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Identification, Mitigation, and Adaptation to Salinization on Working Lands in the U.S. Southeast

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Cover Photograph: Fields of corn are flooded and crops may be ruined for the year by the flooding waters of the Mississippi River in southern Illinois. (Photo courtesy of Robert Kaufmann, FEMA)

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Key Messages

- Soil salinization in the coastal Southeastern United States is becoming more prevalent as storm surges increase in frequency and sea levels rise.
- Salinization reduces the productivity of working lands and can prevent crops from growing.
- Resources are lacking for landowners to understand coastal salinization and how to manage for resilience.
- Action must be taken if the land is to remain profitable as conditions change.

This manual describes the impacts and includes adaptation measures that can be taken to maintain productivity in working lands.

Keywords: Adaptation, agriculture, saline soil, salinity, salinization, sea-level rise.

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Executive Summary

Droughts and heatwaves, floods, wildfires, and hurricanes dominate the news. These disturbances can cause billions of dollars per event in damage to agriculture and forestry. However, saltwater intrusion into the forest, agricultural, and pastureland soils across eastern Coastal and Gulf States can also negatively impact productivity and profitability. Saltwater intrusion's negative impacts include tree and crop death, reduced growth, and crop yield. Even though biological productivity may still be possible, the economic value in maintaining these working lands can be insufficient to justify continued use. Although an exact number of acres being lost per year is not currently known, low-elevation agricultural land in the Southeast is being lost. In Somerset County, MD, 3.5 km^2 of agricultural land became tidal wetland between 2009 and 2017.[1] As the sea level rises, the number of acres impacted by salinization is expected to increase.

Soil salinization driven by saltwater intrusion can occur due to sea-level rise, storm surge, high tides that overtop low-elevation areas, drought, and groundwater pumping, as well as other natural and anthropogenic events. Increases in some types of salinization can be planned given our knowledge of sea-level rise as predicted by the NOAA Sea Level Rise Viewer. However, storm surges are unpredictable from tropical storms that develop quickly and have unpredictable impacts. Storms can bring strong winds that push salts

Salt Marsh in Salcott Creek/Blackwater Estuary. (Photo courtesy of Matthew Barker, Wikimedia Commons; CC BY 2.0 license)

Ghost forest in Nags Head Woods, NC. (Photo courtesy of NC Wetlands from Raleigh, NC; CC BY 2.0 license)

inland, but they also bring precipitation that may help remove the soil salts through leaching. **This guide does not predict the rates of sea-level rise or soil salinization but instead provides mitigation and adaptation practices that can reduce soil salinization impacts on productivity.** Managing for both storm and sea-level rise will require different adaptation and mitigation practices. The frequency and duration events can range from episodic (e.g., shorter duration, but intense coastal storms and hurricanes) to chronic saltwater saturation from sea-level rise and migrating tidal boundaries. Both climate change-induced increases in the frequency and size of storms, and more frequent king [i.e., exceptionally large (perigean spring)] tides can push saltwater farther inland. Much of the Southeast Atlantic Coast has experienced increases in nuisance level flooding since the 1980s,[2] and sea levels have been rising at an accelerating rate globally since the 19th century.[3]

Droughts contribute to salinization by decreasing the amount of available freshwater to flush salts out of soil and groundwater. Water management also contributes to freshwater availability as withdrawal of surface and groundwater for drinking water and irrigation reduce the amount of freshwater available to prevent saltwater intrusion. Hydrological connectivity (e.g., tide gates, valves, levees, agricultural diversions, roadside ditches, and canals) can impact the extent of saltwater intrusion. For example, canals and ditches can act as conduits for saltwater intrusion to reach farther inland, while tide gates and valves can block saltwater from moving inland. Tide gates and valves can be used to block intrusion. However, they can also lead to salinity issues if saltwater is trapped behind them and unable to drain away.

Coastal Virginia, Maryland (Delmarva Peninsula), and North Carolina (Albemarle Pamlico Peninsula) are notable areas where agricultural land is currently negatively impacted by salinization. The area of impacted land is expected to increase in size as sea levels rise and saltwater intrusion moves farther inland. Additionally, hurricanes will continue to bring storm surge and coastal flooding. Thus, there is a great need to identify the current and future areas of soil salinization.

Mitigation measures, including leaching with freshwater and installing water control structures to sustain land productivity at risk of salinization, can be used when they are economically beneficial. Mitigation measures can be attempted, but they are often costly and can be unproductive. Adaptation measures can also be applied in preparation for potential inputs of saltwater. Chronic saltwater inputs will inevitably require landowners to implement adaptation measures, including planting more salt-tolerant crops to continue gaining profit from the cultivation of the land.

This guide is designed to assist the producer (extension agents, landowners, U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) field staff, private consultants) in determining their land's stage of soil salinization. This is a general guide for the U.S. Southeast, and specific recommendations will depend on the producer's site characteristics. Recommendations for mitigating soil salinization may be proposed based on the cause and salinization stage. The guide also provides information regarding expected production reductions for economically important crop species and cultivars across various soil salinity levels. The salinization levels have been divided into stages to allow the producer to assess the soil's condition and management options more easily. At some point, the land may no longer be commercially profitable. Hence, the guide includes a chapter that helps determine when farming or forestry is no longer advisable and when the land could be better used as a conservation easement. The appendix includes lists of useful links and resources containing information on the topics covered in this guide. The recommendations and information provided in these chapters are not meant to replace the need to meet with the county Extension specialist, soil conservation district office, or other professional service providers.

CHAPTER 1

Background

Agricultural productivity provides safe, reliable, and affordable food and agricultural products for the Southeastern United States. Agriculture is a crucial contributor to the region's economic growth and development. Agricultural productivity is impacted by many factors, including soil fertility, water availability, climate, disease, insects, weed control, pests, plant nutrients, and hybrid or variety selection. Many of these factors cannot be controlled, but most can be managed. Salinity is an often-overlooked factor that negatively impacts agricultural productivity in the U.S. Southeast. Salinization in the Southeast is different from salinization in arid climates. The southeast system is both wet and salty. Dry, salty systems, such as those found in arid and semi-arid climates of the Western United States, have been studied for decades, but salinization in wet systems typical of the Southeast presents unique problems. These unique problems include the difficulty of salt removal from wet soils, compounded problems due to waterlogging, and encroaching saline groundwater in coastal areas. Salinization of soils can make land unfarmable. Rising sea levels contribute to soil salinization through raising groundwater tables, increasing saltwater intrusion, and magnifying storm surges in coastal lands.[4]

Salinization is the accumulation of water-soluble salts in the soil. The accumulation can occur very slowly (e.g., sea-level rise) or quickly (e.g., hurricane storm surge), depending on a combination of factors driving salinization. In areas experiencing subsidence, the relative increase in sea-level rise is faster because as the sea is rising, the land is sinking. The Mid-Atlantic States of the Eastern U.S. have been identified as especially vulnerable to coastal flooding due to the co-occurrence of increasing sea-level rise and land subsidence rates. The Mid-Atlantic area has a sea-level rise rate that is accelerating three to four times faster (3.8 mm yr^{-1}) than the global average (~1 mm yr^{-1})[5]. The timing of these impacts is variable and based on the occurrence of tropical storms and sea-level rise, both of which vary tremendously along the east and gulf coasts.

Often, the factors contributing to salinization are connected and work together to accelerate salt accumulation. For example, an area experiencing chronic saltwater intrusion may experience a drought, which concentrates the soil's salts, leading to a salinity spike. However, in some cases, salt-stressed coastal areas can recover to background production levels if freshwater is returned to the system, such as following a large precipitation event or through irrigation flushing of the soil.

Wind plays a significant role in determining how ocean water interacts with the land. Storm surges can be more extensive and last longer depending on the wind direction, the hurricane's strength, the tide, and local hydrological conditions. Large storm surges create more coastal damage from erosion, soil compaction, and saltwater intrusion. Salinity could be introduced as droughts become more frequent. There could be a seasonal salinity increase from groundwater and surface waters that recover when the drought was over. There can be seasonal shifts in the freshwater-saltwater interface due to seasonal changes in groundwater discharge rates and water table depths. These interface changes generally occur in the summer season when water use by vegetation is at its peak. Also, during peak water use, surface waters can be low and subject to tidal flow.

Crop revenue, production costs, farm profitability, and land values can be significantly reduced by salt in the soil. Many crops are yield-dependent, in that higher yields reduce per-unit production costs. Small reductions in yield due to salinization can adversely affect net returns per acre and erode profitability. Fully understanding the impact of salinity on crop production is essential since adaptation practices may extend agricultural land's working life in many areas along the southeast U.S. coast. Understanding how the land is changing will allow producers to proactively plan for the future to minimize productivity declines.

Many crops have known thresholds of tolerance and slopes of decline (table 1) in response to soil salinity.[6,7,8] Salinity is often measured through a solution's electrical conductivity (EC). The salinity threshold of a crop is the point of salinity (EC) at which crop relative yield will begin to drop below 100 percent. The percent relative yield of crops in all commodity types decreases as the salinity increases, but their average decline rates are different (figs. 1–4). Individual crop yield decline values shown in these figures were derived using methods from Maas and Gratten (1999).

The relative yield percentage was calculated using the equation from Maas and Gratten, (1999):

$$Y_r = 100 - b\ (EC_{e-a})$$

where Y_r is the relative crop yield, a is the salinity threshold expressed in dS m^{-1}, b is the slope expressed in percentage per dS m^{-1}, and EC_e is the mean electrical conductivity of a saturated-soil extract taken from the root zone. The decline in percent yield in individual crops varies within commodity type. Actual changes in yield will vary depending on the specific crop genetic variety and site conditions. In this guide, increasing salinity levels are described as salinity stages (table 2).[9] Understanding this decline in productivity and the stage of salinity of the land is important to prepare for future increases in salinity.

Soil salinity stress in trees appears as a decrease in overall vigor, increased insect problems, sparse crown, low growth, mortality, short needle length in pines, small foliage in hardwoods, and overall appearance of poor health. Salinity impacts forest crops by reducing the amount of freshwater for tree use, generating osmotic stress similar to drought stress. Salt stress can cause reduced carbon assimilation in seedlings and produces weaker seedlings compared to non-stressed seedlings.[10] Higher salinity levels and longer durations of exposure may cause salt burning, browning of leaves, and eventual tree death. Salinization suppresses regeneration in tree species, and impacted areas may be slow to recover after a storm that pushed saltwater far inland. When soils are nonsaline, tree seedlings and saplings will regenerate after an event as long as conditions are favorable (i.e., adequate sunlight, nutrients, moisture, temperature, and soil characteristics). Trees can also be stressed from a saturated root zone following a storm or due to an elevated water table due to sea-level rise. Therefore, differentiating the cause of tree stress (i.e., soil salt or waterlogged soil) is essential. Soil elevation often determines if forests will survive or drown. While many row crops have experimentally determined salinity thresholds and slopes of reduction per unit

Table 1—Crop thresholds and slopes as determined by experimental field and lab studies

Crop	Botanical name	Threshold (EC)	Slope (%)
Artichoke, Jerusalem (Tabers)	*Helianthus tuberosus*	0.4	9.6
Asparagus	*Asparagus officinalis*	4.1	2.0
Barley	*Hordeum vulgare*	8.0	7.1
Bean	*Phaseolus vulgaris*	1.0	19.0
Bean, mung	*Vigna radiata*	1.8	20.7
Bermuda grass	*Cynodon dactylon*	12.0*	6.4
Blackberry	*Rubus macropetalus*	1.5	22.0
Boysenberry	*Rubus ursinus*	1.5	22.0
Broadbean	*Vicia faba*	1.6	9.6
Broccoli	*Brassica oleracea (Botrytis)*	2.8	9.2
Cabbage	*Brassica oleracea (Capitata)*	1.8	9.7
Carrot	*Daucus carota*	1.0	14.0
Celery	*Apium graveolens*	1.8	6.2
Clover, alsike	*Trifolium hybridum*	1.5	12.0
Clover, berseem	*Trifolium alexandrinum*	1.5	5.7
Clover, ladino/white	*Trifolium repens*	1.5	12.0
Clover, red	*Trifolium pratense*	1.5	12.0
Corn	*Zea mays*	1.8	7.4
Cotton	*Gossypium hirsutum*	7.7	5.2
Cowpea	*Vigna unguiculata*	4.9	12.0
Cucumber	*Cucumis sativas*	2.5	13.0
Eggplant	*Solanum melongena*	1.1	6.9
Flax	*Linum usitatissimum*	1.7	12.0
Foxtail, meadow	*Alopecurus pratensis*	1.5	9.6
Garlic	*Allium sativum*	3.9	14.3
Grape	*Vitus vinifera*	1.5	9.6
Grapefruit	*Citrus x paradisi*	1.2	13.5
Guar	*Cyamopsis tetragonoloba*	8.8	17.0
Guava	*Psidium guajava*	4.7	9.8
Guayule	*Parthenium argentatum*	8.7	11.6
Harding grass	*Phalaris aquatica*	4.6	7.6
Lemon	*Citrus limon*	1.5	12.8
Lettuce	*Lactuca sativa*	1.3	13.0
Muskmelon	*Cucumis melo*	1.0	8.4
Onion (bulb)	*Allium cepa*	1.2	16.0
Onion (seed)	*Allium cepa*	1.0	8.0
Orange	*Citrus sinensis*	1.3	13.1
Orchardgrass	*Dactylis glomerata*	1.5	6.2
Pea	*Pisum sativum*	3.4	10.6
Peach	*Prunus persica*	1.7	21.0
Peanut	*Arachis hypogaea*	3.2	29.0
Pepper	*Capsicum annuum*	1.5	14.0
Plum, prune	*Prunus domestica*	2.6	31.0
Potato	*Solanum tuberosum*	1.7	12.0
Quinoa	*Chenopodium quinoa willd*	3.0	1.9
Radish	*Raphanus sativus*	1.2	13.0
Rice, paddy	*Oryza sativa*	3.0	12.0
Rye	*Secale cereale*	11.4	10.8
Ryegrass, perennial	*Lolium perenne*	5.6	7.6
Sesbania	*Sesbania exaltata*	2.3	7.0
Sorghum	*Sorghum bicolor*	6.8	16.0
Soybean	*Glycine max*	5.0	20.0
Spinach	*Spinacia oleracea*	2.0	7.6
Squash, scallop	*Cucurbita pepo var. clypeata*	3.2	16.0
Squash, zucchini	*Cucurbita pepo var. cylindrica*	4.9	10.5
Strawberry	*Fragaria x ananassa*	1.0	33.0
Sudangrass	*Sorghum sudanense*	3.0**	9.1**
Sugar beet	*Beta vulgaris*	7.0	5.9
Sugarcane	*Saccharum officinarum*	1.7	5.9
Sweet Potato	*Ipomoea batatas*	1.5	11.0
Tomato	*Lycoperscion lycopersicum*	2.5	9.9
Tomato, cherry	*Lycoperscion lycopersicum-cerasiforme*	1.7	9.1
Triticale	*X Triticosecale*	6.1	2.5
Turnip	*Brassica rapa (Rapifera)*	0.9	9.0
Vetch, common	*Vicia sativa*	3.0	11.0
Wheat	*Triticum aestivum*	6.0	7.1
Wheat (semidwarf)	*Triticum aestivum*	8.6	3.0
Wheat, durum	*Triticum turgidum*	5.9	3.8

Sources: Maas and Gratten (1999),[6] NRCS Technical Notes (1996),[7] Conway (2001).[8]

