of the appropriate type is made according to location and the area where protection is desired. When functioning as an urban area levee they are designed to provide protection from flooding in communities including facilities ranging from residential to industrial. While in agricultural areas the function of levees is to provide protection from flooding in land used for agricultural purposes.

Construction and maintenance of levees is expensive and requires a large volume of burrow material. For coastal protection levees the most practical source of this material is the consolidated sediments in the coastal zone near the area where the proposed levee will be constructed. This dredge material typically consists of very fine, sodium-saturated sediments. However, levees constructed from these materials are highly susceptible to both rill and sheet erosion because sodium saturation difficult vegetative cover to establish and they are constantly affected by increments in the salinity levels due to the intrusion of salt water caused by dredging of canals, storms surge, as well the sea level rise.

Some recently constructed levees have remained barren for three or more years despite repeated efforts to establish a grass cover resulting in formation of rills caused by runoff erosion at the soil surface. To address a solution for vegetative establishment affected by high salt soil concentrations rapid seed germination and stand establishment are critical factors to take in consideration, because salt-stress conditions interfere on seed germination and early seedling growth, considered the most sensitive stages to salinity stress according to Ashraf and Foolad (2005). Bermuda grass demonstrated to be capable of germination in a media where the salinity concentration is 5800 mg. L^{-1}(Peacock and Dudeck. 1989), this tolerance to high salinity levels indicate that bermudagrass with adequate water supply for young plants resulting in ideal moisture levels to allow seed germination, can be used in levees with high salt-soil concentration. However, levees are built with low water infiltration capacity. As a result, moisture availability is inadequate to support germination and growth and the barren levees undergo severe damage from rill and sheet erosion.

The use of a cover layer with six inches of low sodium sediment at the top of the levees has been proposed, though locating barrow areas with sufficient reserves is challenging. In addition, shipping and handling costs of this material will add greatly to the cost of levees renovation and construction. Moreover, there is no evidence to suggest that underlying salts will not rise rapidly and accumulate into the top layer. Because during the wet season water infiltration tend to leach salts downward in the soil profile, but levees have a lower water infiltration capacity, consequently salt leaching will not have significant changes. However, in the ensuing dry season, as a result of evaporation, salts from the lower layer will be carried to the upper layer and the soil solution will become concentrated resulting in an increase in the proportion of salts rendering the top soil ineffective as a medium for plant growth.

VEGETATIVE STABILIZATION OF LEVEES

Vegetation plays an extremely important role to protect and reduce levee erosion in different ways, because it affects both surficial and mass stability of slopes (Gray and Sotir, 1996) by dissipation of the rainfall energy, functioning as a binding soil agent, increasing soil porosity through its root system, and reduces soil moisture by evapotranspiration, thus increasing infiltration and favoring a balance in the soil-plant-atmosphere system.

As an important part of design considerations for levee construction vegetation (trees, bushes, grass, etc) on a levee and its surrounding areas provides protection and enhance aesthetic and natural resources. Therefore, needs to be incorporated in the project as long as it will not diminish the integrity and the functionality of the embankment system or impede ongoing operations, maintenance and flood protection capability (USACE, 2000).

The selection of grasses to be used on levees depends on factors such as growth habit that can interfere in the inspection frequently needed in protection levees. For engineering reasons, grass species with deep root system development are inappropriate for vegetative establishment of levee, because they can destabilize the structure and consequently cause collapse of embankments. In coastal protection levees, an important aspect to consider when selecting the vegetation type is tolerance to high levels of salinity, because sediments used to build the levees are high in salt concentrations and levees closer to the coast are affected by salt water remaining un-vegetated for several years and exposed to soil erosion until vegetation is established (Green et al., 2000).

The most common used turfgrass in the southern of the United States is bermudagrass (*Cynodon dactylon* L.). The predominant choice for this grass extensively used for lawns, athletic fields and golf courses relies on climate conditions given to bermudagrass be a warm-season species. In the southwestern is related to the presence of salts and ions responsible for salinity problems commonly found in the irrigation water that negatively affects the growth of turfgrass (Mancino and Pepper, 1994). Bermudagrass could be a great alternative for vegetative establishment on un-vegetated levees constructed with high soil-salt concentrations because of high tolerance to salinity and also the capacity to survive in sodic soils better than most turfgrass species (Mancino and Pepper, 1994).

EFFECT OF SALT CONCENTRATION ON SEED GERMINATION AND GRASS GROWTH

Salt-affected soils pose several problems for grass establishment and growth. High soil-salt concentrations have been shown to affect plant-water relations; have potential ion toxicities; nutrient imbalances; and degraded soil structure (Ayers, 1952; Flowers and Yeo, 1986; Bernstein 1975; Rengasamy and Olsson, 1991; Hu and Schmidhalter 2005). Mature grasses growing in high-saline conditions exhibit greater drought stress, reduced plant turgor, reduced plant size and vigor and decreased water uptake (Carrow et al., 2001). The most common effect is physiological drought, a condition where high salt concentrations alter a soil's osmotic potential so that water movement into the plant is reduced or under extreme situations reversed (Hayward and Spurr, 1943; Sairam and Tyagi, 2004; Ehleringer and Dawson, 1992). If this condition is prolonged plant death will result.

Drought symptoms of mature grass swards can be visually assessed in the field, whereas, physiological drought effects on seeds are much more difficult to identify. Although, the results of altered soil osmotic potential remains similar between seeds and mature swards; water absorption is essential for initiation of germination process. As seed moisture content is severely reduced from physiological drought conditions, seeds become non-viable.

IDENTIFICATION AND MANAGEMENT OF SALT AFFECTED SITES

The effect of salt in soils can be related in all continents and in a diversity of climatic conditions. Salt-affected soils are extensively more distributed in the arid and semi-arid regions (Abrol et al, 1988) being strongly affected by irrigation water, whereas humid regions are not strongly affected because rainfall causes salts to precipitate and leach to deep depths in the soil profile.

Practices to reduce salt concentrations rely on proper identification of soil characteristics. According to the U. S. Salinity Laboratory (USSL) three soils categories exist: saline, sodic and saline-sodic diagnosed based on electrical conductivity (EC) threshold value of 4 $dS.m^{-1}$ of the soil saturation extract as an index of soil salinity. Depending on the classification, soils will exhibit different effects on plant growth and soil degradation. Saline soils generally do not contribute to poor soil physical properties (Carrow et. al, 2001), but do affect plant-water relations, can result in ion toxicities, and create nutrient imbalances.

Sodic soils present greater challenges, because in addition to characteristics exhibited by saline soils, sodic soils are characterized by poor soil structure as a result of high Na concentrations. In clay soils, de-flocculation of clay particles occur leading to macro-pore collapse. This reduces soil permeability (infiltration and percolation) as well as reduces soil oxygen. The final category, saline-sodic soils is a transitory state between saline and sodic soils. Saline-sodic soils exhibit the same characteristics as saline soils, but as Na is leached from the soil and not replaced by other ions, soil structure is slowly degraded.

Agronomic practices to reduce the effects of salt-affected soils for proper plant growth and development depend on various management practices. Practices include proper site characterization as discussed previously; limiting salt additions such as fertilizer additions or poor irrigation quality; selection of proper species; leaching salts and amendment additions. In the case of the USACE the first three practices have been addressed within the grassing for levees specification.

Understanding factors that determine salt movement in soils is critical to managing salt-affected sites. Because salts ionize in aqueous solutions, salt movement is dependent on soil-water movement. During periods of rainfall, water infiltrates and percolates in the soil moving salts to deeper soil depths. Soil characteristics such as texture and cation-exchange capacity affect water movement and ion availability. For example sands have high infiltration and percolation rates that enhance salt leaching, whereas, clays are composed of fine particles with poor macro-pore structures that limit water infiltration and percolation. Finer soils would require water applied more frequently to achieve a similar level of salt leaching.

Although, rainfall can greatly reduce salt concentration in the root zone, droughty periods have the opposite effect. As water is evaporated from the soil surface, salts migrate upward and can be deposited on the soil surface. These salt deposits in the upper soil would result in extremely high concentrations that would reduce or inhibit seed germination.

ALTERNATIVES TO GRASS STABILIZATION OF LEVEES

Different techniques such as application of gypsum (Yu et al., 2003), Anionic Polyacrylamide (PAM) (Shainberg et al., 1990), hydromulching, and gravel are being used as alternatives to achieve erosion control and enhance vegetative establishment for stabilization of levees (Baharanyi, 2010; Swift, 1984). With establishment of vegetation, protection from erosion caused by the impact of kinetic energy from rainfall and splash can be increased. According to the USDA soil conservation department by managing thick turf, grass or herbaceous vegetation, soil loss due to water erosion may be reduced 100-fold (USDA, 1978).

Traditionally, material such as riprap is used in a variety of ways to stabilize embankments and shorelines. Riprap is a material consisting of graded or crushed stone that may vary depending on the source, but is typically blasted, grizzled, and screened at a quarry. Distinctions among various bank stabilization measures can be made on the basis of how they work, the materials used, their geometry and position in the landscape.

Such installation of various sized rocks, stacked in the soil surface, may be used to grass stabilization and reduction of erosion, but it is very expensive and time consuming to install. In addition, there are potential environmental impacts that are currently in study by resource agencies to assure that the continued use of this material as fill will not be harmful (Fischenich, 2003). Moratoriums on the use of riprap have been established or are being pursued by the National Marine Fisheries Service (NMK), the U.S. Fish and Wildlife Service (USFi&WS), and several State Environmental Quality offices. U.S. Army Corps of Engineer Districts currently invest considerable manpower interacting with applicants and resource agencies on this issue.

Alternatively, concrete blankets (flat soft material filled with concrete or concrete blocks held together with steel cables), or concrete slabs may be used to control erosion at levees. These products, and other similar products, are referred to as "hard armor". Hard armor often dissipates water energy and protects the soil there beneath from eroding away and polluting natural resources (Stancheva et al., 2011; Griggs, 2005; Charlier et al., 2005). One drawback associated to hard armor is the requirement of very large equipment needed to install. Additionally, a significant volume of material must be freighted to the site and a large amount of preparatory work is required before installing the hard armor.

While hard armor is useful for dissipating velocity and countering shear forces associated with runoff water, poor installation often allows the water to splash or divert out of the designated channel, many times leading to the erosion and washout of the hard armor installation itself, also causing impacts on the environment (Stamski, 2005). While concrete blankets are better able to withstand velocity and shear forces, they do little to inhibit the velocity, and, therefore, the destructive force of the water runoff. Another drawback associated with hard armor is that it typically lacks aesthetics associated with other forms of erosion control.

EXPANDED SHALES, CLAYS, AND SLATES-LIGHT WEIGHT AGGREGATE PROPERTIES

The aggregate is a ceramic material produced by an expanding and vitrifying select shales, clays, and slates (ESCS-LWA) process in a rotary kiln. The expansion process occurs by a thermal treatment that can reach temperatures about 1100 °C. The final product can be obtained in various densities and grades between 3-32 mm. In the process a high quality ceramic aggregate is produced conferring properties such as structurally strong, physically stable, durable, environmentally inert, light in weight, and highly insulative. It is a natural, non-toxic, absorptive aggregate that is dimensionally stable and does not degrade over time. The lightweight aggregate density is less than half the unit weight of commercially ordinary aggregates consisting in a unit weight of 36 to 48 lbs ft^3. In addition, presents a water absorption capacity of 16.3% and specific gravity of 1.65.

The porosity and absorption of ESCS-LWA helps manage water use, while reducing soil compaction providing superior drainage and air space system essential to healthy plant growth, increasing soil porosity, and maintaining soil temperature when used in drainage and storm water treatment projects. As a mulch cover at the soil surface could in a long-term because of high compressive strength and resistance to compression or crush under normal conditions, considerably reduce soil erosion absorbing the impact of the rainfall, and protecting the soil from splash and detachment of particles.

Rotary kiln produced lightweight aggregate is an environmentally friendly product that saves material, labor and transportation cost. The use of this lightweight aggregate material allows delivery of more products on each truck, compared to ordinary products, thus promoting a decrease in the number of truckloads required to deliver the same volume of product. As a result, the project benefits from reduced delivery costs, less fuel is consumed, and the community receives the benefit of reduced air and noise pollution and less traffic congestion.

EROSION

Soil has been naturally removed by the action of wind and water erosion for millions of years, however in the present time the effects of men activities is resulting in an accelerate loss of soil in a much faster rate than sol is formed. The effects of erosion caused by wind and water can lead to structural problems and failure of levees. Soil erosion is a result of both detachment by raindrop impact and transport by overland flow. The extent of detachment and the volume of runoff water available to transport particles appear to be related in many soils to the formation of dense, impermeable crusts or seals at the surface of the soil. McIntyre (1958) attributed surface crust formation to compaction of the immediate surface (0.1 mm) by raindrop impact, and formation of a washed-in layer' below this, composed of dispersed clay that clogs and seals water transmission pores.

Erosion is classified in different types such as rill erosion diagnosed by the formation of thin and shallow channels through the action of water flow on the soil surface, very characteristic from areas without vegetative cover (Bradfort et al., 1987); and gullies that indicate an intensified erosion process with deep cavities caused by concentrated flow of water along a channel. These two erosion types are the most evident; however there are others that count for great soil losses.

Soil erosion is determined by the action of numerous factors combined such as rainfall intensity and volume, soil structure and texture, slope gradient, vegetation cover, and land use. Usually in the process of erosion the rates of soil loss are commonly directly related to soil management and land use.

According to Jang et al (2011) in a study to identify the causes of failure at the levees in New Orleans during hurricane Katrina, Briaud (1999, 2001), Hanson (1991, 1993, 1999, 2001) and Lim (2006), there are several factors influencing the erosion behavior of soils, these include degree of saturation, chemicals in erosion fluids, shear strength, electrostatic or Van der Waals forces among particles and minerals, compaction water content, fine content, clay mineralogy, degree of compaction, and particle sizes. Jang et al. (2011) considered the impact of the rainfall on the levees in New Orleans as one main reason associated to the failure occurred.

The effect of water in soil erosion can be effectively reduced by controlling or softening the runoff and taking vegetative cover establishment in consideration. Vegetative cover exerts a great impact on reducing mechanical detachment of soil particles during a rainfall event by intercepting the impact of water (Wei et al., 2007).

There is a very large quantity of efficient practices to reduce erosion available. According to Baharanyi (2010) the best management practices include: mulching, permanent seeding on disturbed areas, improvement of soil stability via long-term vegetation, and diversion of water from slopes.

The benefits of using ESCS-LWA can greatly impact runoff erosion because it impairs storm water runoff by promoting a tortuous pathway for the water. It will increase the infiltration rate and allow a better draining of soils. The ESCS-LWA has been used extensively in site development and in horticultural applications for the promotion of plant growth. When blended into soil, the LWA absorptive, porous, ceramic characteristics provide critical soil aeration necessary for plant growth and survival. Although the LWA has been used extensively in a diversity of ways, there is no related work of uses for erosion control. The indicative as a great alternative to be used in the levee surface for erosion control relies on predictable performance facts: removes total solid solutes (TSS) and solid material to prevent clogging, hydraulic conductivity allows fast, free drainage, requires lower maintenance cost and extends service life comparing to other materials being used due to its ceramic properties which reduces material degradation and a high angle of internal friction which provides stability and strength. Economical advantages include reduced weight resulting in lower freight and handling costs.

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CHAPTER 2: USE OF EXPANDED SHALES, CLAYS, AND SLATES – LIGHT WEIGHT AGGREGATE (ESCS-LWA) FOR EROSION CONTROL ON LEVEE EMBANKMENTS CONSTRUCTED FROM HIGH SALINE SOILS

INTRODUCTION

Louisiana's residents and coast have been severely impacted by hurricanes throughout history. As coastal wetlands have deteriorated (Gagliano et al., 1981; Walker et al., 1987; Penland et al., 1990), construction of levees has become an integral component in protecting and securing people and territory from land loss and flooding (Tobin, 1995). However, salt water intrusion in southern Louisiana has resulted in borrow pit sediments high in salt concentrations being used to renovation and construct levees (personal communication Steve Finnegan). Although high saline soils are suitable from a construction standpoint of attaining high compaction, saline concentrations are often too high for germination and growth of grass species specified for levee soft armoring (Beasley et al., 2010).