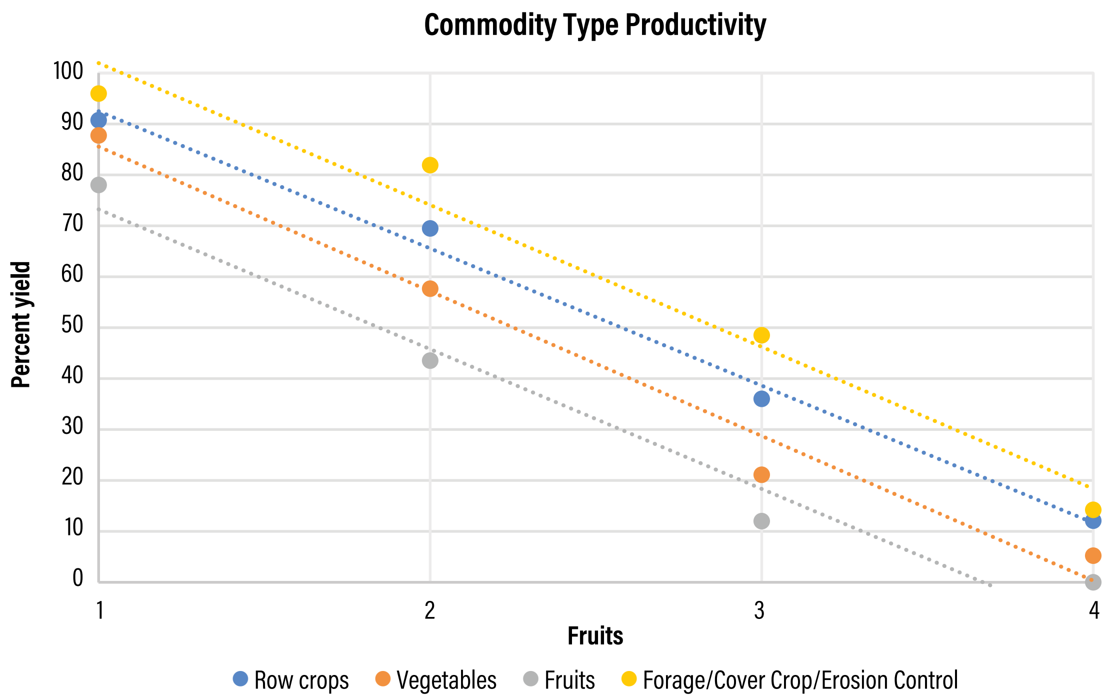


Figure 1—Generalized commodity average of the decrease in yield across four stages of soil salinity.

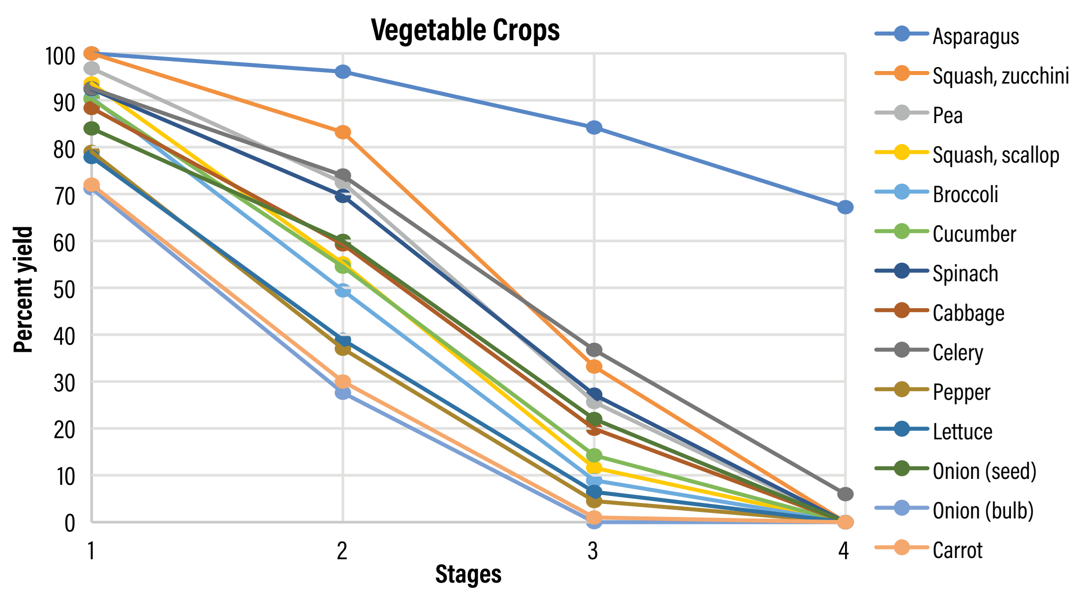


Figure 2—Generalized vegetable crop changes in yield across four stages of soil salinity.

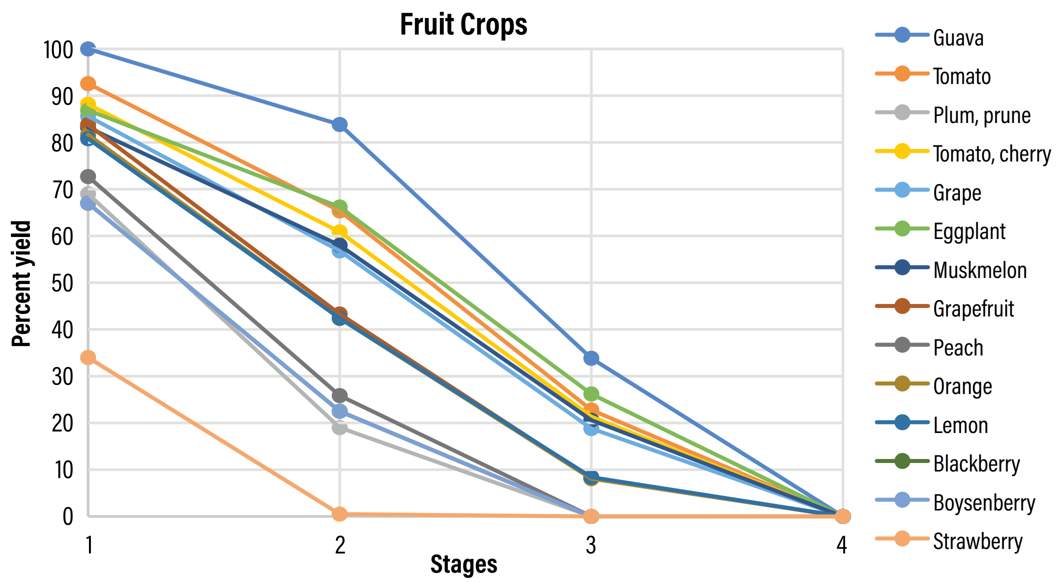


Figure 3—Generalized fruit crop changes in yield across four stages of soil salinity.

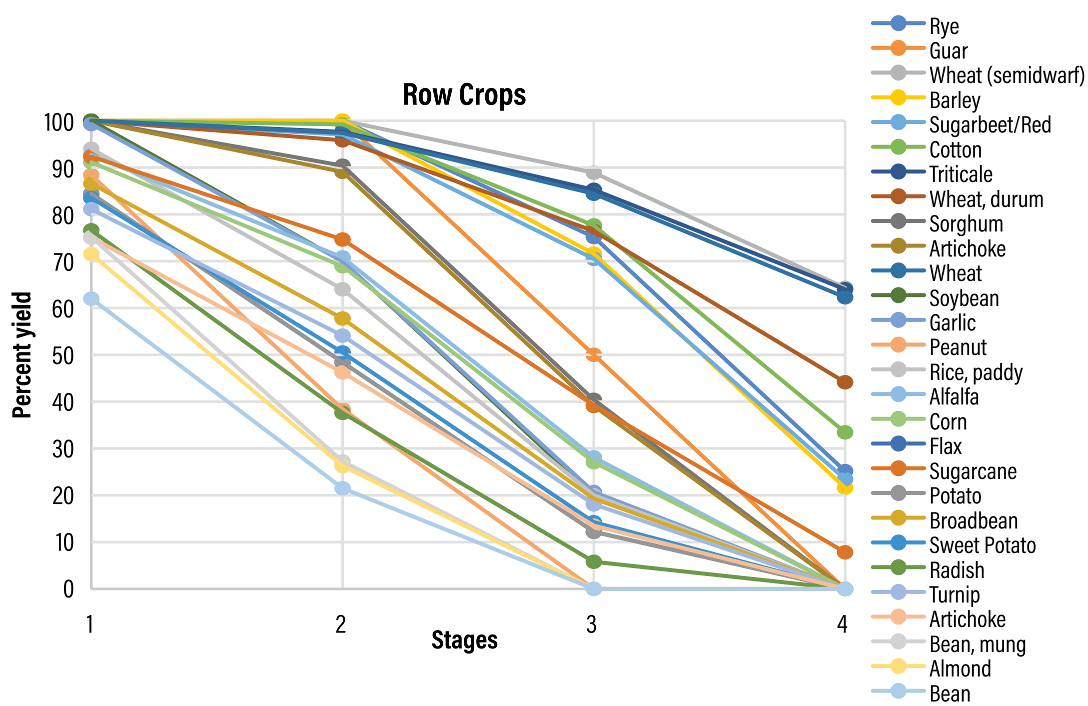


Figure 4—Generalized row crop changes in yield across four stages of soil salinity.

Table 2—Soil salinity classes as defined by McGeorge (1954)[9] and salinization stages as defined in this guide

Salinity class	Stage	Electrical conductivity (EC)
		dS m^{-1} or mmhos cm^{-1}
Nonsaline	Zero	0–2
Slightly saline	One	2–4
Moderately saline	Two	4–8
Strongly saline	Three	8–16
Extremely saline	Four	>16

increase in salinity, these values have not been determined for tree species. The life cycle of trees is much longer than for crops, so long-term data are necessary to determine the full effect of salinization. Thus, most studies have focused on seedling impacts[11] or examining tree death following hurricanes and storms.[12]

Adaptative or preventative measures or practices (e.g., field buffers, increasing drainage capacity, cover crops to remove salinity, flushing) should be considered along with their effectiveness and cost. For example, the plant material associated with buffers and excavation costs to increase the width, depth, or ditching length can be expensive. Soil salinization can also damage capital expenses like buildings, equipment, and machinery. Equipment service life is shortened, maintenance costs are elevated, and operating efficiency decreases due to salt corrosion. As capital items are expensive, deciding whether to replace them can impact farm profitability. This manual will provide some case studies as examples of the cost/benefit of managing salinated soil crops.

LEFT: **Ghost forests along the Seward Highway, near Anchorage, AK. (Photo courtesy of Alan Grinberg; CC BY-NC-ND 2.0 license);** RIGHT: **Mangrove to marsh transition zone. (Photo courtesy of USGS)**

CHAPTER 2

Assessing and Minimizing Salinity Risk to Soil

2.1 General Discussion

Landowners and managers need science-based strategies to formulate sound management plans in the face of climate change. Landowners need to understand the causes of salinization and knowing how to take a soil sample for testing used to measure salinity is useful. National Resources Conservation Service (NRCS) field staff or the local extension agent can be contacted to assist with soil sampling or to sample for the landowner. Salinity can change with depth in the soil profile. For certain crops, salinity in the top soil layer can impact seed germination, in which case planting seedlings would be better. Salinity in lower soil layers could move upward through the soil profile during dry periods.

Salinization and Soils in the Coastal Zone

Soil salinization can occur due to changing water demands, sea-level rise, drought, storm surge, groundwater pumping, and other natural and anthropogenic events.[13] Event frequency and duration can be episodic (e.g., intense coastal storms and hurricanes) or chronic (e.g., saltwater saturation from sea-level rise and migrating tidal boundaries). When saltwater along the coast inundates (i.e., floods) freshwater and terrestrial soils, saltwater intrusion occurs at the top of the soil profile and moves downward. The depth of intrusion during a saltwater flooding event depends on the saltwater volume and how long saltwater remains on the soil surface. Wetter soils have less pore space for saltwater to percolate, while dry soils allow more saltwater to move downward. Additionally, the soil properties themselves determine the rate at which water moves through the soil profile. Soils with higher clay content are less permeable than those with high sand content, resulting in slower water movement in clay soils.

Saltwater can also start at the bottom of the soil profile and move upward in the form of saline groundwater. For example, rising sea levels can impact freshwater aquifers and increase the salinity of the groundwater. Groundwater can move upward through the soil profile through capillary action. As water evaporates at the soil surface, deeper water moves upward through the soil profile to replenish the evaporating water. As the sea level rises, groundwater levels may also rise due to pressure from the saltwater-freshwater interface, which is the point where saltwater and freshwater push against each other. The sea level cannot rise without the upper boundary of the interface, which makes freshwater levels rise.

The physical and chemical characteristics of soils influence the potential for salt retention from coastal saltwater inundation (e.g., storm surge), intrusion (e.g., sea-level rise), or both. This chapter evaluates soil properties and factors that can determine salt retention in soils due to coastal saltwater inundation and intrusion. The soil risk assessment evaluates the salt retention potential of soil properties alone but does not consider the saltwater inundation, hydraulic gradients, or topography duration.

Knowing the saltwater inundation duration is essential because the negative impacts on crops will increase with more extended saltwater inundation. Inundation over 24 hours creates an oxygen-deficient condition for vegetation that are not flood-tolerant, in addition to increasing the level of toxicity to plants from saltwater. Higher salinity levels require the need to cultivate more salt-tolerant crops. However, if salinity levels are reduced, less salt-tolerant crops could once again be profitable.

There is limited information regarding how the duration and frequency of saltwater inundation impacts soil salinity. However, salinized soils may recover more fully as the time between saltwater inundation events and freshwater inputs increase. The long-term impact on soil productivity is dependent on the duration of inundation, soil texture, and soil moisture conditions before inundation occurs. Producers may want to consider irrigating non-saturated soils with freshwater before saltwater inundation to protect against increases in salinity and long-term soil productivity consequences. Producers may want to also consider irrigating saline soils with freshwater to assist with flushing out salts that may have accumulated during an inundation event.

In addition to being productive working lands, non-salt-impacted coastal soils are also a critical buffer for inland soils. Salinization, coastal erosion, and natural vegetation loss can all occur if coastal soils become degraded. Understanding how salt is retained and the impacts on coastal soils will increase a producer's knowledge and ability to cope with salinized soil migration.

The Retention of Salts and their Relation to Soil Properties

Several factors determine the retention of salts in upland soils due to saltwater inundation. These factors are soil texture, saturated hydraulic conductivity, cation exchange capacity, sufficient cation exchange capacity, and water table fluctuations. Soils with higher sand content are likely to have good drainage and retain fewer salts, while soils with higher clay content are less well-drained and more likely to retain salts. Sandy soils have a lower cation exchange capacity, a lower extractable cation exchange capacity, a higher saturated hydraulic conductivity, and typically have reduced impacts from saltwater inundation. Saturated hydraulic conductivity is a measure of the rate at which fluid moves through the soil, so soils with a high saturated hydraulic conductivity drain well and are less susceptible to salinization. The cation exchange capacity and the effective cation exchange capacity are two measures of the number of exchangeable cations in the soil. If the amount of exchangeable cations in the soil is high, the soil more readily retains soluble salts. Thus, clay soils retain salts and drain more slowly than sandy soils due to their low saturated hydraulic conductivity and higher cation exchange capacity.

Evaluation Criteria

Understanding the current salinization stage of the land is an essential first step toward addressing negative salt impacts. This soil salinization manual divides salinization into six stages, ranging from non-impacted land to chronic surface water. Several relatively simple tests can be done to determine the current soil salinity stage. State government and university laboratories, listed in Appendix IV, can perform these tests. Check with the local laboratory to see if there is a testing fee.

The physical, chemical, and hydraulic properties of coastal soils determine their ability to retain salts when exposed to saltwater inundation. Criteria have been identified by the U.S. Department of Agriculture (USDA) Natural Resources Conservation Service

(NRCS) to evaluate the potential of soils to retain salts based on their properties and characteristics. The evaluation criteria are:

- **1:5 Electrical Conductivity (EC 1:5)**—Test that measures the existing electrical conductivity of soil, which can be used to estimate the soil's current salt content.
- **Percent Sand**—Soils with a higher sand content are well-drained and less likely to retain salts.
- **Depth to Water Table**—A shallow water table could increase salt buildup in the soil. A shallow water table supplies water for evaporation at the soil surface and plant water use in the root zone through upward movement. Dissolved salts in the groundwater, when brought upward through capillary action, build up in the soil surface. A shallow water well can be installed near the field to measure water table depth.
- **Cation Exchange Capacity (CEC)**—Soluble salts are more readily retained by soils with higher cation exchange capacity, such as clays.
- **Effective Cation Exchange Capacity**—Measures the total amount of exchangeable cations in the soil. The higher the effective CEC, the more likely the soil will retain salts.

2.2 Soil Testing for Salt

Soil analyses are required to assess the salinity level and to identify the specific solutes that comprise the salt in the soil. A thorough sampling of the site is recommended. Samples from an area representing the field should be taken using a soil probe from depths of 0–15 cm (0–6 inches) and 15–30 cm (6–12 inches). Soil experts can assist with the interpretation of analysis results.

Quick Bioassay Method

This could be an initial test prior to sending in soil samples to a lab for analysis. Producers can perform a simple experiment (bioassay) on their own with a small amount of soil from affected areas before planting large acreages of forage crops, especially ryegrass and clovers. The bioassay can help predict potential crop injury. A bioassay does not measure the amount of salt residue present in the soil, but it may indicate whether enough salt residue is present to injure seedlings.

To begin the bioassay procedure, take soil samples in the top 3 inches from several locations in the field suspected of having high salt content. Mix the soil samples together in a clean plastic pail. You will need about a quart of soil for the bioassay. If possible, also take separate samples from fields that did not receive any saltwater intrusion. These samples can be labeled as "check" samples. Plastic bottles and boxes, milk cartons, and cottage cheese containers are appropriate containers in which a bioassay can be conducted.

Punch holes in the bottom of the containers to allow water drainage. Sprinkle a small amount of seed (about a teaspoon) in each container of soil and cover the seeds with about ½ inch of soil. Wet the soil with water, but do not saturate it. Place the containers in a warm location (70–75 °F) where they can receive ample sunlight. Keep the containers moist.

Within 7–10 days, injury symptoms should become apparent. Possible symptoms include no germination, partial germination, slowed emergence, or seedlings appearing to be dried out. It is a good idea to compare the germination and growth of the seedlings in the salt-affected containers to those in the "check" containers. Although this is not a precise experiment, it should provide an idea of how various forage species may germinate and grow in areas affected by saltwater intrusion.[14]

Salinity Survey Techniques

Measuring the electrical conductivity (EC) of the saturated extract is the standard method of estimating soil salinity. The saturated extract is an extract from the soil sample following saturation with water. The electrical conductivity of the soil extract is determined in a laboratory. Some laboratories use different methods to measure EC, so understanding the method used is essential when viewing soil analysis results. This guide uses EC values obtained from a saturated paste extract as its standard. The saturated paste extract may also be used to measure pH and analyze specific solute concentrations such as sodium, magnesium, calcium, potassium (common salt-forming cations), bicarbonate, carbonate, sulfate, chloride, and nitrate (common salt-forming anions).

Soil analysis should also be performed to understand the sodicity of the soil. **Differentiating between saline and sodic soils is essential because this guide addresses saline, not sodic soils**. Sodicity is the accumulation of sodium salts specifically. Sodium salts deteriorate soil structure and create waterlogged conditions. The level of sodicity is related to the texture, cation exchange capacity, and infiltration properties of the soil. High levels of sodicity may lead to crop failure. Agronomic consultants and extension agents can assist with soil testing and understanding testing results. Soil management and the potential amendment recommendations will depend on the results of soil analysis. Soil analysis should include soluble salts, sodium levels, EC, ESP (exchangeable sodium percentage), pH, and texture.

Salts can accumulate at different levels of the soil profile. An analysis of individual samples collected from each soil horizon will provide information about the chemical differences among soil horizons. Sampling each horizon is different from the 0–15 cm and 15–30 cm samples previously mentioned. When horizon-level soil samples are collected, they should not contaminate samples from other depths. The samples at each depth should be crumbled, air-dried, thoroughly mixed, and placed in labeled containers. Labels must include the date, upper and lower profile depths of the sample, and site name and location. The soil surface conditions, crop appearance, crop history, yield, and next crop should also be noted for each sample site. Care should be used to prevent contamination of the samples, including keeping them dry, and they should be sent to the same laboratory for analysis to reduce laboratory bias errors. Soil testing laboratories for Southeastern States are in Appendix IV.

Soil testing laboratories analyze a small soil volume to generate management recommendations for the land manager/applicant. The land manager should try to collect samples that adequately represent the desired total land area. However, many agricultural fields display substantial variation in soil texture, topography, and land-use history. The number of cores needed to reduce variation within the sample varies with the represented area size. Many agencies and university extension services recommend a minimum of 10 cores per sample to as high as 20 cores per sample (each sample represents one soil horizon/core). NRCS recommends that one composite sample (a mix of the samples collected from the same soil profile depth across the cores) per 20 acres or less is sufficient for testing in uniform fields. In smaller fields, one sample every 5 acres is recommended. Unique areas such as low spots, contour strips, and visible salinity stress areas should be sampled separately.

The potential for a soil to retain salts is dependent on the soil's electrical conductivity, total dissolved solids, soil pH, water table depth, and cation exchange capacity. Soil should be tested for these parameters in an assessment of the soil's condition. The parameter terms are described below.

- **Electrical conductivity (EC)** is a measure of the electrical current conducted by a saturated soil extract at a specific temperature. A higher amount of salts in the solution increases the EC and subsequent toxicity to plants. Electrical conductivity measures the overall water-soluble salts but does not differentiate between the types of salts. EC units of measure are decisiemens per meter ($dS\ m^{-1}$) and millimhos per centimeter ($mmhos\ cm^{-1}$), which are equivalent ($1\ dS\ m^{-1} = 1\ mmhos\ cm^{-1}$). In this guide, EC is used to define the stages of salinization. Measurements of EC are used to determine approximate crop yield reductions due to salinity.
- **Total dissolved solids (TDS)** are measured by evaporating a liquid solvent and measuring the mass of the residues. TDS is an alternative way to measure salts in a solution but contains similar information to EC. An approximate TDS can be estimated by multiplying the EC ($dS\ m^{-1}$) of moderately saline samples by 640 or the EC of very saline samples by 800. The units for TDS are milligrams per liter ($mg\ l^{-1}$) or parts per million (ppm), which are equivalent.
- **Soil pH** is a measure of the hydrogen ion concentration in soil solution. The soil pH scale ranges from 0 to 14: pH 7 is neutral, pH <7 is acidic, and pH >7 is alkaline or basic. Many arable soils have a pH in the range of 6.0–7.0. Soil pH affects soluble salts because ions react differently at varying pH levels. Therefore, soil pH is often included in soil salinity evaluations and discussions. Soluble salts also impact the soil pH, and pH is a valuable soil measure without being a direct measure of salinity. Changes in soil pH bring about changes in plant nutrient availability because microbial activity levels respond to soil pH levels. As soil pH increases, the following elements become limiting: iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), cobalt (Co), phosphorus (P), and boron (B).
- **Water table depth (WTD)** is the depth below the soil surface where the soil saturated zone is located. The water table depth can be measured by installing a monitoring well and using a water level meter. If the water table is often within 30 cm (11.81 inches) of the soil surface, dissolved salts in the saturated zone can move upward into the root zone through capillary action and evaporation from the soil surface, thus increasing the salts and salinity of the soil.
- **Cation Exchange Capacity (CEC)** is the total capacity of a soil to contain exchangeable cations. CEC is usually measured on microscopic scales such as soil particles smaller than 2 mm (0.08 inches). CEC is a measure of the soil's negatively charged particles to attract and retain positively charged ions. Soil with a high CEC can retain a higher amount of salts and fertilizer nutrients.

Soil Potential Rating Classes

After soils have been tested using the methods outlined above, the data should be plotted on a property map to approximate where soil salinity is an issue. The determination of the severity of salt retention potential can be categorized using the guidelines outlined in tables 3 and 4.

The likelihood of soils to retain salt from coastal saltwater inundation is defined in rating classes from very low to high potential. The rating is determined by taking the average of the rating for each criterion. Table 4 can be used to find the salinity class for each of the evaluation criteria.

Table 3—The interaction of soil texture and EC in determining salinity class[15]

	Degree of Salinity (salinity classes)				
Texture	**Non-saline**	**Slightly saline**	**Moderately saline**	**Strongly saline**	**Very saline**
	$EC_{1:1}$ method (dS m^{-1})				
Course to loamy sand	0–1.1	1.2–2.4	2.5–4.4	4.5–8.9	>8.9
Loamy fine sand to loam	0–1.2	1.3–2.4	2.5–4.7	4.8–9.4	>9.4
Silt loam to clay loam	0–1.3	1.4–2.5	2.6–5.0	5.1–10.0	>10.0
Silty clay loam to clay	0–1.4	1.5–2.8	2.9–5.7	5.8–11.4	>11.4
	$EC_{1:5}$ method (dS m^{-1})				
Sand 85–100%	<0.05	0.05–0.15	0.15–0.3	0.3–0.9	>9.0
Sand 75–85%	<0.1	0.1–0.2	0.2–0.5	0.5–1.3	>1.3
Sand 60–75%	<0.15	0.15–0.3	0.3–1.0	1.0–1.65	>1.0
Sand <55%	<0.2	0.2–0.35	0.35–1.5	1.5–2.0	>2.0
	EC_e method (dS m^{-1})				
All textures	0–2.0	2.1–4.0	4.1–8.0	8.1–16.0	>16

Table 4—Soil factors used in determining potential soil salt retention[15]

	Low Potential	Moderate Potential	High Potential
Depth to Water Table *centimeters, (inches)*	>152.4 (60)	>50.8 to 152.4 (20 to 60)	50.8 (20) or less
Depth to Restrictive Layer *centimeters, (inches)*	<50.8 (20)	50.8 to 152.4 (20 to 60)	>152.4 (60)
Cation Exchange Capacity *milliequivalents per 100 grams*	<3	3 to 5	>5
Effective Cation Exchange Capacity *milliequivalents per 100 grams*	<3	3 to 5	>5
Soil Organic Matter *percent*	<2	2 to 5	>5
Slope *percent*	>15	8 to 15	<8
Saturated Hydraulic Conductivity *micrometers (inches) per second*	>40.0 (0.0016)	10.0 to 40.0 (0.00039 to 0.0016)	<10.0 (0.00039)

Cation Exchange Capacity—weighted average from 0 to 12 inches from the soil surface
Effective Cation Exchange Capacity—weighted average from 0 to 12 inches from the soil surface
Soil Organic Matter—weighted average from 0 to 12 inches from the soil surface
Saturated Hydraulic Conductivity—weighted average from 0 to 60 inches from the soil surface

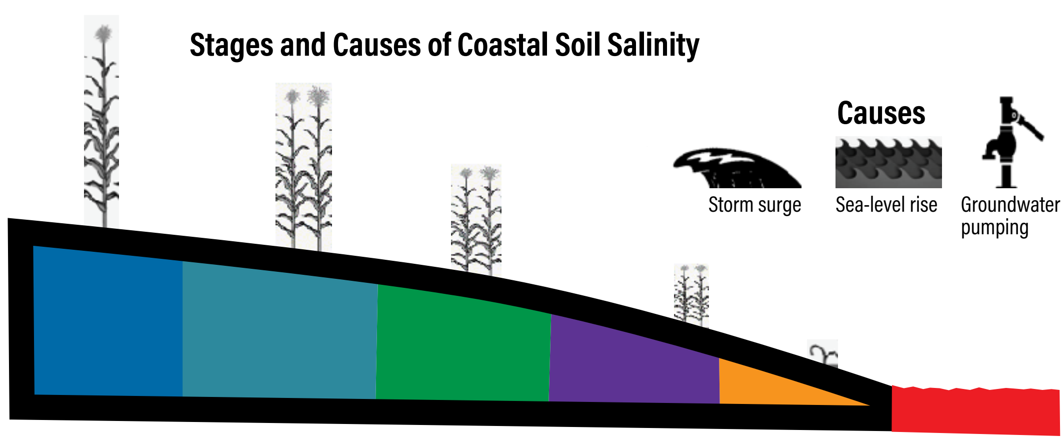
Soil Rating Definitions

- **High Potential:** Soils in this rating class have the most characteristics for salt retention due to coastal saltwater inundation. Terrestrial soils that already contain ocean-derived salts and have a 1:5 electrical conductivity present in the National Soils Inventory Database (NASIS) are rated *high potential*.
- **Moderately High Potential:** Soils in this rating class have a higher number of soil properties and characteristics for salt retention than do moderate potential soils but lower than high potential soils.
- **Moderate Potential:** Soils in this rating class have a higher number of soil properties and characteristics for salt retention than low potential soils but lower than moderately high soils.
- **Low Potential:** Soils in this rating class have a higher number of soil properties and characteristics for salt retention than very low potential soils and lower than moderate soils.
- **Very Low Potential:** Soils in this rating class have the least number of soil properties and characteristics for salt retention due to coastal saltwater inundation.

2.3 Stages of Soil Salinization

Overview of Salinization

Soil salinization dynamics are site-specific to the hydrology, location, topography, management practices, and local weather events (e.g., floods, droughts, hurricanes), making the exact behavior of the salt impacts challenging to predict. This guide has combined soil degrees of EC with frequency and duration of salt inundation events to create six stages of soil salinity (fig. 5). The mitigation (if any), adaptation (if any), and various crops yields are presented for each stage.



	Stage Zero	Stage One	Stage Two	Stage Three	Stage Four	Stage Five
	Non-Impacted EC = < 2 dSm^{-1}	Sporadic Salinity EC = 2 < 4 dS m^{-1}	Recurring Episodic Salinity EC = 4 < 8 dS m^{-1}	Low Chronic Salinity EC = 8 < 16 dS m^{-1}	High Chronic Salinity EC = 16 < 25 dS m^{-1}	Chronic Surface Water EC = >25 dS m^{-1}
Uses	**Commercial**	**Commercial**	**Commercial**	**Commercial**	**Non-Commercial**	**Saltwater Marsh**
Mitigation:	No	Yes	No	No	No	No
Adaptation:	No	Yes	Yes	Yes	No	No
Wetland Restoration/Easement:	No	No	No	No	Yes	Yes

Figure 5—The stages and causes of coastal soil salinity.