Over time these protective earthen embankments have eroded as a consequence of no vegetative coverage (Beasley et al., 2010). This has led to federal and state governmental agencies increasing expenses related to erosion repairs and increased fears of potential underperformance during storm surges. Various methods to establish vegetation to reduce erosion and structurally protect levees have been employed including hydro-mulching, mat installations, gypsum application, organic materials, and anionic polyacrylamide (PAMs) (Flanagan et al. 1997, Stern et al. 1991, Agassi and Ben Hur 1992, Entry et al., 2003); but many of these attempts have either resulted in little to no grass establishment; are not allowed due to construction specifications regarding organic matter content; or have not provided adequate sustained erosion resistance during the vegetative process. Current adopted federal USACE specifications to prevent salt from affecting soft armor establishment involves soil salinity testing to insure adequate salt concentrations <4.68 $dS.m^{-1}$ prior to being used in the final lift (Beasley et al., 2010). This requirement has resulted in soils being harvested and transported from farther distances with increased construction costs.

Movement of sediment via surface runoff, until an effective barrier is applied, impairs open water bodies polluting their use for drinking, industry use, wildlife, agriculture, fisheries, and aesthetics as well as affects the structural stability of levees. Sediment is recognized as one of the most common impairments in the United States and throughout the world (USEPA, 2000). For example, on croplands an average of 17 tons ha^{-1} is estimated to erode every year in the United States (Pimentel et al, 1995). Of the erosion that occurs 30% is believed to be natural erosion while up to 70% is the result of anthropogenic activities such as construction or changes in land use (USEPA, 1998). In the case of levees, erosion poses an increased risk of structural deterioration and lowered performance of these anthropogenic structures.

Vegetation such as grasses are often prescribed to reduce erosion because many grass species are perennial, self-repairable, relatively easy to establish, and economical. According to Gray and Sotir (1996), herbaceous vegetation is beneficial in reducing surface erosion by foliage and plant residues intercepting kinetic rainfall energy that detaches soil particles; binding soil particles with root systems to hinder soil movement; plant residues filters suspended sediments in flowing runoff water; slows surface flowing waters for greater infiltration as well as increases soil porosity and permeability to delay the onset of saturation and runoff. However, conditions such as high soil salinity can severely limit vegetation establishment and growth. Therefore, the use of vegetative alternatives such as mulches or hard armoring should be evaluated.

Researchers have shown the use of mulches can significantly reduce soil erosion and pollutant transfer during vegetation establishment. Mannering and Meyer (1963), Meyer et al.

(1970), Lattanzi et al. (1974), and Krenitsky et al. (1998) have all demonstrated the effect of mulches to reduce runoff flow and significantly limit erosion. Mulches provide a transitional soil cover until vegetation is established. Mulches provide increased erosion resistance by decreasing splash erosion from rain drop impact that results in soil detachment and restricting soil particle movement by disrupting flow velocity. Mulches or mats composed of organic materials vary in erosion resistance in terms of rills developing beneath the mulches or blankets under harsh environments conditions (Meyer et al., 1972; Kramer and Meyer, 1969; Foster et al., 1982; Thompson et al., 2001). The soft armor alternative of hard armoring involves the use of materials such as rock or concrete, or other materials resistant to breakdown for slope protection. Although effective, many hard armor alternatives so expensive that their costs can greatly limit their use.

One proposed method to protect levees embankments not suitable for soft armoring is a product that provides hard armor protection without significant cost increases. One such mulch product could be expanded shales, clays, and slates-light weight aggregate (ESCS-LWA) formed during a vitrification process. Because ESCS particles are similar in size to pea gravel but with 1/3 the weight, the volume and weight of ESCS-LWA needed to protect an embankment from erosion should provide an economical hard armor alternative compared to acceptable soil required for capping. Therefore the objectives of this study were 1) characterize the ability of ESCS-LWA to reduce erosion and 2) evaluate the effect of ESCS-LWA on vegetation establishment from seed.

MATERIALS AND METHODS

Greenhouse Experimental Setup

Experiments were conducted at Louisiana State University Agricultural Center Burden Research Center in Baton Rouge, La, (30°24'42"N, 91° 6'12"W) were initiated 5 July 2011 and 18 May 2012. Sixteen trays (76.2 cm x 127 cm x 10.16 cm) with internal areas of 0.96 m^2 were filled with USACE approved levee construction soil collected from the Bonnet Carre Spillway borrow pits (30°2′24″N 90°25′48″W). The soil consisted of 55.4% clay, 29.9% silt and 14.7% sand with a pH of 8.2 and fertility of 45.91 mg P ha^{-1} and 254.37 mg K ha^{-1}. Soil was ground using a grinder (No. 60 Power Grist Mill, The C.S. Bell Co., Tiffin, Ohio) to a more useable consistency before being placed into trays. Soil was applied in 2 to 3 cm layers, wetted, and tamped to compaction soils. Once trays were filled with soil, surface irregularities were smoothed to create a uniform surface for mulch applications.

Trays were arranged in a complete randomized design with four replications. Treatments consisted of ESCS-LWA applied to cover 50%, 100%, and 150% of the soil surface with corresponding densities of 52.000, 104.000, and 156.000kg.ha^{-1}. Bare soil trays served as controls. All treatments were seeded with common bermudagrass (*Cynodon dactylon* L.) at 75 lbs PLS ha^{-1}. Rates of bermudagrass seeding vary from turf establishment specification to specification and among organizations. No fertilizers, pesticides, or supplemental irrigation except rainfall simulations were applied throughout the experiments.

Runoff System and Experimental Design

Simulated rainfall was applied to the trays using a mobile Tlaloc 3000 rainfall simulator (Joern Inc., West Lafayette, IN), based on the design of Miller (1987) and Humphry et al. (2002) with modifications to be used in trials inside a greenhouse. The shower head of the Tlaloc 3000 was fitted with a nozzle (Fulljet ½ HH SS 50WSQ, Spraying Systems Co., Wheaton, IL) having a spray angle of 104^{o} (± 5 %)(USDA,2008) attached to the greenhouse structure 305 cm above the soil surface and the water piping, and pressure gauge connected to a hose at the end to control and maintain a constant pressure of 7.5 psi and water flow. The water utilized at the rainfall simulations was obtained from the East Baton Rouge municipal water system. The amount of water discharged at the rainfall event was 70 mm h^{-1} for all surface runoff events.

Each tray was placed on a wood pallet to allow easy transport and placement under the rainfall simulator. Trays were placed at a 30% slope to mimic a levee embankment. At the lower end of each tray, PVC troughs were placed to collect and direct runoff waters into a plastic collection reservoir (114L). Collection reservoirs weights and water samples were recorded or collected every five minutes for 30 minutes after the onset of runoff. Water samples were collected in 50 ml plastic for a total of six samples per tray.

Rainfall Simulation and Vegetation Measurements

Prior to rainfall simulations antecedent soil moisture was measured using capitance sensors (EC5 Datalogger-EM50; Deacon Devices, Inc., Pullman, WA). During rainfall simulations the time until the onset of runoff and total runoff volume were measured. Samples collected during simulations, 40 ml were used to determine total solids (TS). Total solids analyzes was performed following the specifications of USEPA method 160.2 (USEPA, 1999). Post simulation soil moisture was measured for 30 d every 10 days. Thirty days after the initiation of the trials, vegetative ground coverage was assessed and shoot biomass was clipped at the soil surface from a 0.0096 m^2 area. Biomass samples were dried at 70 ^{o}C for 72 hours and the mass recorded.

Field Experimental Setup

A levee embankment located in southern Louisiana near Chauvin (29°26′49″N, 90°35′37″W) was selected for field tests because un-vegetated levee embankments had been constructed from soils with high salinity concentrations (>31.25 $dS.m^{-1}$) and the embankments are prone to erosion from 1550 mm of average annual rainfall. The experiment was initiated 4 November 2011 to 6 August 2012.