- **Stage Zero: Non-Impacted Land**—Baseline site characteristics are established at Stage Zero. At this stage, working land productivity is not yet impacted by salinity. However, the soil may be at risk of experiencing salinization due to proximity to a saltwater source. Crop relative yield is 100 percent of the possible yield without salinity stress, though crop yield remains subject to other stress factors (e.g., insects, disease, drought).
- **Stage One: Sporadic Salinity**—Stage One salinity soil is characterized as having sporadic, episodic salinity events. Initial salinity levels can be high or low depending on the soil conditions before and after the saltwater event. Some sites in this stage can recover from salinization events.
- **Stage Two: Recurring Episodic Salinity**—Stage Two salinity soil is characterized by having recurring episodic events. Salinization events occur so frequently that the site cannot sustain crops with low salinity tolerance thresholds. The soil salinization events occur at intervals that do not allow enough time for soil salinity levels to return to a non-saline state.
- **Stage Three: Low Chronic Salinity**—Stage Three salinity soil is characterized by a sustained or increasing level of soil salinity (as measured by EC) at a stressful level to most crops. The rate of soil salinity increase is likely to be slow and gradual (e.g., sea-level rise). Forest crops will no longer be productive. This is the last salinization stage (except for cotton) where commercial agricultural productivity can occur. If soil is in Stage Three, the landowner should start planning for the possibility of converting their land into a conservation easement or other non-commercial use.
- **Stage Four: High Chronic Salinity**—Stage Four salinity soil productivity is no longer profitable for the cultivation of commercial crops due to high salinity levels. Water levels are high, and areas of standing water emerge. Wetland and salt-tolerant plant species begin to colonize affected areas. The land would best be suited for use as a conservation easement.
- **Stage Five: Chronic Surface Water**—Stage Five salinity soils have converted to a saltmarsh, with high salinity levels and some open water. The area is regularly flooded by tides. The best use of this land would be for wildlife habitat and inland protection.

Soil Salinity Stage Progression

The stages of soil salinization do not necessarily progress in order. Soil salinity can increase or decrease depending on site characteristics and interactions with salinization events. For example, a specific site could experience recurring episodic salinity events (Stage Two) for some time. However, if the events were to stop, the land could recover to the point of moving back to Stage One if conditions such as drainage and freshwater input were favorable.

In contrast, an area could be salinized to the point of Stage Four with its first salinity event and never recover. Unfavorable conditions such as poor drainage and low freshwater input could impede site recovery from a storm surge with a very high salt input (e.g., brackish water with an EC = 25 dS m^{-1}). These stages are discussed in more detail in the following chapters and outlined in figure 5.

Soil Health Conservation Practices for Maintaining Cropland Resiliency to Salinization

Healthy soil will help improve crop productivity, especially under stressors such as salinity and drought. The primary way to achieve good soil health is by utilizing four fundamental management principles:

- **Minimize soil disturbance.** Minimize tillage or use no-till if the soil is well-drained. These practices help slow/reverse soil carbon losses (improve carbon sequestration), stabilize soil aggregates for improved infiltration, and promote biological activity.
- **Maximize soil cover.** Crop residue, mulch, and/or compost protect the soil surface from wind and water erosion forces. Organic residues on the surface also help conserve water for plant consumption and reduce soil temperatures at the surface.
- **Maximize the biodiversity of plant species.** Plant diverse crop rotations when possible. Different plant species are associated with distinct soil microbial communities. Aboveground, diversity can help improve soil organic matter, promote aggregate stability for increased water infiltration, and alleviate compaction.
- **Maximize the presence of living roots in the soil.** Living plant roots exude organic compounds that feed soil microbes and help bind soil particles together. Plant roots are also involved in complex biochemical communication with soil microbes whereby beneficial organisms are recruited, and pathogenic microorganisms are deterred. These combinations of factors create a healthier soil microbial population.

Each of these management principles are described separately but can be combined and form the basis of an Integrated Soil Health Management System (USDA-NRCS Soil Health Technical Note 450-05).[16] **These principles can and should be applied, if possible, no matter what stage of salinity is occurring as they promote crop productivity. Their importance is amplified as stages of salinity increase.**

Applying Appropriate Conservation Practices

The USDA NRCS identifies conservation practices that promote soil health (table 5). Appropriately selected annual cover crops can be planted to mitigate short term or episodic saline flooding events. However, perennial plant species used in practices such as Forage/Biomass Planting (Practice 512)[17] and Conservation Cover (Practice 327)[17] can be used to achieve more long term soil health benefits. An index of national conservation practices[17] can be found under technical resources on the NRCS website.

Table 5—Conservation practices that can be used in a soil health management system to help achieve improved soil health

Soil Health Principle	Conservation Cover (327)	Conservation Crop Rotation (328)	Cover Crop (340)	Forage & Biomass Planting (512)	Pest Mgmt. Conservation System (595)	Mulching (484)	Nutrient Mgmt. (590)	Prescribed Grazing (528)	Residue & Tillage Mgmt. (329/345)
Minimize Soil Disturbance	✓			✓	✓		✓	✓	✓
Maximize Soil Cover	✓		✓	✓		✓		✓	✓
Maximize Biodiversity	✓	✓	✓	✓				✓	
Maximize Living Roots	✓	✓	✓	✓				✓	

Source: USDA-NRCS Soil Health Technical Note 450-05.[16]

CHAPTER 3

Stage Zero: Non-Impacted Uplands in Proximity to Impacted Lands

3.1 General Discussion

Baseline site characteristics are established at Stage Zero. At this stage, working land productivity is not yet impacted by salinity. However, the soil may be at risk of experiencing salinization due to proximity to a saltwater source. Crop relative yield is 100 percent of the possible yield without salinity stress, though crop yield remains subject to other stress factors (e.g., insects, disease, drought).

Setting a baseline is essential when determining how salinization can impact working lands. The relative impact of saltwater can be more accurately assessed once the baseline productivity is known. Non-impacted soils in proximity to affected lands are likely susceptible to salinization. The amount of time taken for these lands to experience salinity increases depends on the site conditions and salinization drivers discussed in the introduction. Soils with an electrical conductivity between 0 and 2 dS m^{-1} are considered non-saline. Salts can be flushed from the land if soil is well-drained, and the timing and amount of rainfall is sufficient to flush the soils. Both the lack of drainage and freshwater input contribute to salinity accumulation in the soil.

3.2 Productivity and Economic Limitations

There will be a negligible impact on crop productivity during Stage Zero, even though there may be some small increases in salinity. Traditional crops can be cultivated in a business-as-usual approach. However, monitoring of soil conditions is advised for early detection of soil salinity change.

3.3 Mitigation and Adaptation Measures

No specific salinization related mitigation or adaptation measures are needed in Stage Zero because natural flushing will take care of any salt in the system. However, employing some basic soil health and conservation practices is advisable, regardless of the salinization stage, to help the cropland become more resilient to changing climatic conditions.

3.4 Environmental Impacts

Soil salinization can have direct impacts through the accumulation of salt in the soil. There can also be indirect impacts on the ecosystem as the non-salinized soils become more susceptible to other disturbances. Additionally, increased stress on the impacted land can spill over onto adjacent, non-salinized areas. For example, non-impacted lands have increased susceptibility to common reed (*Phragmites australis)* when the site is near other lands that are salinized. Common reed spread is associated with agriculture and is a problem in the coastal region of the Eastern United States.

Common reed is an invasive species that negatively impacts native biodiversity and habitat. However, common reed can have benefits such as nutrient remediation and shoreline stabilization.[18] (See photo left.)

Abandoned cropland encourages the Phragmites invasion. (Photo by Chris Miller, USDA-NRCS)

The best way to prevent or minimize the invasion of common reed into a cropped field and to protect water quality is to establish a dense vegetative cover at the edge of the field. Useful edge-of-field NRCS practices to reduce invasion risks include Field Border (386), Filter Strip (393), Riparian Herbaceous Cover (390), and Riparian Forest Buffer (391).[17] Additional field scale practices may also be implemented, such as Forage and Biomass Planting (512) and Conservation Cover (327).[17] If a field is adjacent to an eroding shoreline, the Streambank and Shoreline Protection (580)[17] may be needed. The practices or combination of practices recommended will vary depending on site conditions, resource concerns to be addressed, and the producer's land management goals.

3.5 Probable Outcomes for Stage Zero Land

Stage Zero salinized soil would likely remain in stage zero classification indefinitely if climate change was not increasing sea levels. However, climate change is expected to cause an average increase in a sea-level rise of 45.4 cm (17.9 inches) across the U.S. Southeast by the year 2050.[19] Beyond this time, studies suggest that sea-level rise could reach up to 90 cm (35.4 inches) by 2100. In the Mid- and Upper Atlantic, 90 cm of sea-level rise would inundate over 2,600 km^2 (642,000 acres). Along the entire eastern U.S. coastline, from the Atlantic Ocean to the Gulf of Mexico, over 87,000 km^2 (21 million acres) could be at risk of being inundated from storm surges by 2100.[20] The NOAA Sea Level Rise Viewer provides the location-specific prediction of sea-level rise. Other tools and resources are presented in Appendix I of this guide.

In addition to sea-level rise, extreme weather events such as droughts and storms are expected to increase in frequency and intensity. Recent decades have seen an increase in tropical cyclone activity in the Atlantic.[21] Increased temperatures and changing precipitation regimes are expected to lead to more drought.[22] Wet areas are expected to become wetter, and dry areas are expected to become drier. For coastal areas, less freshwater may be available for saltwater intrusion irrigation mitigation. The salinity of tidal rivers can increase during low flow periods.[23] Predicting coastal soil response to climate change is difficult due to the dynamic and interactive nature of saltwater intrusion and land. Although currently not impacted, Stage Zero lands in proximity to Stage One areas should be closely monitored for changing conditions.

CHAPTER 4

Stage One: Commercial Upland Introduction of Salinity

Stage One salinity soils are the first to show symptoms of saltwater intrusion. The impacts may be subtle, and the producer may not notice the slight decrease in productivity relative to yearly production variability. However, early intervention can significantly improve the resiliency of the soil to additional salinization. This chapter will review how to identify, mitigate, and adapt to soil salinization's emerging problem.

Stage One Characteristics

Stage One soil salinization is characterized by low levels of salinity. In this stage, mitigation measures may be possible to improve soil salinity levels. Stage One salinity soil is characterized as having sporadic, episodic salinity events. Initial salinity levels can be high or low depending on the soil conditions before and after the saltwater event. Some sites in this stage can recover from salinization events.

EC: detectable

2<4 dS m^{-1}

Crop options: many

Numerous crops have a salinity threshold to produce 100 percent relative yield in this stage, though more sensitive plants begin to have reductions in yield due to salinity.

Practically treatable? Yes

4.1 General Discussion

The initial introduction of salinity could come from salt spray from ocean water, high tides such as king [i.e., exceptionally large (perigean spring)] tides, storm-driven flooding, saltwater intrusion during a drought, or saline irrigation water. Soil salinity levels could be relatively high due to an extreme event. However, if saltwater is introduced due to a chronic condition such as the slow movement of saltwater intrusion due to sea-level rise, the soil salinity level is likely to start at a low level and gradually increase at a slow rate. In the latter case, the initial introduction of salinity will be at low levels. Therefore, low lying areas are the first to be exposed to salinity.

In agriculture, heavy equipment tracks can leave depressions in fields where salt can pool after the initial stages of saltwater intrusion. Monitor these areas for early signs of soil salinization.

4.2 Productivity/Economic Limitations

The initial impacts on crop productivity from salt to the soil depend on saline condition, salinity level, and exposure. Salinity impacts crop yield when soil salt levels reach or exceed the tolerance threshold specific to the crop (table 1, ch. 1). The crop yield decreases as salinity increases above a crop salt tolerance threshold (table 6). Crop yield decline due to salinity can be estimated as described in Chapter 1. However, crop yield is a product of multiple interacting factors, such as climate, water availability, nutrient availability, pests and disease, and soil conditions, along with salinity. The estimates of crop yield under various salinity levels do not account for yield reductions due to other factors and are estimated as if other conditions are ideal (e.g., no yield loss due to insects, disease, drought).

Table 6—Percent crop yield at the low and high limits of Stage One soil salinization for row crops, vegetables, and fruits at 2 dS m^{-1} to 4 dS m^{-1}

Crop	Botanical name	% Yield at 2 dS m^{-1}	% Yield at 4 dS m^{-1}
Row Crops			
Corn	*Zea mays*	99	84
Flax	*Linum usitatissimum*	96	72
Sugarcane	*Saccharum officinarum*	98	86
Potato	*Solanum tuberosum*	96	72
Broadbean	*Vicia faba*	96	77
Sweet Potato	*Ipomoea batatas*	95	73
Radish	*Raphanus sativus*	90	64
Turnip	*Brassica rapa (Rapifera)*	90	72
Artichoke, Jerusalem (Tabers)	*Helianthus tuberosus*	85	65
Bean, mung	*Vigna radiata*	96	54
Almond	*Prunus duclis*	91	53
Bean	*Phaseolus vulgaris*	81	43
Vegetables			
Cabbage	*Brassica oleracea (Capitata)*	98	79
Celery	*Apium graveolens*	99	86
Pepper	*Capsicum annuum*	93	65
Lettuce	*Lactuca sativa*	91	65
Onion (seed)	*Allium cepa*	92	76
Onion (bulb)	*Allium cepa*	87	55
Carrot	*Daucus carota*	86	58
Fruits			
Tomato, cherry	*Lycoperscion lycopersicum- cerasiforme*	97	79
Grape	*Vitus vinifera*	95	76
Eggplant	*Solanum melongena*	94	80
Muskmelon	*Cucumis melo*	92	75
Grapefruit	*Citrus x paradisi*	97	70
Peach	*Prunus persica*	94	52
Orange	*Citrus sinensis*	95	69
Lemon	*Citrus limon*	94	68
Blackberry	*Rubus macropetalus*	89	45
Boysenberry	*Rubus ursinus*	89	45
Strawberry	*Fragaria x ananassa*	67	1

Rates of soil recovery from saltwater events will be prolonged if hydrological features (e.g., roads, levees, or flood gates) trap saline water inland. Salinity can also cause the release of nutrients (e.g., nitrogen and phosphorous) and export them from the soil.[24] Loss of nutrients may increase the amount of fertilizer required to produce crops. Increases in sodium due to increases in salinity may bring about clay dispersion, change the soil structure, and lead to poor drainage, severely reducing crop yield.

Salinization allows the invasion of unwanted opportunistic vegetation species to colonize existing plant communities. As salinity is introduced, a decrease in plant community diversity is likely to be observed. Plant communities that are not adapted to wet and/or saline soils may be vulnerable to marsh migration.[25] The control of invasive species within crop fields will require more control measures as salinity increases, which will reduce the total profit from the crop.

Forestry

Forest stands are likely to recover from a single salinization event but may be impacted in the short term. At low salinity (i.e., 2–4 dS m^{-1}), seedling growth of trees such as loblolly and pond pine may be unaffected.[26] However, during a storm, inundation by brackish water can reduce trees' capacity to move water, leading to immediate damage to the forest. High salinity (i.e., >16 dS m^{-1})[27] stress in trees can reduce sap flow (the movement of fluid in the tree), slow basal area and tree height growth, and lead to death, sometimes from a single storm event. Mature trees are more likely to be resilient to soil salinity than young regenerating trees. Soils can recover from individual events of Stage One salinization, especially when the event is followed by rainfall. However, a storm surge followed by drought may amplify the impact of salinity stress on trees as a lack of freshwater can concentrate the salinity in the soil. Tree mortality can be delayed after experiencing flooding and salinity from a storm surge, so post-hurricane management should consider the level of salinization. If the salinization level is high and salinity enters the groundwater near the rooting zone, the soil could take years to recover and cause long-term tree damage. Seedlings such as green ash, water tupelo, and bald cypress may recover from exposure to salinity as high as 16 dS m^{-1}. However, growth rates could initially be reduced. Seedlings could die in 2–6 weeks if exposed to saline water >25 dS m^{-1} for 48 hours.[28] Revegetation after saltwater intrusion will depend on returning the soil salinity to lower levels. High elevation plays a significant role in the recovery as these areas are more likely to drain salt out of the soil during precipitation events. Conversely, low-elevation sites do not permit the removal of salt from the soil. However, during short-term, lower salinization events, trees are likely to improve.

4.3 Environmental Impacts

Saltwater interaction with soils can release nutrients from fertilizers, leading to nitrogen and phosphorus export. Nitrogen and phosphorus export can lead to harmful algal blooms that later die and decompose by bacteria that then degrade the habitat for animals and cause other harmful coastal ecosystem effects. The nutrient release rate will depend on sea-level rise, salinity level, storms, drought, connectivity to water bodies, and land-use decisions, including fertilizer application.

4.4 Mitigation Measures

Mitigation measures can be either shorter term or annual practices that can be implemented in the early stages of soil salinization. The usefulness of these techniques depends on salinization's cause, extent, and depth of the water table. If the groundwater table is shallow, many mitigation practices are not possible because the soil is too wet, and the water will not drain. With sea-level rise, the water table will continue to get closer to the surface, and mitigation will become less and less of an option. Soil salinity levels are more likely to decline from infrequent salinization events (one every 10 years) compared to chronic inputs of salt. If the salinity source is continuous, then adapting to salinity will be necessary. The following mitigation strategies can be used in the early stages of salinization, in addition to adaptation measures described in the next section and the following chapters. [Mitigation measures are less viable options in the later stages of salinity. Instead, adaptation practices should be used.]

- **Water Control.** Water control infrastructure such as flood gates, dikes, levees, and valves can be used to prevent some saltwater intrusion. However, these structures can also trap salinity behind them when they are overtopped. Whether or not the water level exceeds the structure height is determined by the water height of storm surges or high tides. Eventually, due to sea-level rise, existing water control structures will be overtopped more easily. Refer to NRCS Conservation Practice Standard 356 (Dike).[17] Commonly associated practices include: Structure for Water Control (587), Irrigation Water Management (449), Wildlife Habitat Management (644), and Wetland Creation (658).[17] However, structure construction could hinder conversion options to a conservation easement when the productivity level decreases beyond economic viability. Additional information on Wetland Reserve Easements and Conservation Compliance Determinations is available through the Natural Resources Conservation Service.
- **Irrigation Methods.** Leaching soils with freshwater can reduce salinity in well-drained soils and conditions where the groundwater table is not close to the surface. If leaching is suitable, irrigation with 6 inches of freshwater can reduce salinity by up to 50 percent, though the leaching process can be slow and take several years. As sea levels rise, leaching will become less of a viable option. Soil amendments such as gypsum may increase the removal of soluble salts when combined with freshwater irrigation. Gypsum is high in calcium and may react with the soil's exchange site to release sodium. The composition of soluble salts in the soil, sodium, EC, ESP, pH, texture, and fertility will influence whether gypsum use is recommended. Soil analysis laboratories can provide a specific recommendation for using soil amendments at a particular location. For more information, see the NRCS Conservation Practice Standard, Amending Soil Properties with Gypsum Products Code 333.[17]
- **Soil Health.** Utilize soil health management techniques described in Stage Zero by employing no-till or minimum tillage, improving year-round cover, adding organic amendments, and diversifying crop rotations. Refer to Conservation Practice Standards 329/345,[17] Residue and Tillage management, for more information.

- **Helpful Strategies.** Additional strategies include shifting planting dates to avoid field operations during wet/flooded conditions, controlling/limiting heavy machinery traffic to minimize soil compaction, and land leveling or subsurface drainage if hydrologic conditions allow. In more salinized fields, leave a field fallow for a season with weeds controlled through herbicides or shallow mechanical tillage (discing). Leaving the field fallow for a season will reduce plant water use and promote salt leaching deeper into the soil profile through increased drainage. Cover crops such as barley and vetch also promote salt leaching in irrigated systems. Cover crops may have the added benefit of reducing soil salt accumulation at the next cash crop planting.[29] Planting crops on shallow ridges or raised beds will keep plant roots above the more saline soil zone. In some exceptional circumstances, dredge or spoil material may be available for land application to add elevation to low lying fields. Refer to NRCS conservation practice standard Spoil Spreading, Code 572[17] to adequately spread this material.
- **Deep Tillage and Organic Amendments.** Deep tillage (plowing), along with soil amendments, may be a viable method to reduce salts if salt is only concentrated in the upper depth (5–10 cm or 2–4 inches) of the soil. For example, organic amendments such as mulch, leaf compost, or biochar can be incorporated into the soil to reduce the salt concentration. These amendments help improve soil organic carbon and "dilute" the salt effect by reducing sodium on a large percentage of the soil exchange sites (clays and silts). However, deep tillage does not work in shallow groundwater tables. Refer to NRCS Conservation Practice Standard 324, Deep Tillage.[17] As climate change continues to raise groundwater tables in coastal areas, this will become increasingly less useful.

4.5 Adaptation Measures

Adaptation measures are long-term techniques that adjust business-as-usual agricultural practices to remain productive. Examples include crop-pasture rotation, grass crop rotation, cover cropping, and silvopasture. Crop-pasture rotation is an adaptation strategy to continue profitably managing the land. Grass crop rotation with row crop systems can reduce runoff, erosion rates, and environmental impacts in non-salinized lands. Cover cropping provides many benefits, including erosion management, increased soil organic carbon sequestration, and improved soil physical, chemical, and biological characteristics. The integration of livestock with these systems increases the net return, though integration demands more skill and knowledge because a two-crop system is more complex.[30]

The NRCS employs a host of conservation practice standards and specifications to plan best management practices on farms to solve various natural resource problems. These practice standards in the Field Office Technical Guide (FOTG) are updated and revised periodically with new vegetative planting and engineering design recommendations. Many of the vegetation conservation practices[17] such as Riparian Herbaceous Buffers (390), Filter Strips (393), Field Border (386), Streambank and Shoreline Protection (580), Cover Crop (340), Conservation Cover (327), and Forage and Biomass Planting (512) are useful practices in helping a farmer buffer crop fields from coastal flood damage and salinization problems. Plant species recommended to be used in these practices provide water quality improvement by plant nutrient removal from potential soil legacy nutrients released by saltwater flooding. Contact the county NRCS Field Office for information on conservation practices and plant recommendations given specific soils and site conditions.

Producers should consider crop insurance programs regardless of the crops that are planted. The USDA Noninsured Crop Disaster Assistance Program (NAP) provides financial assistance to producers that are not able to be insured when low yields, loss of inventory, or prevented planting occur due to natural disasters. Consult the local extension agent regarding insurance program options.

Changing Planted Species and Crop Rotations

During the early stages of salinization, switching crops is not required but could become a viable option as salinization continues. If salinization occurs due to infrequent weather events, continuing business as usual agricultural practices could make economic sense. If salinity levels are steadily increasing, converting to more salt-tolerant crops may make more economic sense. The salinity tolerance of traditional crops is shown in table 1. Traditional crops with higher thresholds for salinity should be considered when salt initially appears in the soil. Switching to alternative crops could also be done at this point, but cultivating traditional crops may be best to continue while possible. Alternative crops are described more fully in Chapters 5 and 6.

Cover crops are useful for erosion control, while salts are leaching from the soil. If the salinity is in the top 5–7 cm (2–3 inches) of the soil profile, deep plowing combined with cover crops such as barley, tall fescue, or perennial ryegrass can assist with salt leaching. A permanent vegetative crop established before the salinization occurred can be left in place and combined with gypsum application where applicable, and freshwater irrigation can be used to reduce salinity. The salt content in most soils in Stage One will recover in 6–12 months.

Table 1 includes the salinity and electrical conductivity (EC) thresholds for salt-tolerant plants. The EC threshold is the maximum value that does not reduce relative yield below the species' yield under non-saline conditions. The reduction of yield due to an increase of one decisiemen EC (expressed as a slope) is also factored into determining a species' salt tolerance. Species with a steep slope have a high reduction in yield as EC increases. Therefore, species with a steep yield loss slope are less salt-tolerant than a crop with a low slope. If the initial salinity levels are low, there could be few noticeable effects, and salt-sensitive plant species may still produce acceptable yields. However, as the salinity levels increase, more salt-tolerant varieties of plants will remain resilient to unpredictable climate conditions and weather events.

4.6 Probable Outcomes

Coastal areas will continue to experience impacts from salinity due to natural climate-related drivers. The hydrology, soil type, connectivity to saltwater intrusion, and proximity to the ocean of a site will determine the rate at which soil experiences salinization, combined with unpredictable climate-driven events. Saltwater intrusion, along with rising sea levels and increasing drought severity, is expected to impact a growing extent on the Southeast coast. Continuous saltwater intrusion combined with storms stress upland ecosystems and convert them to saline wetlands or emergent marsh.[4]

CHAPTER 5

Stage Two: Commercial Upland, Recurring Episodic Salinization

As salt concentrations continue to increase in the soil, productivity reductions will be more pronounced at this stage. Additionally, the salt crust may be more noticeable on the soil surface. These soils are still productive, but there are fewer crop choices that will tolerate elevated salt levels. This chapter discusses these options.

Stage Two Characteristics

Stage Two soil salinization is characterized by more frequent episodic salinity events. Salinity levels in this stage increase and exhibit less recovery. The more frequent occurrence of salinity events provides less time for recovery between events, and salinity levels increase. Salinization events occur so frequently that the site cannot sustain crops with low salinity tolerance thresholds. The soil salinization events occur at intervals that do not allow enough time for soil salinity levels to return to a non-saline state.

EC: detectable

4<8 dS m^{-1}

Crop options: some

Some crops (n=14) are available that have a salinity tolerance threshold to produce 100 percent relative yield at this stage. However, at the higher end of salinity stage, few crops produce >70 percent yield (n=11).

Practically treatable? No

5.1 General Discussion

Recurring episodic salinization events will build up soil salinity and push systems past their ability to recover. In Stage Two soil salinization, electrical conductivity values range from 4 to 8 dS m^{-1}. However, 4–8 dS m^{-1} electrical conductivity can also briefly occur in other stages. In Stage Two, increasing pressure from natural climate-related drivers and decreasing time between events leaves less time for recovery and increases soil salinity. The increase in salinity could happen gradually over a long period, or an increase could happen rapidly due to an extreme event.

5.2 Productivity/Economic Limitations

Under salt stress, wetland forest production is reduced, and tree seedling mortality occurs.[10] Agricultural crop yields also decline with increasing salinity levels, though they have varying thresholds. These thresholds determine the rate of yield decline (tables 7 and 8).

Table 7—Percent crop yield at the low and high limits of Stage Two soil salinization for row crops, vegetables, fruits, and forage/cover crops/erosion control at 4 dS m^{-1} to 8 dS m^{-1}

Crop	Botanical name	% Yield at 4 dS m^{-1}	% Yield at 8 dS m^{-1}
Row Crops			
Barley	*Hordeum vulgare*	100	100
Sugar beet/Red beet	*Beta vulgaris*	100	94
Cotton	*Gossypium hirsutum*	100	98
Triticale	*X Triticosecale*	100	95
Wheat, durum	*Triticum turgidum*	100	92
Sorghum	*Sorghum bicolor*	100	81
Artichoke	*Cynara scolymus*	100	78
Wheat	*Triticum aestivum*	100	95
Soybean	*Glycine max*	100	40
Garlic	*Allium sativum*	99	41
Quinoa	*Chenopodium quinoa willd*	98	91
Alfalfa	*Medicago sativa*	85	56
Corn	*Zea mays*	84	54
Flax	*Linum usitatissimum*	72	24
Sugarcane	*Saccharum officinarum*	86	63
Potato	*Solanum tuberosum*	72	24
Broadbean	*Vicia faba*	77	39
Sweet Potato	*Ipomoea batatas*	73	29
Radish	*Raphanus sativus*	64	12
Turnip	*Brassica rapa (Rapifera)*	72	36
Artichoke, Jerusalem (Tabers)	*Helianthus tuberosus*	65	27
Rice, paddy	*Oryza sativa*	88	40
Vegetables			
Asparagus	*Asparagus officinalis*	100	92
Squash, zucchini	*Cucurbita pepo var. cylindrica*	100	66
Pea	*Pisum sativum*	94	51
Squash, scallop	*Cucurbita pepo var. clypeata*	87	23
Broccoli	*Brassica oleracea (Botrytis)*	81	18
Cucumber	*Cucumis sativas*	81	29
Spinach	*Spinacia oleracea*	85	54
Cabbage	*Brassica oleracea (Capitata)*	79	40
Celery	*Apium graveolens*	86	62
Pepper	*Capsicum annuum*	65	9
Lettuce	*Lactuca sativa*	65	13
Onion (seed)	*Allium cepa*	76	44
Carrot	*Daucus carota*	58	2
Fruits			
Guava	*Psidium guajava*	100	68
Tomato	*Lycoperscion lycopersicum*	85	46
Tomato, cherry	*Lycoperscion lycopersicum- cerasiforme*	79	43
Grape	*Vitus vinifera*	76	38
Eggplant	*Solanum melongena*	80	52
Muskmelon	*Cucumis melo*	75	41
Grapefruit	*Citrus x paradisi*	70	16
Orange	*Citrus sinensis*	69	16
Lemon	*Citrus limon*	68	17
Forage/Cover Crops/Erosion Control			
Ryegrass, perennial	*Lolium perenne*	100	81
Cowpea	*Vigna unguiculata*	100	63
Sudangrass	*Sorghum sudanense*	91	55
Vetch, common	*Vicia sativa*	89	45
Clover, berseem	*Trifolium alexandrinum*	86	63
Clover, alsike	*Trifolium hybridum*	70	22
Foxtail, meadow	*Alopecurus pratensis*	76	38
Clover, red	*Trifolium pratense*	70	22
Clover, ladino/white	*Trifolium repens*	70	22
Orchardgrass	*Dactylis glomerata*	85	60

Species with zero yield at the high end Stage Two salinity include: almond, bean, bean (mung), blackberry, boysenberry, bnion (bulb), beach, beanut, blum (prune), strawberry

Table 8—Crops that would be suitable for growing under Stage Two soil salinization

Common name	Botanical name	EC threshold (dS m^{-1})
Row Crops		
Guar	*Cyamopsis tetragonoloba*	8.8
Barley	*Hordeum vulgare*	8.0
Cotton	*Gossypium hirsutum*	7.7
Sugar beet/Red beet	*Beta vulgaris*	7.0
Sorghum	*Sorghum bicolor*	6.8
Triticale	*X Triticosecale*	6.1
Artichoke	*Cynara scolymus*	6.1
Wheat	*Triticum aestivum*	6.0
Wheat, durum	*Triticum turgidum*	5.8
Quinoa	*Chenopodium quinoa willd*	3.0
Forage/Cover Crop/Erosion Control		
Bermuda grass	*Cynodon dactylon*	12.0
Fescue, tall	*Festuca arundinacea*	7.0

Forestry

The moderate levels of salinity in Stage Two are likely to negatively impact forest growth and productivity. Signs of salinity stress will begin to persist (i.e., decrease in overall vigor, increase in insect problems, sparse crown, low growth, mortality, short needle length in pines, small foliage in hardwoods, and overall appearance of poor health). Forests in poor health are at a higher risk for pests and diseases. Forest recovery between salinity events will depend on the frequency and intensity of their reoccurrence. After an event, the forest's health should be assessed and may need to be harvested. In some cases, trees should be harvested before their quality deteriorates. Once harvested, the condition of the land and options for land-use change should be assessed. Seedlings are not adapted to continuous moderate to high salinity levels and may have difficulty reestablishing and maintaining productivity if soil salinity remains elevated. Production in mature forests declines with moderate to high levels of salinity. In areas where salinization events happen often and include intense storms, tree mortality could increase up to 85 percent with soil salinity in the 4–8 dS m^{-1} range.[12]

5.3 Environmental Impacts

Ecosystem carbon dynamics can change due to saltwater intrusion, meaning ecosystem productivity and carbon storage potential can be reduced. For example, saltwater intrusion can cause forest death, and vegetation change to shrubs and grasses. As soils become slightly saline, forests become stressed and seedling survival declines. Reduced seedling vigor can inhibit forest regeneration. Without regenerating, the forest community will change to shrubs and grasses. Following forest death, salt-tolerant species will invade. The rate of forest retreat coincides with the rate of sea-level rise.[31]

5.4 Adaptation Measures

Managing the impact of saltwater intrusion will require producers to use more adaptive and innovative agricultural practices. Producers in these impacted areas may not need to completely abandon their affected fields if site assessment tools and appropriate conservation practices are used. However, in some cases, wetland conservation easements may be the best option. Easements would result in previous cropland being converted to wetlands either through natural regeneration or planned wetland creation. The benefit to the producer would be a one-time acreage payment for the land acquisition. The ecosystem benefit would be the additional floodwater storage that may help protect and buffer adjacent cropland. One consideration is water control structures. Structure construction could hinder conversion options to a conservation easement when the productivity level decreases beyond economic viability. Additional information on Wetland Reserve Easements and Conservation Compliance Determinations are available through NRCS. Check with the local extension agent or NRCS field staff for more information on conservation easements.