A 864 m^2 area was tilled using a motorized walk behind tiller to a depth of 5 cm to smoothen the soil surface from rills that had developed due to no vegetative cover. Soil samples were collected and analyzed for pH 8.7 and fertility of 75.19 mg P kg^{-1} and 462.81 mg K kg^{-1}, but no amendments were added. The area was raked to remove debris, rolled to compact the soil surface, and delineated into 12 experimental units 7.5 m wide and 36 m long down the slope. Treatments were arranged in a randomized complete block design with four replications. Treatments included ESCS-LWA applied at 50% and 100% ground coverages with densities of 52.000 and 104.000 $kg.ha^{-1}$, respectively, and bare ground serving as controls. Treatments for ESCS-LWA were based on greenhouse erosion and vegetation establishment results. The ESCS-LWA treatments were applied at the apex of the levee and raked downward to achieve desired ground coverages. The experimental area was seeded with perennial ryegrass (*Lolium perenne* L.) at 159 kg PLS ha^{-1}. Perennial ryegrass was selected because it was allowed according to turf establishment specification for environmental conditions at that time of year.

Field Measurements

The field trial was only accessible by boat. Therefore, measurements were collected at the convenience of our cooperators at 12, 36, and 116 days after installation (DAI). At each site visit rill number was counted, soil samples were collected, plant coverage was assessed, and soil moisture was measured. After 116 d the site was to be disturbed through soil filling and grading activities. After learning these activities were delayed, final soil samples were collected for salt analysis. Soil samples were analyzed by the Louisiana State University Soil Testing and Plant Analysis Laboratory for salt concentration using the 1:2 dilution method.

Statistical Analyses

Data from RFS and the field trials were analyzed using the mixed procedure in the statistical software SAS (Preacher and Hayes, 2004). In each trial, the density of ESCS-LWA application was the only fixed factor. All means including soil moisture, time until the onset of runoff, runoff volume, TS losses, and plant measurements were separated according to Fisher's protected LSD at an α=0.05.

RESULTS

Rainfall Simulation Trials

Time until onset of surface runoff

In the first runoff simulation, bare soil resulted in the fastest runoff times at 224s followed by a pattern of higher ESCS-LWA ground coverages of 150 and 100% releasing surface runoff at 486s and 621s compared to 875s for 50% ESCS-LWA ground coverage (figure 1). However, the second rainfall simulation resulted in runoff release times of 104, 140,101, and 128s for bare soil, 50, 100, and 150% ground cover by ESCS-LWA, respectively.

Runoff release was influenced by upper soil moisture as demonstrated with higher soil moistures increasing with higher ESCS-LWA ground coverages prior to the first rainfall simulation (figure 2). At 150% ESCS-LWA ground cover, soil moisture was 26% followed by 15 and 8% for 100 and 50% ESCS-LWA ground cover, respectively. The exception was the bare soil control (0% ground cover) that had lower soil moisture of 9% compared to 100 and 150%

ESCS-LWA ground coverages. Soil moisture prior to the second rainfall was similar for bare soil controls and 50 and 100% ESCS-LWA ground coverages at 6, 8, and 8%, respectively. Again, the 150% ESCS-LWA resulted in the highest soil moisture prior to the second RFS at 15%.

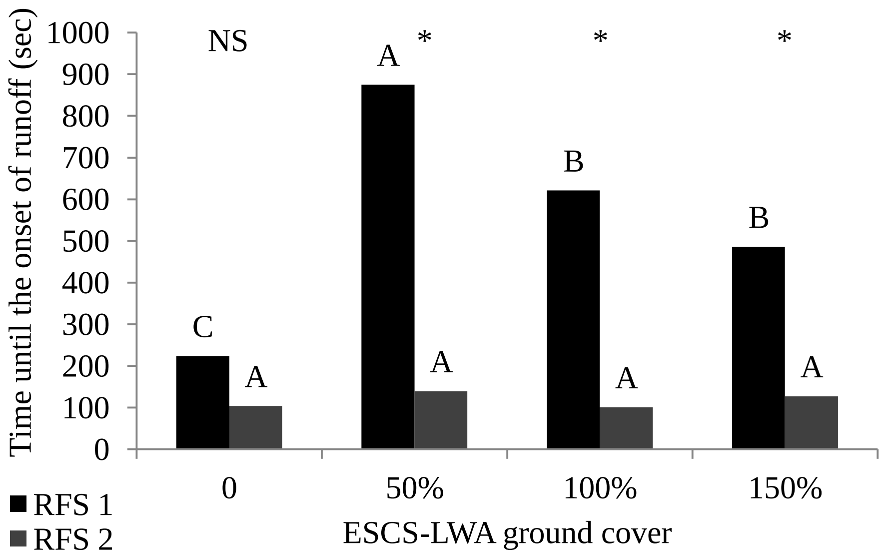

Figure 1. Influence of ESCS-LWA ground coverages of 0, 50, 100, and 150% on the time until the onset of runoff from rainfall simulations performed for a 30-min period at 70 mm h^{-1}. Means are separated according to Fisher's LSD (α=0.05) with letters representing differences across ground coverages within rainfall simulation. Differences in means across rainfall simulations within ground coverages are indicated with asterisks (*).

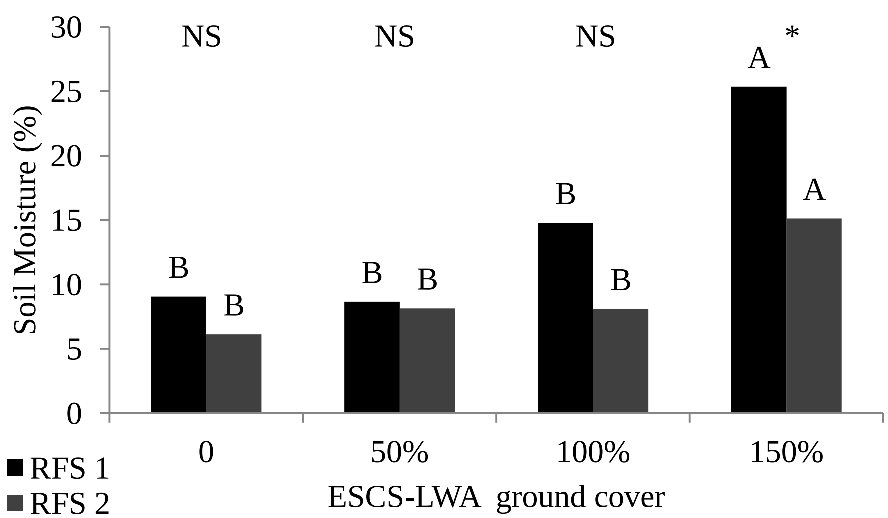

Figure 2. The effect of ESCS-LWA ground coverages of 0, 50, 100, and 150% on moisture retention at the soil surface prior to rainfall simulations. Means are separated according to Fisher's LSD (α=0.05) with letters representing differences across ground coverages within rainfall simulation. Differences in means across rainfall simulations within ground coverages are indicated with asterisks (*).