Agricultural practices that can manage the impacts of salinity stress include planting more salt-tolerant crops, using crop-pasture rotation, and applying conservation practice standards. Another alternative strategy would be growing value-added alternative niche conservation plants. Alternative crops on these marginal lands may provide valuable ecosystem services and potentially provide additional farm income. The opportunity to profit from alternative crops depends on locating specialized markets for the product. Some potential options are discussed below.

Saltmarsh Hay Production

Native salt meadow cordgrass (*Spartina patens*), or saltmarsh hay, was historically harvested from natural tidal marshes and used for a wide array of applications: bedding for horses and cattle, cattle feed, weed-free mulch (due to the inability of seeds to germinate outside the salt environment) for nursery and vegetable production, biodegradable packing material to ship fragile items, increased traction on roads, protecting and curing concrete, and production of saltmarsh hay rope. However, most of these “farmed” wetland areas on the East Coast are no longer accessible due to sea-level rise and storm damage to dikes and levees through the years. Opportunities exist for farmers to plant a crop of salt meadow cordgrass in the marginal, salt-impacted transition zone between the wetland and the upland. These marginal lands were once traditionally farmed, but they are no longer economically productive due to periodic flooding and salt concentrations. However, they may be suitable for the production of salt meadow cordgrass. Salt meadow cordgrass markets vary locally and may not be applicable or profitable everywhere.

‘Flageo’, ‘Sharp’, and ‘Avalon’ are three varieties developed by the USDA-NRCS Plant Materials Program. ‘Flageo’ is best used to stabilize high saltmarshes, interdune swales, low coastal dunes, and highly erodible inland sites with deep sands. ‘Avalon’ is best used for marsh habitat restoration purposes, dune stabilization and restoration projects, and shoreline protection applications at high energy sites. ‘Sharp’, a Gulf Coast strain, appears to produce the most biomass of the three. Further testing is being done by the NRCS Cape May Plant Materials Center. These varieties all have some degree of natural tolerance for saline environments and will also grow in higher elevation, sandy dune, and shoreline sites. (See photos on the following page.)

In Delaware, annual dried biomass production ranged from 3175 kilograms (3.5 tons)/acre to 5806 kilograms (6.4 tons)/acre in a study examining multiple harvest dates and single harvest dates on research plots. There was no advantage of multiple harvests during the growing season in terms of biomass production.[32] As with any farming operation, harvesting should only be done when soil conditions are appropriate to

LEFT: Natural stand of salt meadow cordgrass. (Photo by Marilee Lovit, Go Botany); RIGHT: Harvesting salt hay. (Photo by Joseph Smith)

reduce compaction. Fertilization can significantly improve yields in saline soils. Fertilizing cordgrass in a Stage One (8 ppt salinity) salt meadow can significantly improve crop yield.

Seashore Mallow

Seashore mallow (*Kosteletzkya virginica*) is another plant that provides ecosystem services, as well as potential income. Seashore mallow is a wetland species that is native to the Mid-Atlantic and Gulf Coast States. Seashore mallow has been studied for its potential use as an ecosystem engineering tool in the transition zone between wetland and upland in agricultural fields experiencing saltwater flooding. Planting seashore mallow in these riparian areas can increase organic matter in the soil, utilize nutrients coming from upland fields, and encourage other desirable native species to volunteer while discouraging the invasion of common reed. In addition to these ecosystem benefits, various value-added products could potentially be marketed from seashore mallow. The oilseed produced by the mallow has been researched as a biodiesel product. The chopped, dormant stems of native grasses and seashore mallow have highly absorbent fibers and show promise as poultry house bedding material and cat litter. Research has shown that seashore mallow is more adsorbent than sawdust, which has been the poultry industry standard for years. The use of native grass bedding also results in less footpad dermatitis on the birds. Additionally, the chopped biomass residue is used to manufacture products associated with the erosion control industry and in the natural gas extraction industry. Seashore mallow can be readily seeded as well as harvested using conventional farm equipment. (See photos below and on following page.)

Seashore mallow seeding: conventional LEFT and no-till RIGHT. (Photos courtesy of Dr. Jack Gallagher and Dr. Denise Seliskar of the University of Delaware)

LEFT: An established stand of seashore mallow; RIGHT: Closeup of the mallow flowers. (Photos courtesy of Dr. Jack Gallagher and Dr. Denise Seliskar of the University of Delaware)

Integrated Multifunctional Buffers

One conservation best management practice is establishing or maintaining existing natural buffer systems adjacent to waterways or wetlands. These buffers provide ecosystem services for erosion control, water quality improvement, and wildlife habitat and potentially slow the invasion of Phragmites into fields if present on the wetland margins. Where potential markets exist, the possibility of establishing multifunctional buffers of deep-rooted native warm-season grasses such as switchgrass (*Panicum virgatum*), coastal panicgrass (*Panicum amarulum*), prairie cordgrass (*Spartina pectinata*), Eastern gamagrass (*Tripsacum dactyloides*), and wetland forbs such as seashore mallow (*Kosteletzkya virginica*) for biomass harvesting may be profitable as an alternative income source. (See photos below.)

Farmers may be able to extend productivity on impacted land by planting salt-tolerant crops. Research is being conducted to find the tolerance of crops (e.g., varieties of barley, sorghum, soy, switchgrass) planted and harvested with equipment that farmers already have. Conservation practices may provide protection for non-impacted areas, improve water quality, and provide income sources.

LEFT: Crops protected in a Maryland field with buffer planting ; RIGHT: Unprotected field with no buffer planting (right). (Photos by Chris Miller, USDA-NRCS)

Refer to Plant Materials Technical Note # 3 Planting and Managing Switchgrass as a Biomass Energy Crop[33] for more specific information on establishing bioenergy crops. The ground stem can also be used in various erosion control products.

Regardless of the crops planted, landowners use insurance and disaster recovery programs to buffer against loss. For example, the USDA Farm Service Agency Noninsured Crop Disaster Assistance Program (NAP) provides financial assistance to producers of crops that cannot be insured when low yields, loss of inventory, or prevented planting occur due to natural disasters. Consult with the local extension agent, NRCS, and FSA field offices to learn more.

5.5 Probable Outcomes

Sea-level rise will continue to bring saltwater further inland, reducing the soil's ability to recover and changing land to the point where salinity is well-established. Ecosystem biogeochemistry could be influenced by processes that occur along with salinization. Alkalinization and sulfidation occur with chronic salinization and may become more rapid with each event. Alkalinization raises soil pH and may reduce phosphorus availability. Sulfidation increases sulfide of soil and may produce hydrogen sulfide, which is toxic to plants.[13] Forest and cropland will decline in productivity to the point where adaptation measures will be required to continue keeping the land productive.

CHAPTER 6

Stage Three: Commercial Upland, Well Established, Chronic Salinization

If soil is in Stage Three, the landowner should start planning for the possibility of converting their land into a conservation easement or other non-commercial use. Stage Three salinized soils are at the transition from marginally productive to non-productive. Therefore, careful soil sampling and consideration of species selection are needed before row crops are planted. These lands are no longer suitable for tree replanting even if a seedling would initially grow at Stage Three levels of soil salinity. The likelihood that a seeding would reach a commercially viable sawtimber stage is low due to the long (i.e., 25+ year) rotation length and continued sea-level rise.

Stage Three Characteristics

Stage Three sites experience chronic salinization and a steady increase in soil salinity levels. The options for economically feasible yields are increasingly limited due to increasing soil salinity. Stage Three salinity soil is characterized by a sustained or increasing level of soil salinity (as measured by EC) at a stressful level to most crops. The rate of soil salinity increase is likely to be slow and gradual (e.g., sea-level rise). Forest crops will no longer be productive. This is the last salinization stage (except for cotton) where commercial agricultural productivity can occur.

EC: detectable

$8<16$ dS m^{-1}

Crop options: few

At the high end of Stage Three, no crops have a salinity tolerance threshold that allows for 100 percent relative yield, though some crops can still be cultivated at the lower end of salinity levels.

Practically treatable? No

6.1 General Discussion

Stage Three salinization would fall under the traditional classification of "strongly saline" soil salinity class[9] with an electrical conductivity ranging from 8 to 16 dS m^{-1}. During chronic salinization, sulfidation begins to occur. Examples of well-established salinization can be seen in the Delmarva and North Carolina Albemarle-Pamlico peninsulas. In these areas, saltwater intrusion causes farmland to become unprofitable with traditional planting practices. Sea-level rise will cause further saltwater intrusion into aquifers. Salt spray, a continuous source of salt in coastal areas, will continue, and its reach will move farther inland as shorelines move due to sea-level rise.

6.2 Species Tolerance

At 8–16 dS m^{-1} electrical conductivity, species with higher salt tolerance are best suited for cultivation. However, not many plant species can tolerate waterlogged and saline environmental conditions (table 9).

Table 9—Threshold tolerance of species that will grow in Stage Three salinized soils

Common name	Botanical name	EC threshold (dS m^{-1})
Row Crops		
Rye	*Secale cereale*	11.4
Wheat (semidwarf)	*Triticum aestivum*	8.6
Barley	*Hordeum vulgare*	8.0
Sugar beet/Red beet	*Beta vulgaris*	7.0
Cotton	*Gossypium hirsutum*	7.7
Triticale	*X Triticosecale*	6.1
Wheat, durum	*Triticum turgidum*	5.8

Forestry

Stage Three salinity stress makes commercial forestry no longer a viable option for the impacted land. In Stage Three, trees exhibit a severe decrease in overall vigor, increase in insect problems, sparse crown, inferior growth, increased mortality, short needle length in pines, small foliage in hardwoods, and increased overall appearance of poor health. Forestry operations in these areas are unlikely to be successful. Chronic salinity can be identified in forests by encroaching salt-tolerant species, such as Wax myrtle *(Morella cerifera)*.[34] The land can be left to transition naturally into saltmarsh, converted to a conservation easement, or cultivated with alternative salt-tolerant crops. For these reasons, there will not be any further discussion of forestry management beyond this stage.

6.3 Productivity/Economic Limitations

Coastal forests will be experience high levels of water stress and mortality at this stage of salinization. At the point of chronic salinization, alternative crops and conservation easements are the sustainable choice to gain additional profit off the land. Few crops can perform at 100 percent yield in these sustained levels of salinity (table 10). The market for alternative crops is less well established than traditional crops and varies by region. Consumer demand may also be low for some of the products from alternative crops. The approximate percent yield for some common crops are shown below (table 10).

Table 10—Percent crop yield at the low and high limits of Stage Three soil salinization for row crops and vegetables at 8 dS m^{-1} to 16 dS m^{-1}

Crop	Botanical name	% Yield at 8 dS m^{-1}	% Yield at 16 dS m^{-1}
Row Crops			
Rye	*Secale cereale*	100	50
Wheat (semidwarf)	*Triticum aestivum*	100	78
Barley	*Hordeum vulgare*	100	83
Sugar beet/Red beet	*Beta vulgaris*	94	47
Cotton	*Gossypium hirsutum*	98	57
Triticale	*X Triticosecale*	95	75
Quinoa	*Chenopodium quinoa willd*	91	75
Wheat, durum	*Triticum turgidum*	92	61
Wheat	*Triticum aestivum*	95	74
Sorghum	*Sorghum bicolor*	81	0
Sugarcane	*Saccharum officinarum*	63	16
Vegetables			
Asparagus	*Asparagus officinalis*	92	76
Celery	*Apium graveolens*	62	12

Species with zero yield at the high end of Stage Three salinity include: alfalfa, artichoke, broadbean, broccoli, cabbage, carrot, cherry tomato, corn, cucumber, eggplant, flax, garlic, grape, grapefruit, guar, guava, lemon, lettuce, muskmelon, onion (seed), orange, pea, pepper, potato, radish, rice, sorghum, soybean, spinach, squash, squash (scallop), sweet potato, tomato, turnip, and zucchini.

6.4 Environmental Impacts

Saltwater intrusion will expand the range of invasive halophytes. Common reed is likely to be the dominant species in salt-impacted coastal ecosystems. Invasive species can rapidly colonize abandoned agricultural fields due to their high nutrient levels and low organic matter.

Saltwater intrusion will impact the biogeochemistry of the environment. Saltwater contains sulfides, which react with iron oxides in the soil. Once the soil's sulfide buffering capacity has been reached, available iron causes an accumulation of free sulfides in soils and sediments. Sulfur inputs from saltwater impact biogeochemical reactions, including phosphorus cycling and phosphorous export to surrounding waters. Sulfidation creates a toxic environment for plants and causes plant stress and death.[13]

6.5 Adaptation Measures

Halophyte agriculture may allow impacted lands to remain viable and productive. Management practices (e.g., crop-pasture rotation, salt-tolerant buffers) and conservation practices may help prolong cultivation practices. Alternative crops, such as salt meadow cordgrass (*Spartina patens*), seashore mallow (*Kosteletzkya virginica*), switchgrass (*Panicum virgatum*), coastal panicgrass (*Panicum amarulum*), prairie cordgrass (*Spartina pectinata*), and Eastern gamagrass (*Tripsacum dactyloides*) can be planted in an entire field, not just in buffers or field edges as recommended in previous salinization stages. If continued cultivation of the land is not pursued, field abandonment will allow the inward migration of wetlands and marshes.

Specialty markets for halophytic crop products harvested from the natural tidal marsh or limited commercial production are being investigated on a small scale in the

Mid-Atlantic States and on a larger scale in Europe. Restaurateurs in the Netherlands are creating a demand for Glasswort (*Salicornia)* to be used in salads, soups, and as a garnish for various foods. Demand is very high in Europe for glasswort, but there is currently limited commercial production of this species. The demand may be slow to evolve in the United States as markets are slow to develop. Halophyte agriculture may eventually need to be adopted in localized geographic areas of the Eastern United States to remain viable and productive.

Regardless of the crops planted, insurance and disaster recovery programs are available. For example, the USDA Farm Service Agency Noninsured Crop Disaster Assistance Program (NAP) provides financial assistance to producers of crops that cannot be insured when low yields, loss of inventory, or prevented planting occur due to natural disasters. Consult with the local extension agent, NRCS, and FSA field offices to learn more.

6.6 Probable Outcomes

As salinity levels continue increasing, fewer crops will be cultivated as a sustainable income source. The profit from cultivation will decline as crop yield declines, up to the point where continuing farming the land no longer makes economic sense. The groundwater table will increase as sea level increases, making flooding more likely and decreasing drainage rates following flooding. At this time, the soil may become too wet to farm.

Forage field with salinity. (Photo coutesy of USDA Photo Library)

CHAPTER 7

Stage Four:
Noncommercial Upland

Stage Four salinized soils are no longer commercially viable with traditional farming approaches. Although some crops will still have limited production in these soils, the economic benefit will be marginal. Additionally, these soils frequently flood, so harvesting becomes an increasing challenge. Therefore, this chapter focuses on using these soils as a pasture or as a conservation easement to protect more inland areas from decline.

Stage Four Characteristics

Stage Four is characterized by having high levels of salinity. Halophytes dominate the landscape, and areas with standing water will become more prevalent. Stage Four salinity soil productivity is no longer profitable for the cultivation of commercial crops due to high salinity levels. Water levels are high, and areas of standing water emerge. Wetland and salt-tolerant plant species begin to colonize affected areas. The land would best be suited for use as a pasture or conservation easement.

EC: detectable

16<25 dS m^{-1}

Crop options: Halophytes

Halophyte grass species

Practically treatable? No

7.1 General Discussion

As saltwater intrusion progresses, soil salinity levels will exceed 16 dS m^{-1}. Productivity will be reduced, and traditional crop operations will no longer be economically feasible. Almost none of the standard row crops grown across the Atlantic Coast will tolerate these conditions, leaving room for the establishment of halophytic, salt-tolerant species. Land managers might want to convert their salt-affected agricultural land directly to wetland, receiving a one-time property payment through a conservation easement. However, in some areas, conversion to non-cultivated working land may be possible, which might give land managers more profitable opportunities. These options include the conversion of cropland to biomass production or livestock-pasture operations. The decision to pursue these should be discussed with a local extension agent.

7.2 Species Tolerance (Upper Threshold Limit)

NRCS has identified salt-tolerant herbaceous plants and their upper pH limits recommended for conservation practices in Stage Four of salinity (table 11). The plant's upper pH limit must fall within the site's soil pH class range to be effective (table 12).

Table 11—Relative alkaline pH/salt-tolerant herbaceous conservation plants

	Upper pH limit	Soil salt tolerances
Plant species/varieties/selections		
Cordgrass, Saltmeadow (*Spartina patens*) 'Flageo' (NC), 'Sharp' (FL)	8.0	Strong
Cordgrass, Smooth (*Spartina alterniflora*)	8.0	Strong
Dropseed, Seashore (*Sporobolus virginicus*)	8.0	Strong
Paspalum, Seashore (*Paspalum vaginiflorum*)	8.0	Strong
Bermudagrass (*Cynodon dactylon*) 'Coastal', 'Tifway'	7.5	Strong
Coastal Panicgrass (*Panicum amarum var. amarulum*) 'Atlantic' (VA)	7.6	Moderate-Strong
Switchgrass (*Panicum virgatum*) High Tide Germ. (MD), Timber Germ. (NC), 'Miami' (FL)	7.5	Moderate-Strong
Bluestem, Little (*Schizachrium socparium*) Dune Crest Germ. (NJ)	8.5	Moderate
Cordgrass, Prairie (*Spartina pectinata*) Southampton Germ. (NY)	8.5	Moderate
Dropseed, Sand (*Sporobolus cryptandrus*)	8.0	Moderate
Teff (*Eragrostis tef*)	8.0	Moderate
Lovegrass, Purple (*Eragrostis spectablilis*)	7.5	Moderate
Zoysiagrass (*Zoysia japonica*) 'Meyer', 'SR9100'	7.5	Moderate
Bluestem, Big (*Andropogon gerardii*) Suther Germplasm (NC)	8.0	Slight
Little Bluestem (*Schizachyrium scoparium*) Suther Germplasm	8.0	Slight
Bluestem, Splitbeard (*Andropogon scoparius*) Ft. Cooper Germ. (FL)	7.5	Slight
Gamagrass Eastern (*Tripsacum dacyloides*) 'Highlander' (MS), 'Meadowcrest' (NY)	7.5	Slight
Indiangrass (*Sorghastrum nutans*) 'Americus', Newberry Germplasm	7.5	Slight
Millet, Japanese (*Echinochloa frumentacea*) 'Chiwapa' (MS)	7.5	Slight
Paspalum, Florida (*Paspalum floridanum*) Mid-Atlantic Germ. (MD)	7.5	Slight
Cool Season Grasses		
Alkaligrass (*Puccinellia distans*) 'Fults', 'Salty'	8.5	Strong
Sudangrass (*Sorghum halpense*)	7.5	Strong
Barley (*Hordum vulgare*) 'Seco'	8.5	Moderate-Strong
Fescue, Tall (*Lolium arundinacea*) 'KY-31', 'Arid', 'Alta', 'Goar','Mohave'	8.5	Moderate
Fescue, Slender Creeping Red (*Festuca rubra* var. *rubra*) 'Dawson', 'Shoreline'	8.0	Moderate
Wildrye, Canada (*Elymus canadensis*) 'Mandan'	8.0	Moderate
Rye (*Secale cereale*)	8.0	Moderate
Ryegrass, Annual (*Lolium multiflorum*)	8.0	Moderate
Bentgrass, Creeping (*Agrostis palustris*) 'Seaside', 'Southshore'	7.5	Moderate
Ryegrass, Perennial (*Lolium perenne*) 'Brightstar SLT', 'Manhattan 3', 'Catalina', 'Fiesta III', 'Paragon', 'Divine', 'Williamsburg'	7.5	Moderate
Sweetgrass (*Hierochloe odorata*)	7.5	Moderate
Oats (*Avena sativa*)	8.5	Slight
Wheat (*Triticum aestivum*)	8.0	Slight
Fescue, Hard (*Festuca trachyphylla*) 'Durar', 'Warwick'	8.5	None
Fescue, Sheep (*Festuca ovina*) 'Covar'	8.0	None
Wildrye, Virginia (*Elymus virginicus*) Kinchafoonee Germplasm (FL)	7.5	None
Legumes/Forbs		
Seaside goldenrod (*Solidago sempervirens*) Monarch Germplasm	7.5	Strong
Alfalfa (*Medicago sativa*)	8.5	Moderate
Yellow sweetclover (*Melilotus officinalis*)	8.0	Moderate
Rape (*Brassica napus*)	7.5	Moderate
Clovers; (*Trifolium* spp.) White Dutch, Red, Ladino, Alsike	7.5	Slight

Table 12—Soil pH classes

pH Class	pH
Ultra acid	<3.5
Extremely acid	3.5-4.4
Very strongly acid	4.5-5.0
Strongly acid	5.1-5.5
Moderately acid	5.6-6.0
Slightly acid	6.1-6.5
Neutral	6.6-7.3
Slightly alkaline	7.4-7.8
Moderately alkaline	7.9-8.4
Strongly alkaline	8.5-9.0
Very strongly alkaline	>9.0

7.3 Impacts

High salinity levels will initiate a transitional period in which colonization and the eventual dominance by halophytic plant species will occur. The location of transition is difficult to predict because the factors that cause the transition are complex. However, the speed at which the transition process happens mainly depends on landscape slope and disturbance pressures such as the area's rate of sea-level rise and frequency of storm surge/coastal flooding events.

Saltwater intrusion into the water table moves salinity levels farther inland while storm surge events push standing water and marsh farther past the seaward boundary. Shallow slope gradients increase the rate at which these boundaries move inland. As water tables rise closer towards the soil surface, drainage capacity and productivity will decrease, resulting in frequently saturated conditions. Due to the reduction in drainage capacity, areas of standing water occur after heavy precipitation. These areas may further enable halophyte and marshland pioneer species growth, resulting in more significant management needs or abandonment of areas.

Most crops are reduced to zero yields in Stage Four. Table 13 shows an approximate percent yield for the plants that tolerate EC values from 16 dS m^{-1} to 25 dS m^{-1}. As these yield estimates are based on otherwise ideal growing conditions, even these are unlikely to prove profitable in real growing conditions of Stage Four salinized lands.

Table 13—Percent crop yield at the low and high limits of Stage Four soil salinization for row crops and vegetables at 16 dS m^{-1} to 25 dS m^{-1}

Crop	Botanical name	% Yield at 16 dS m^{-1}	% Yield at 25 dS m^{-1}
Row Crops			
Wheat (semidwarf)	*Triticum aestivum*	78	51
Cotton	*Gossypium hirsutum*	57	10
Triticale	*X Triticosecale*	75	53
Wheat, durum	*Triticum turgidum*	61	27
Wheat	*Triticum aestivum*	74	51
Vegetables			
Asparagus	*Asparagus officinalis*	76	58

Species with zero yield at the high end of Stage Four salinity include: barley, celery, rye, sugar beet/red beet, and sugarcane.

Forestry

Forests can survive at Stage Four, though their productivity will be very low. Tree mortality will lead to salt-tolerant vegetation such as cattail (*Typha* sp.), common reed, and sawgrass (*Cladium* sp.) moving into the open spaces left by the dead trees. Salt-tolerant species may pull additional salt to the soil surface due to their shallow roots. Freshwater tree seedlings are unlikely to grow in a more saline environment.[28]

7.4 Adaptation Measures

Potential marketability for biomass products is improving, especially within areas of the Northeast. Livestock bedding materials created from cultivated salt-tolerant grass species prove to be more effective than standard materials while also showing reduced disease transmission in livestock. Implementation of these grass species creates opportunities for biomass production and profit, and it may also work to stabilize soils eroded by traditional crop rotations.

Conversion of cropland to livestock-pasture operations appears to have a much more sizeable risk potential (e.g., hoof diseases and injury risk from the uneven ground) than biomass production. Livestock systems require land managers to possess an alternative skill set compared to traditional crop rotation systems.[30] While livestock readily digests halophytic plant tissues, these species possess high mineral content and low energy content levels that have been linked to weight loss and other detrimental effects. However, studies have shown the feasibility of mixed halophyte forage implementation in livestock diets. With proper freshwater access, forages containing a blend of high energy components (i.e., legumes) and halophytic plant species may be used in livestock production. The economic feasibility of conversion to livestock-pasture operations would rely on conversion costs (i.e., equipment, inventory, planting costs) and the ability to produce high-energy forage components on non-impacted land.

Other options to consider include leasing the land for hunting, selling, or donating land into a conservation easement. Conservation easements reduce the property tax on the land, which is economically beneficial, protects the land during transition to saltmarsh, and allows the landowner to retain property rights and amenities while agreeing not to use the land for development purposes. They can also provide recreational opportunities in hunting, fishing, and wildlife-related recreation, which also brings economic benefits to the surrounding community. Additional Conservation Programs by the NRCS are discussed further in Appendix V.

Regardless of the crops planted, every landowner should take advantage of available insurance and disaster recovery programs. For example, the USDA Farm Service Agency Noninsured Crop Disaster Assistance Program (NAP) provides financial assistance to producers of crops that cannot be insured when low yields, loss of inventory, or prevented planting occur due to natural disasters. Consult with the local extension agent, NRCS, and FSA field offices to learn more.

7.5 Probable Outcomes

Eventually, soil-water content and regular standing water will become too high and frequent to maintain pastureland and livestock. Many of the potential forage plant species will not tolerate both high salinity levels and inundation. Land managers should consider enrolling in wetland easements or promoting the restoration of native wetland vegetation. The local NRCS field staff or extension agent can provide details on options and how to enroll. Despite the loss of profitable land, conversion to wetland entails other benefits such as monetary compensation, tax incentives, and added flood and erosion protection for adjacent farmlands. To maximize the benefits of conversion, proper planning and communication between the land manager and specialists, such as local extension agents, is crucial.

CHAPTER 8

Economic Case Study

An economic case study was carried out to determine certain crops' economic profitability in the first four salinization stages. The case study was based solely on crop prices without the consideration of government incentives and subsidies. The study area was the Tidewater Area in eastern North Carolina, an area of roughly 2.8 million acres (11,600 km^2) that includes the cities of Creswell, Edenton, Elizabeth City, Kitty Hawk, Morehead City, Pantego, and Swan Quarter as well as Capes Hatteras and Lookout and Ocracoke Island.

Converting tidewater wetlands for agricultural purposes has occurred by section over a long time. By the late 18th century, the first large-scale drainage of deep organic soils had begun in Washington County for rice production. A century later, large areas in the northeastern part of the State around the Great Dismal Swamp and on the Albemarle-Pamlico Peninsula had been converted to cropland. Around this time and into the early 20th century, timber companies acquired large tracts of coastal swampland for logging, especially for shingles from Atlantic white cedar. With the desirable timber removed, much of this land was sold for development. In the years after World War II, as equipment and cultural practices improved and competition for land increased, land conversion to cropland gained momentum in the Tidewater Area.

The area is a nearly level coastal plain crossed by broad, shallow valleys containing meandering river channels. Elevation ranges from sea level to <25 feet (7.6 m). Generally, local relief is <3 feet (1 m). Most valleys terminate in the estuaries along the coast, where tidal marshes are being created by sea-level rise.

The Tidewater Area has extensive pocosins, formations of decomposed peat. Pocosins form from accumulating dead plant material and its transformation into a muck, and are found on broad, flat inter-stream divides with few dissecting streams for water removal. The soil materials underlying them are slowly permeable clayey to sandy mineral sediments that remain water-logged almost perpetually.

Together, these factors led to the formation of cypress and Atlantic white-cedar forests. Under the anaerobic and acidic conditions, organic matter decayed slowly and accumulated while the forests eventually drowned in the accumulating muck or burned and fell.

Since 1890, sea level has risen about 1 foot (0.3 m), with implications for the long-term, continued intensive use of this area. Much of the land on the Albemarle-Pamlico Peninsula is <5 feet (1.52 m) above sea level. Coastal shoreline erosion is symptomatic of long-term, continuing sea-level rise.

Methods

Crop budgets were developed using North Carolina State University (NCSU) Agricultural and Resource Economics (ARE) Enterprise Budgets for the Tidewater Area for each crop and production system combination. All crop budgets were for the crop year 2019. All variable and fixed costs, input rates, and amounts used were those contained in the budgets. All costs were adjusted to 2019 prices using the Bureau of Labor Statistics CPI Inflation Calculator. Labor and tractor/machinery cost estimates were for those directly associated with field operations (i.e., planting and harvesting).

Production systems considered in this analysis included conventional tillage (CV), no-tillage (NT), strip-tillage (ST), and organic (O). Corn and soybean were analyzed using all four production systems. Cotton was analyzed using conventional and no-tillage, while wheat was analyzed using conventional tillage and organic production.

The switchgrass budget assumed that there was already an established stand. Establishment costs were allocated to fixed costs and depreciated over 20 years. Switchgrass yield declines were 74 percent at EC=5 and 44 percent at EC=10. Crop yields in the enterprise budgets were considered from non-saline settings, i.e., EC=0, and adjusted by the percentage decline associated with the electrical conductivity levels of 2, 4, 8, and 16 (see tables 6, 7, and 10 above).