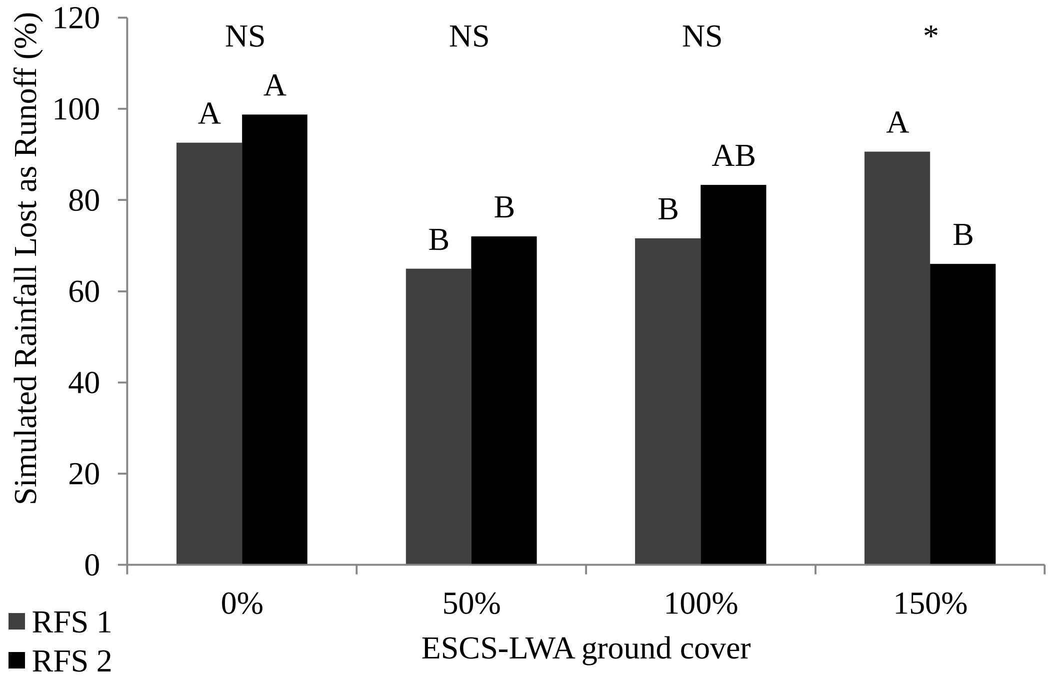

Figure 3. The effect of ESCS-LWA ground coverages of 0, 50, 100, and 150% on the rainfall applied lost as runoff volume from rainfall simulations performed for a 30-min period at 70 mm h^{-1}. Means are separated according to Fisher's LSD (α=0.05) with letters representing differences across ground coverages within rainfall simulation. Differences in means across rainfall simulations within ground coverages are indicated with asterisks (*).

Total solids lost during rainfall simulations

In general, increasing ESCS-LWA coverages resulted in reduced TS losses compared to bare soil controls across each RFS. Ground coverages of 100 and 150% with ESCS-LWA resulted in TS losses of 465 and 160kg ha^{-1} for RFS1 and 1029 and 238kg ha^{-1} for RFS2 compared to 10657 and 6232kg ha^{-1} corresponding TS losses for bare soil controls (figure 4). The most varied response occurred with 50% ESCS-LWA ground cover. During the first RFS, 50% ESCS-LWA ground cover exhibited similar TS losses at 631kg ha^{-1} to 100% ESCS-LWA TS losses. However, TS losses increased more than 11-fold from RFS1 to RFS2 (figure 4).

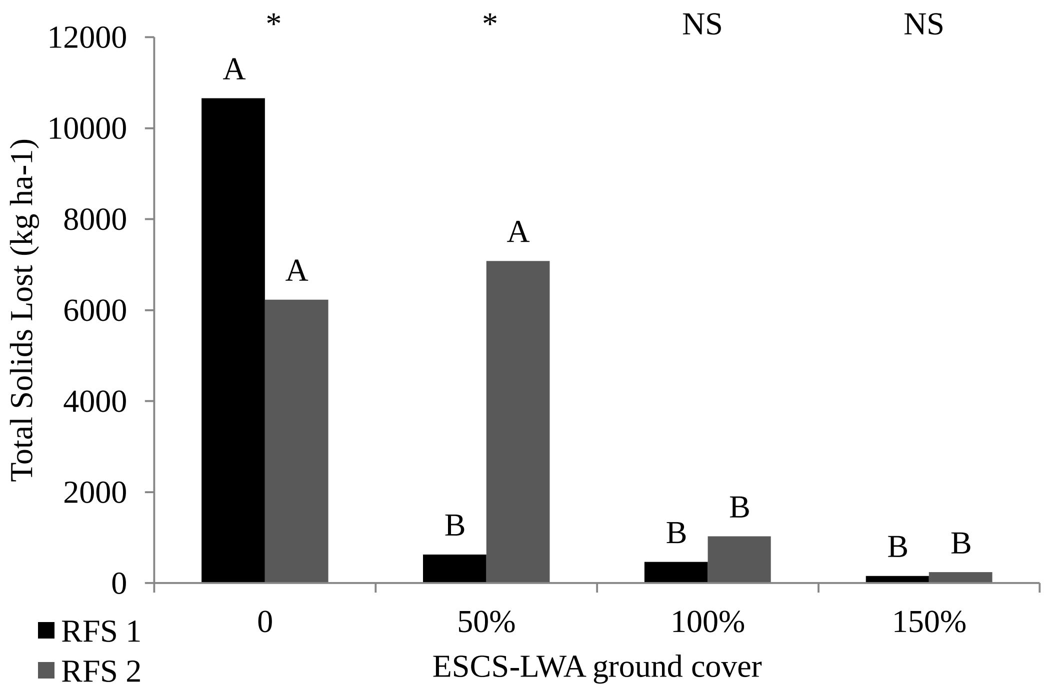

Figure 4. The effect of ESCS-LWA ground coverages of 0, 50, 100, and 150% on the runoff sediment yield from rainfall simulations performed for a 30-min period at 70 mm h^{-1}. Means are separated according to Fisher's LSD (α=0.05) with letters representing differences across ground coverages within rainfall simulation. Differences in means across rainfall simulations within ground coverages are indicated with asterisks (*).

Erosion resistance may be partially explained using the analyses of TS losses during the 30-min RFS. During the first RFS all ESCS-LWA ground coverages resulted in less than 2000 kg ha^{-1} TS losses during the first 20 min past the onset of runoff with bare soil exhibiting a pattern of increasing TS losses (figure 5). In the case of the 50 and 100% ESCS-LWA ground coverage treatments, TS losses slightly increased after 25 min past the onset of runoff (figure 5).

In the second RFS TS losses observed 25 to 30 min after the onset of runoff in first RFS from the 50 and 100% ESCS-LWA ground coverages had increased TS losses (figure 6). Bare soil controls continued to exhibit high TS losses over the 30-min RFS with 50% ESCS-LWA ground cover resulting in similar losses (figure 6). The 100% ESCS-LWA ground cover only slightly increased but was above the 150% ESCS-LWA ground cover.

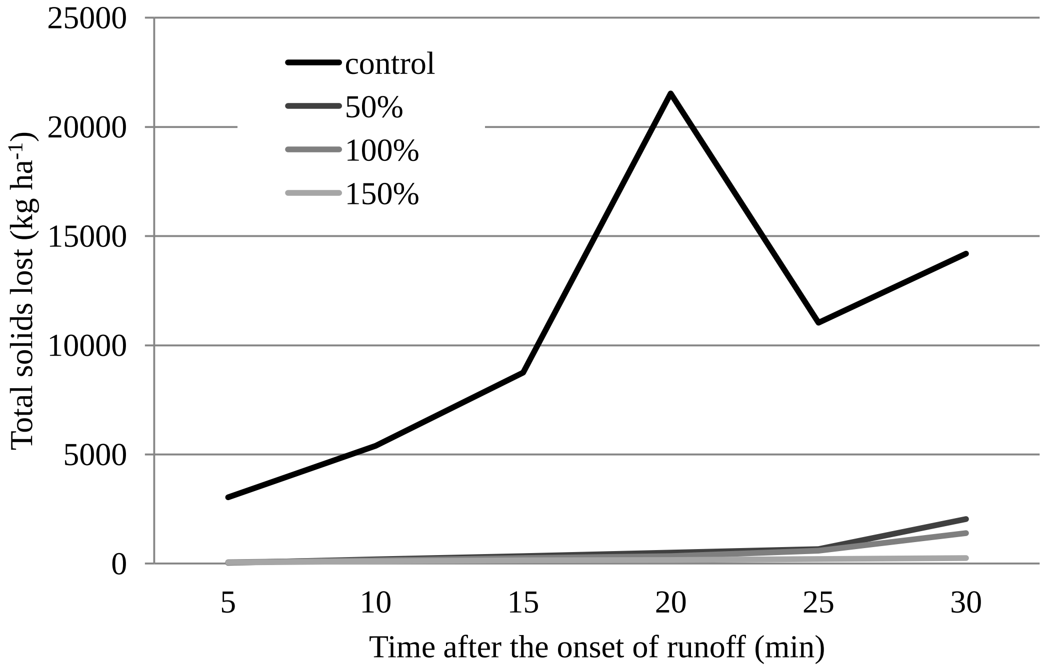

Figure 5. The effect of ESCS-LWA ground coverages of 0, 50, 100, and 150% on total solids losses within intervals of 5 minutes after the onset of runoff from the first rainfall simulation performed for a 30-min period at 70 mm h^{-1}.

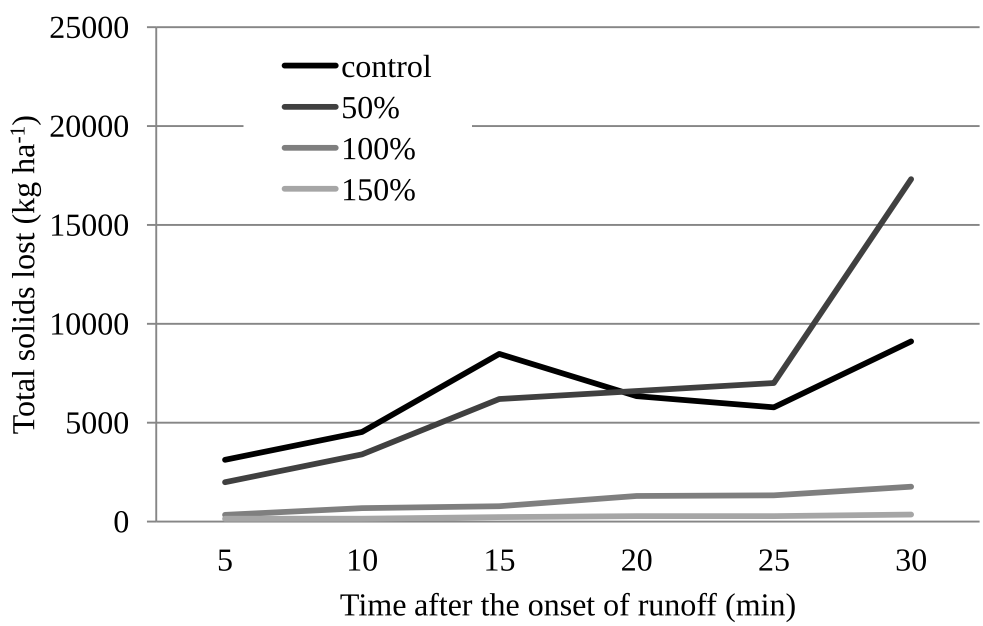

Figure 6. The effect of ESCS-LWA ground coverages of 0, 50, 100, and 150% on total solids losses within intervals of 5 minutes after the onset of runoff from the second rainfall simulation performed for a 30-min period at 70 mm h^{-1}.

Post rainfall simulation vegetation establishment

After RFS were completed common bermudagrass ground cover was assessed over a 30-d period. After the first and second RFS common bermudagrass ground cover was highest for 50 and 100% ESCS-LWA treatments at 10 to 20, 50 to 70, and 90 to 95 at 10, 20, and 30 d; whereas common bermudagrass never exceeded 5% or 40% for bare soil controls and 150% ESCS-LWA ground cover. These trends in common bermudagrass establishment were also evident after the second RFS with exceptions of 150% ESCS-LWA attaining 70% common bermudagrass ground cover and the remaining ESCS-LWA ground coverages of 50 and 100% exhibiting a slower common bermudagrass establishment at 10 and 20 days after RFS.

Table 1. Percentage of bermudagrass ground coverage and biomass shoots harvested of ESCS-LWA ground coverages of 0, 50, 100, and 150% for a period of 30 days within intervals of 10 days after the rainfall simulations performed for a 30-min period at 70 mm h^{-1}.

Rainfall simulation	Rainfall (days)	0	50	100	150
		---------------------	%	-----------------------	
	10	0C	10A	20A	5B
2011	20	5C	50A	70A	20B
	30	5C	90A	95A	40B
	10	0B	3B	10AB	15A
2012	20	0C	10B	40A	40A
	30	3C	75B	95A	70B
		Biomass dry weight kg.ha^{-1}			
		-----------------------	%	---------------------	
2011	30	0.04B	0.62A	0.82A	0.74A
2012	30	0C	1.06B	2.73A	2.83A

Means are separated according to Fisher's LSD (α=0.05) with letters representing differences across ground coverages within rainfall simulation.

One factor that may have contributed to the increase in common bermudagrass establishment in ESCS-LWA compared to the controls was moisture retention. Although soil moisture was only measured in after the second RFS, the data clearly demonstrated increasing ESCS-LWA ground coverage retained moisture over the 30-d measurement period. At the end of the 30 days 100 and 150% ESCS-LWA resulted in 13.9 and 6.9% soil moisture reductions from 41.1 and 38.7% soil moisture, respectively, 24 h post RFS compared to a 17.6 reduction for bare soil controls. Application of ESCS-LWA for 50% ground cover resulted in similar losses of soil moisture of 19.1% from 41.3% compared to bare soil controls.

Differences in common bermudagrass establishment between the ESCS-LWA did not affect harvested shoot biomass. After the first RFS, shoot biomass was similar across all ESCS-LWA ground coverages at 0.62, 0.82, and 0.74. Interestingly, even though common bermudagrass establishment coverages were similar between all ESCS-LWA applications, bermudagrass biomass was between 2.73 and 2.83 $kg.ha^{-1}$ for ESCS-LWA 100 and 150% ground coverages after the second RFS. Bermudagrass biomass from the 50% ESCS-LWA ground cover was less than 1.06% of shoot biomass for the 100% and 150% ESCS-LWA ground coverages.

Table 2. The effect of ESCS-LWA ground coverages of 0, 50, 100, and 150% on moisture retention at the soil surface for a period of 30 days within intervals of 10 days post rainfall simulation performed for a 30-min period at 70 mm h^{-1}.

	Days after rainfall simulation			
Ground cover	1	10	20	30
---------%--------	--------------------%---------------------			
0	31.6B	14.0D	11.5C	8.3C
50	41.3A	22.2C	14.4C	10.3C
100	41.1A	27.1B	19.5B	16.4B
150	38.7A	31.9A	26.8A	22.5A

Means are separated according to Fisher's LSD (α=0.05) with letters representing differences across ground coverages.

Field Trial

Erosion from levee embankment

Erosion from the field trial differed across ESCS-LWA ground coverages with 50 and 100% resulting in no rilling 116 DAI compared to bare soil with 4 rills (table 3). In general rill development in the control was observed to become wider and deeper each sequential observation date as rainfall totals accumulated from 0.3 mm December 2011 to 1.2 mm February 2012 (table 4).

Table 3. The effect of ESCS-LWA ground coverages of 0, 50, and 100% on preventing rills formation at an un-vegetated levee for a period of 116 days with three evaluations at 12, 36 and 116 days after ESCS-LWA ground coverages application.

Days after ESCS-LWA application	Number of rills formed		
	0%	50%	100%
12 d	0A	0A	0A
36 d	4A	0B	0B
116 d	5A	0B	0B

Means are separated according to Fisher's LSD (α=0.05) with letters representing differences across ground coverages within days of evaluation.

Table 4. The effect of ESCS-LWA ground coverages of 0, 50, and 100% on preventing rills formation at an un-vegetated levee for a period of 116 days with three evaluations at 12, 36 and 116 days after ESCS-LWA ground coverages application.

Month	Temp. (°C)			Humidity (%)			Wind (km h^{-1})		Precip. (mm)
	High	avg	low	high	avg	low	high	avg	sum
Nov	21	16	10	99,2	88,9	57,9	26	10	0,3
Dec	18	13	8	99,3	92,7	69,9	29	11	0,3
Jan	19	14	8	98,7	86,8	59,5	26	11	0,2
Feb	18	15	10	98,7	89,7	70,8	26	12	1,2
Mar	24	19	14	100,0	91,1	64,8	26	10	3,3
Apr	25	20	15	99,2	87,2	59,2	27	10	2,9
May	29	24	19	99,8	81,2	60,0	21	10	0,0
Jun	31	26	21	99,8	89,0	61,5	23	7	0,4
Jul	30	26	22	100,0	93,9	68,2	24	4	0,5
Aug	30	26	22	100,0	95,1	70,7	26	7	3,1

As observed in the RFS trials, increasing ESCS-LWA ground cover was able to retain soil moisture. Soil covered with 100% ESCS-LWA consistently resulted in >12% and 4 to 5% increases in soil moisture of bare soil controls and 50% ESCS-LWA ground coverage. Increase in soil moisture retention and accumulated rainfall affected salt concentrations in the upper 10 cm of soil (figure 7).

Salt concentrations decreased to 20 and 14dS.m^{-1} at 116 DAI from 43 and 43dS.m^{-1} 12 DAI for 50 and 100% ESCS-LWA ground coverages, respectively (figure 8). Although all treatments resulted in a decline in soil salt concentrations, bare soil controls resulted in less of a magnitude of change in salt concentrations and even showed an increase in salt concentration from 116 to 217 DAI (figure 8) as evaporative conditions increased with increases in temperature from 15 to 26 ^{o}C (table 4).

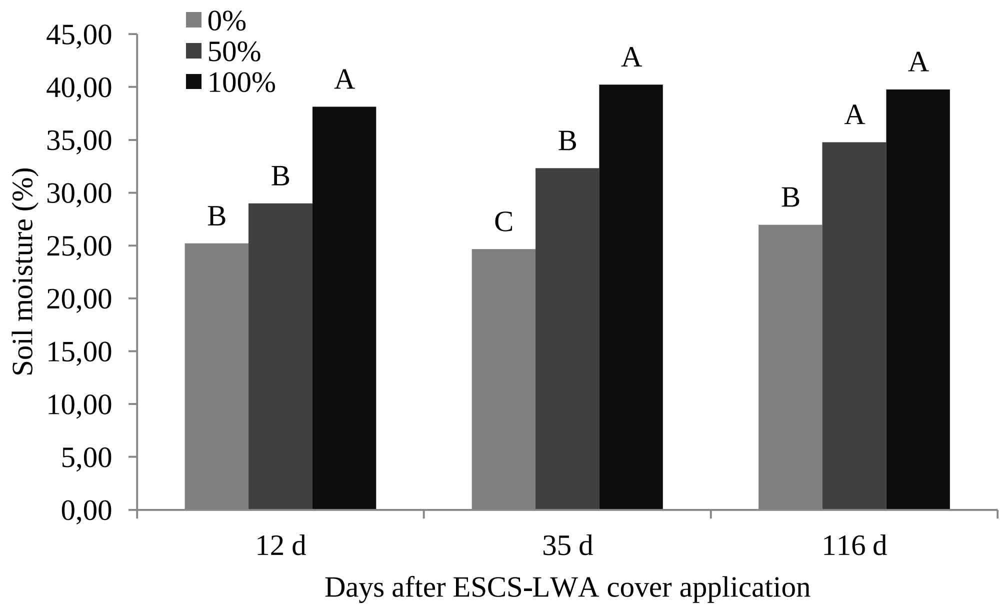

Figure 7. The effect of ESCS-LWA ground coverages of 0, 50, and 100% on moisture retention at the soil surface on a levee with high salinity concentrations levels for a period of 12, 35, and 116 days within field conditions of varying precipitation and irradiance. Means are separated according to Fisher's LSD (α=0.05) with letters representing differences across ground coverages at days of moisture readings.

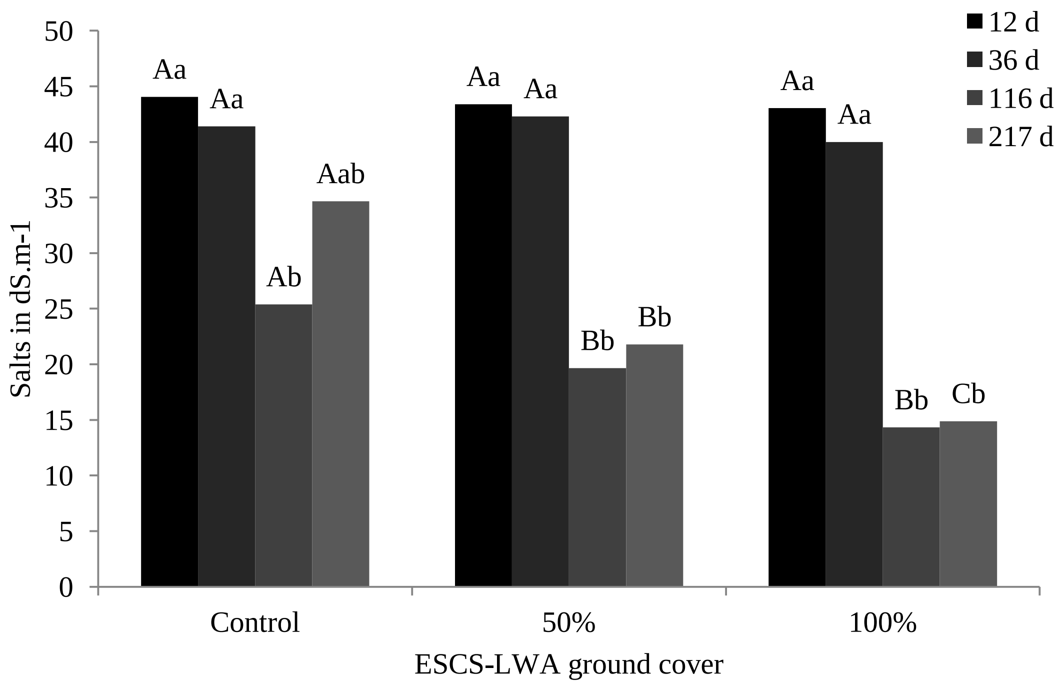

Figure 8. The effect of ESCS-LWA ground coverages of 0, 50, and 100% on salt concentrations at the soil surface on a un-vegetated levee originally high in salinity concentrations levels for a period of 12, 35, 116, and 217 days under field conditions of varying precipitation and irradiance. Means are separated according to Fisher's LSD (α=0.05) with capitol letters representing differences across ground coverages and small letters representing days of soil sample collection.

Decreasing salt concentrations and increasing soil moisture retention allowed perennial ryegrass to germinate and establish under these extreme saline conditions on sloped clay embankments after several months under un-vegetated conditions. ESCS-LWA treatments resulted in perennial covers of 53 and 88% for 50 and 100% ESCS-LWA ground coverages (table 5). Bare soil did result in 5% coverage particularly in rills created from high surface water flow. Another consideration is the effect of the ESCS-LWA ground coverages to reduce seeds from washing away down slope well evidenced in the ryegrass ground coverage at the slope.

Table 5. Vegetation percentage coverage response to ESCS-LWA ground coverages of 0, 50, and 100% at an un-vegetated levee for a period of 116 days with three evaluations at 12, 36 and 116 days after ESCS-LWA ground coverages application under field conditions.

Days after ESCS-LWA application	Vegetation percentage coverage		
	0%	50%	100%
12 d	0A	0A	0A
36 d	0A	0A	0A
116 d	5C	53B	88A

Means are separated according to Fisher's LSD (α=0.05) with letters representing differences across ground coverages within days of evaluation.

DISCUSSION

Use of ESCS-LWA for erosion control would be appropriate for areas with steep slopes, subject to periodic drought, or under conditions generally non-conducive for vegetation establishment. Under the conditions tested ESCS-LWA was able to reduce TS losses 465 and 160kg ha^{-1} for RFS1 and 1029 and 238kg ha^{-1} for RFS2 when applied at 100% and 150% ground coverages compared to 10657 and 6232 kg ha^{-1} for bare soil. Like other erosion resistant covers and well-established vegetation, ESCS-LWA provided a consistent barrier to erosion especially as ground coverage increased from 0 to 50 to 100 and 150%. The inability of 50% ESCS-LWA ground cover to consistently decrease TS loading is attributed to increased incident of splash erosion and rill development observed in the second RFS. Therefore factors such as raindrop size and intensity, soil type, and slope may have greater effect on ESCS-LWA performance when applied at less than 100% ground cover. Research that has examined changes in soil vegetative coverage has reported increased erosion often occurs at sparser vegetative coverages as a result of bare areas connecting to one another during the runoff process (Lang, 1979, Mwendera and Saleem, 1997, Borst, 2011). Rill development within the soil concentrates water flow to allow greater erosion (Bryan, 2000). However, applying 100% ESCS-LWA ground cover provides ample protection to reduce TS movement from a 30% sloped clay soil during intense precipitation.

Based on the TS data from RFS and field evaluation, long-term erosion resistance performance would be expected for ESCS-LWA compared to less durable organic based mulch products because ESCS-LWA is an inorganic product resistant to microbial degradation. However the differences in vegetation, a perennial biological cover, and ESCS-LWA deserve further inquire to understand the benefits and drawbacks of ESCS-LWA as an erosion control product. Vegetation has been shown to increase soil infiltration capacity to reduce runoff occurrence and severity as a result of high biomass of shoots and root densities (Beard and Green, 1994); whereas ESCS-LWA applied to a soil's surface should not alter soil structure to affect hydraulic drainage processes below the soil surface. Grasses have been reported to reduce soil moisture through transpiration to increase soil infiltration capacities and surface runoff potential. Rather ESC-LWA appears to act as a barrier between the soil-atmosphere continuum to disrupt evaporative processes to retain soil moisture. A pattern of greater soil moisture at higher ESCS-LWA applications was measured. For example, 150% ESCS-LWA ground cover retained >22.5% of soil moisture over a 30-d period post RFS compared to 8.3% for bare soil controls (table 2). Similar findings concerning moisture retention have been reported regarding mulch use in landscapes (Meyer et al., 1972).

Increased soil moisture in turn resulted in faster runoff release during rainfall simulations. This suggests higher soil moisture retention with increasing ESCS-LWA ground coverages would increase a sites susceptibility to surface runoff occurrence and possibly increased erosion severity. Research has clearly characterized and demonstrated the direct correlation between antecedent soil moisture and runoff susceptibility and by definition surface runoff is the saturation of soil to the point of overland flow (Pote et al., 1996). However, based on the data for erosion and water volumes lost as a percentage of applied rainfall, ESCS-LWA applied at 100 and 150% ground coverages may act as a filter for suspended solids retention but more than likely is effective as a barrier in preventing soil detachment. ESCS-LWA slows water flow to allow greater soil infiltration as demonstrated by the reduced runoff volumes of 50 and 100% ESCS-LWA ground coverages.

Although the erosion resistance gained through the application of ESCS-LWA would be suitable for many sloped sites subject to surface runoff, ESCS-LWA's ability to retain soil moisture also proved advantageous in accelerating common bermudagrass establishment. The transition of ESCS-LWA to a vegetative cover could strengthen an embankment that it has greater erosion resistance over time. Establishment of vegetation has been shown to significantly decrease erosion on slopes as demonstrated in research conducted by Easton and Petrovic, 2004 and Burwell et al. 2011). Although, ESCS-LWA coverage of 150% had the greatest reduction in TS loading and retained the highest soil moisture over the 30-day observation period, bermudagrass establishment lagged ESCS-LWA ground coverages of 50 and 100%. The increased density of ESCS-LWA material at 150% ground cover most likely resulted in greater soil shading. Bermudagrass does not necessarily require irradiance to germinate (Baldwin et al., 2008), but increasing irradiance levels has been shown to have a positive effect on germination. The other consideration is that common bermudagrass germination occurred but seedlings did not have sufficient carbohydrate reserves to allow leaves to emerge above the ESCS-LWA 150% ground cover density to perform photosynthesis. Other plant species may be more tolerant to germinate and grow in higher ESCS-LWA densities. However, until further investigation into ESCS-LWA densities and plant species is conducted the application of 100% ESCS-LWA remains the best practice for increased erosion resistance and grass establishment.

The performance of the ESCS-LWA to reduce erosion in the form of rilling in the field trial was expected. However, what was not expected was the growth of the perennial ryegrass under the highly saline soil conditions. High soil salt concentrations have been reported to result in poor seed germination and plant growth at much lower concentrations than measured at this site. Applications of ESCS-LWA performed according to RFS measures for 100% ground cover and showed surprising erosion resistance at 50% ESCS-LWA ground coverage. This increase performance at 50% ground coverage is probably due to perennial ryegrass establishment which prevented rill development. Failure to establish vegetation would most likely have affected 50% ESCS-LWA ground cover performance over a longer duration.

The declines in soil salt concentrations were unexpected, but given the ability of ESCS-LWA to reduce erosion and decrease runoff volume through the creation of a tortuous pathway resulted in greater water infiltration and salt leaching in the upper 10 cm of soil. Over the 116 d observation period, 100% ESCS-LWA ground cover reduced soil salt concentrations 32.5% from $43 dS.m^{-1}$ whereas controls decreased to a lesser extent over the same period. In addition, the increase in soil salt concentrations during summer temperature extremes when perennial ryegrass was dead was typical for bare soil. Salts movement in soil have been shown to be mediated by water movement (Brady and Weil, 1996). Because the field trial was not designed to examine the use of ESCS-LWA for grass establishment under highly saline conditions for levee embankments, further study is warranted given the positive results of vegetation establishment in an area that had remained un-vegetated in excess of three years. Therefore, ESCS-LWA should provide acceptable erosion resistance for extended durations to allow vegetation establishment on embankments constructed from highly saline clay.

CONCLUSION

The objectives of this research to characterize the ability of ESCS-LWA to reduce erosion and evaluate the effect of ESCS-LWA on vegetation establishment from seed resulted in a successful achievement based on the findings.

The application of ESCS-LWA at 100% provided consistent erosion control during RFS and resulted in the highest grass coverage for all ESCS-LWA ground coverages tested. The ability of ESCS-LWA to reduced erosion is a result of its creating a barrier to soil detachment from splash erosion and decreasing water flow for greater water infiltration. Post-RFS ESCS-LWA increased soil moisture over a 30-d period for common bermudagrass establishment and transition to a vegetative cover, but that application rates above 100% ground cover may affect plant establishment. Field trials indicated ESCS-LWA may have also have the benefit of reducing high soil salt concentrations for vegetative establishment while protecting the embankment from erosion.

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CHAPTER 3: SUMMARY

Vegetation establishment on levees is not only important for erosion control but also for maintaining structural integrity. Levee embankments are important structures for insuring safety and protection of Louisiana's vulnerable coast and land to flooding. To protect levees form severe real erosion and failure, hard and soft-armoring have been used as a barrier to reduce sediment losses; however most hard armoring materials are expensive whereas the more economical soft armoring requires continued maintenance. Levees constructed with high soil-salt sediments that remain un-vegetated for years are extremely exposed to erosive forces, requiring addition of soil to replace the material eroded resulting in extra costs to a levee construction project. To control erosion at the soil surface, the application of mulch is widely used and recommended. Although most of the research done on mulch in field conditions does not reflect the adequate long-term period of time for vegetation establishment the light weight aggregate proposed for erosion control in this study was capable of proving its efficacy controlling erosion for a period longer than 16 weeks applied in field experimentation.

VITA

Murilo de Santana Martins was born in Salvador, Bahia, Brazil. He attended the Federal University of the Reconcave of Bahia at Cruz das Almas, Bahia, where he received his Bachelor of Science degree in Agronomy Engineer in February 2008. During his undergraduate time, Murilo was granted with a research scholarship for three years and worked on different research projects at his university and at the Brazilian company for farming research and development, ranging from development of farming machinery to molecular biology and transgenic studies. He was also granted with a research scholarship to participate in a fellowship program among his university, Louisiana State University and University of Minnesota before his graduation. After graduation, Murilo worked six months as a research associate under Dr. Breitenbeck at Louisiana State University, Baton Rouge, working on Chinese tallow tree propagation and biofuel production. Murilo was then accepted by The Graduate School at LSU to the Department of Plant, Environmental, and Soil Sciences, and began working on his Masters of Science under Dr. Jeff Beasley and Dr. Gary Breitenbeck with a focus on erosion control on levee embankments constructed with high soil-salt concentrations.