Corn, soybean, and wheat prices and basis were averages taken from the usual month of harvest at elevators and feed mills in Cofield, Creswell, Elizabeth City, and LaGrange, NC, and Norfolk and Wakefield, VA. Cotton prices were those provided by the cotton enterprise budgets. Switchgrass biomass prices were taken from the Internet Hay Exchange.

Results

Net returns and yields per acre for each crop and production system combination at the soil electrical conductivity (EC) levels of 0, 2, 4, 8, and 16 (0, 5, and 10 for switchgrass) are given in the tables below. Net returns are returns to land, labor, capital, and management calculated as gross revenue minus all variable and fixed costs following harvest. Gross revenue was estimated by multiplying crop yield times the crop price at harvest.

Corn

Most Tidewater corn is planted in April and the early part of May. Usually, the crop is harvested in September or early October, but harvesting may extend to as late as mid-November. Much of the crop is used in livestock feed. However, the use of corn for biofuel production fuel has risen substantially over the last 15 years.

Corn is sensitive to salinity, and yields begin to decline early in the onset of Stage One salinity levels. Corn is generally not commercially viable by Stage Two levels regardless of the production system employed. However, organic production may remain profitable into Stage Two's lower salinity levels due to the product's premium per-bushel price. Price drops of as little as 5–10 percent can significantly erode profitability.

Net returns varied by cropping systems. The non-organic systems' per-acre net returns were positive ($40 to $76 per acre) in Stage One salinity levels, although 6- to 13-percent lower than at Stage Zero. With the onset of Stage Two salinity levels, net returns became negative (-$4 to -$41 per acre) and continued to decline as salinity increased. Organic production net returns were positive ($274 per acre) in Stage One and remained so through Stage Two levels ($123 per acre). However, organic corn was the only corn production system with a positive return at the beginning of Stage Two, which highlights the dependence of the crop's success on premium (organic) per-unit prices.

Table 14—Crop yield under varying production systems and electrical conductivity (EC)

		Soil electrical conductivity (EC) (dS m-1)				
		0	2	4	8	16
		Stage 0	Stage 1	Stage 2	Stage 3	
Crop	Production System	Crop Yield (tons per acre)				
Corn	CV[1]	149	148	125	80	0
Corn	NT[2]	149	148	125	80	0
Corn	ST[3]	148	147	124	80	0
Corn	O[4]	107	106	90	58	0
Cotton	CV	830	830	830	813	473
Cotton	NT	900	900	900	882	513
Soybean	CV	41	41	41	16	0
Soybean	NT	41	41	41	16	0
Soybean	ST	41	41	41	16	0
Soybean	O	30	30	30	12	0
Wheat	CV	50	50	50	50	39
Wheat	O	43	43	43	43	34
		Soil electrical conductivity (EC) (dS m-1)				
		1.2#	5#	10#		
Switchgrass	bio-mass	6	4	3		

[1] Conventional tillage
[2] No tillage
[3] Strip tillage
[4] Organic
#Sun, Y.; Niu,G.; Ganjegunte, G.; Wu, Y. 2018. Salt tolerance of six switchgrass cultivars. Agriculture. 8(5): 66. https://doi.org/10.3390/agriculture8050066.

Table 15—Net returns for crops under varying production systems and electrical conductivity (EC)

		Soil electrical conductivity (EC) (dS m-1)				
		0	2	4	8	16
		Stage 0	Stage 1	Stage 2	Stage 3	
Crop	Production System	Net Return (dollars per acre)				
Corn	CV[1]	69	64	(17)	(179)	(470)
Corn	NT[2]	46	40	(41)	(202)	(494)
Corn	ST[3]	81	76	(4)	(165)	(454)
Corn	O[4]	283	274	123	(180)	(726)
Cotton	CV	47	47	47	34	(232)
Cotton	NT	106	106	106	92	(196)
Soybean	CV	4	4	4	(198)	(332)
Soybean	NT	(12)	(12)	(12)	(214)	(348)
Soybean	ST	34	34	34	(167)	(301)
Soybean	O	124	124	124	(225)	(457)
Wheat	CV	(30)	(30)	(30)	(30)	(76)
Wheat	O	(62)	(62)	(62)	(62)	(160)
		Soil electrical conductivity (EC) (dS m-1)				
		1.2#	5#	10#		
		Net Return (dollars per acre)				
Switchgrass	bio-mass	30	(74)	(194)		

[1] Conventional tillage
[2] No tillage
[3] Strip tillage
[4] Organic
#Sun, Y.; Niu,G.; Ganjegunte, G.; Wu, Y. 2018. Salt tolerance of six switchgrass cultivars. Agriculture. 8(5): 66. https://doi.org/10.3390/agriculture8050066.

Cotton

In Tidewater cotton fields, planting season begins early in May and usually concludes by mid-June. Cotton harvest peaks in October and November but may run into mid-December. Most Tidewater cotton is upland or short-staple cotton used in clothing, and for home and hospital/medical uses.

Cotton can tolerate higher soil salinity levels, maintaining high productivity levels through Stage Two and into the lower salinity levels of Stage Three. However, once salinity levels exceed an EC of ~8 dS m^{-1}, productivity falls off rapidly. In the lower range of salinity in Stage Three, the net returns were positive for both conventionally tilled ($34) and no-tillage ($92) cotton production systems. However, as salinity increased, net returns fell significantly.

Soybeans

Soybeans are generally planted in late May and June in the Tidewater Area. Harvesting is usually completed in November but may begin in October and extend to mid-December. Tidewater producers tend to have lower yields and higher per-bushel production costs relative to producers in other soybean producing areas of the United States. Higher yields reduce per-bushel production costs.

Soybean yields are unaffected by Stage One salinity levels. However, as salinity levels move into Stage Two, the crop's yields rapidly decline. Net returns using CV, ST, and organic production systems were positive through Stage One and the lower levels of Stage Two, while those using NT were negative in all salinity stages. Returns were marginal ($4 per acre) using conventional tillage systems. Strip tillage returns ($34 per acre) were higher, but the organic production system offered even higher returns. The per-acre net returns for organic production were the second highest of all the crop-production systems analyzed. Remembering that the high net returns from organic soybean production are dependent on premium per-bushel prices that may or may not be sustainable is important. In Stage Three salinity levels, soybean net returns for all production systems were negative (-$167 to -$225 per acre).

Wheat

Soft red winter (SRW) wheat is grown in the Tidewater Area of North Carolina. The wheat is sown in the fall, giving the crop time to establish before becoming relatively dormant with the arrival of cold winter temperatures. The crop resumes growth in the spring and is usually harvested in early summer. By late July in North Carolina, most wheat has been harvested.

Wheat is one of the few crops relatively unaffected by higher Stage Three soil salinity levels. Even at the onset of Stage Four, wheat yields remain high relative to almost all other species. However, the yields are probably not commercially viable.

Despite wheat's resilience to increasing soil salinity, net returns remained negative across the entire EC spectrum. Even the premium per-bushel prices associated with organic production could not push returns into the positive. Relative to other wheat-producing regions, Tidewater Area growers may face marginal yields and high production costs, which reduces profitability. Warmer, humid growing conditions there may reduce yields and increase pest pressures, which increase production costs. Higher yields reduce per-bushel production costs.

Switchgrass

Percentage yield declines available for switchgrass were not as detailed as those of the other crops. Yield decline estimates for electrical conductivities of 1.2, 5, and 10 were available, and those corresponded with Stages Zero, Two, and Three soil salinity ranges. In Stage Zero, returns for switchgrass biomass were positive ($30 per acre) but became negative (-$74 per acre) in Stages Two and Three.

Conclusions

Except for wheat and no-tillage soybeans, net returns per acre were positive at the beginning of Stage One. Cotton had the highest salinity tolerance and was able to produce a positive net return at the beginning of Stage Three. Once a species' threshold soil salinity tolerance was reached, net returns quickly became negative.

Despite being the most salt-tolerant crop, wheat net returns were never positive across all soil salinity levels, including non-saline. Even premium prices could not push organic wheat production into positive territory. The negative wheat returns reflect overall market conditions for the commodity. For several years, wheat plantings and production have been on a long-term downward trend. According to the USDA Economic Research Service, since peaking in 1981, U.S. wheat planted has dropped by more than 30 million acres, with production falling by close to 900 million bushels.[35]

Across all soil salinity levels, organic corn and soybean production yields were 25- to 30-percent lower than those for all tillage-based production systems. Despite the yield reductions, organic corn and soybean production offered attractive net returns for 2019. However, those returns are most likely anchored in the premium per-bushel prices paid. Small declines in product prices can quickly erode positive net returns.

There seems to be a soil salinity level threshold for all crops but cotton. Net returns from cotton production remained positive for all but the highest soil salinity levels. Once salinity levels enter the Stage Two range, net returns decline quickly into the negative, and aside from cotton, few cropping options remain.

CHAPTER 9

Stage Five: Saltmarsh

The soil in a Stage Five field has transitioned into a semi-aquatic system, with standing or tidal brackish water often present. Grazing is no longer a likely option, as water, foot rot, and potential for unseen holes pose a danger to livestock. Although not viable for commercial production, saltmarshes are important waterfowl and wildlife habitats, and these areas could have the potential for inland protection, hunting leases, and recreational or aesthetic value. Additionally, the land has value as a conservation easement. The environmental characteristic of different wetland ecosystems is shown in table 16.

Stage Five Characteristics

Stage Five is characterized by having high salinity and being influenced by the tides. Saltmarsh species and open water become present in the landscape. Stage Five salinity soils have converted to a saltmarsh, with high salinity levels and some open water. The area is regularly flooded by tides.

EC: detectable

>25 dS m^{-1}

Crop options: none

Practically treatable? No

9.1 General Discussion

As further saltwater intrusion occurs, the cost-effectiveness of cultivation and running operations will decrease. However, managing these areas may still provide benefits in the form of ecosystem services. Saltmarsh environments sequester more carbon annually compared to agricultural lands[36] and can help stabilize eroding shorelines. Many native species occupy saltmarsh environments leading to greater biodiversity rates. Natural lands tend to increase public attention and the desire for recreational areas as well. Marshes and wetlands also improve water quality through their ability

Table 16—The environmental characteristics of different wetland ecosystems

Site characteristics	Saltmarsh	Brackish wetland
Water classification	Saltwater	Mix of fresh and salt
Salinity	High (20–35 ppt)	Varies (0.5–20 ppt)
Vegetation	Herbaceous	Woody and herbaceous
Ocean influence	Tidal	Tidal and event-based
Location	Coastal	Transition zone

to filter contaminants and sediments. Saltmarsh ecosystems can reduce impacts from coastal flooding and damages associated with hurricane activity. Reductions in coastal mangrove/marshland areas raise the potential for severe damages to vulnerable infrastructure, cities, and inland ecosystems.[37] Working lands may be converted to a wetland easement where the landowner receives payment for converted acreage. The benefits of conversion would protect adjacent farmland and provide benefits to the surrounding ecosystems and communities.

9.2 Impacts

As sea levels continue to rise, saltmarsh ecosystems move farther inland in a phenomenon called "marsh migration." As these areas migrate, the threat of invasive plant species increases. For example, the common reed is known to outcompete and replace critical native species. Saltwater intrusion and marsh migration inland also pose a severe threat to forest land along the coast. Hardwood species (e.g., oak, maple, and hickory) that are sensitive to soil salinity and inundation start to die and rot from the bottom up. Eventually, as salinity increases, more salt-tolerant species such as loblolly pine, holly, beech, and sweetgum will also die.[38] These decaying forest areas are referred to as "ghost forests" due to the large-scale mortality and discoloration of the rotting bark. Ghost forest formation is typically followed by conversion to saltmarsh. Areas such as ghost forests provide a space for marshes to migrate inland, which is necessary for tidal marsh ecosystem persistence as sea levels rise.

9.3 Species Tolerance

Saltmarshes are inhabited by plant species able to tolerate moderate to high salinity ranges. Soil salinity and inundation state are variable within different marsh zones. The low marsh zone area is usually at a low elevation and in direct contact with open water or the saltwater source; therefore, the low marsh experiences frequent flooding associated with the tidal activity. Species that are salt-tolerant and can withstand long periods of inundation thrive in the low marsh zone.

The zone residing above the low marsh is referred to as the high marsh zone. The high marsh may encompass large swaths of the area and tends to be saturated with infrequent inundation. High marshes can be saltier than low marshes because of evaporation, and less frequent tidal flushing increases soil salt concentrations. This zone contains few grass and flowering species.

At higher elevations, high marsh begins to blend into an area referred to as the upland border. This zone has high biodiversity due to low saturation levels and reduced soil salinity. Depressions within the high marsh area's microtopography are referred to as pannes and frequently fill with stagnant water. Salinity levels within and around pannes tend to be significantly higher than the surrounding high marsh. Deep pannes that remain filled for extended periods are denoted as pools. Species that occupy the various saltmarsh zones can be found in table 17 on the following page.

Table 17—Common species present in Stage Five salinity soils

Low marsh	
Smooth cordgrass (*Spartina alterniflora*)	
Seashore alkali grass (*Puccinellia maritima*)	
Seaside arrow grass (*Triglochin maritimum*)	
Narrowleaf cattail (*Typha angustifolia*)	
Sea cavender (*Limonium nashii*)	
Glasswort (*Salicornia* spp.)	
High marsh	
Saltmarsh aster (*Symphyotrichum subulatum*)	
Spike grass (*Distichlis spicata*)	
Black grass (*Juncus gerardii*)	
Needlegrass (*Juncus roemerianus*)	
Saltmeadow grass (*Spartina patens*)	
Seashore gaspalum (*Paspalum vaginatum*)	
Coastal dropseed (*Sporobolus virginicus*)	
Rose mallow (*Hibiscus moscheutos*)	
Seashore mallow (*Kosteletzkya virginica*)	
Upland border	
Switchgrass (*Panicum virgatum*)	
Coastal panicgrass (*Panicum amarulum*)	
Sweet gale (*Myrica gale*)	
Wax myrtle (*Myrica cerifera*)	
Groundsel (*Baccharis halimifolia*)	
Marsh elder (*Iva frutescens*)	
Seaside goldenrod (*Solidago sempervirens*)	
Pannes	
Glasswort (*Salicornia* ssp.)	
Smooth cordgrass (*Spartina alterniflora*)	
Pools	
Widgeon grass (*Ruppia Maritima*)	
Eelgrass (*Zostera marina*)	

9.4 Adaptation Measures

During the conversion of cropland to saltmarsh, proper management must promote the valuable native species that will yield the most benefits to the area and landowner. Leaving the area unmanaged results in a deficient wetland environment and the promotion of salt-tolerant and invasive plant species. Many of the plant species used as traditional forages will not tolerate salinity levels above the Stage Four threshold. When going through the conversion process, land managers, in cooperation with a local extension agent, should select a sensible variety of salt-tolerant species or nurse plants that may help with the transitioning of the working land. These species help to create an environment where key species are unhindered by soil quality or invasive species.

Regardless of the crops planted, every landowner should take advantage of available insurance and disaster recovery programs. For example, the USDA Farm Service Agency Noninsured Crop Disaster Assistance Program (NAP) provides financial assistance to producers of crops that cannot be insured when low yields, loss of inventory, or prevented planting occur due to natural disasters. Consult the local extension agent, NRCS, and FSA field office for more information.

9.5 Probable Outcomes

As sea levels continue to rise at an accelerated rate, saltmarsh ecosystems will eventually transition into open water areas. The amount of time saltmarshes can persist is uncertain and depends on the natural and anthropogenic drivers of saltwater intrusion.[39] If accretion levels are high, marshes may persist for long periods due to their ability to maintain elevations relative to sea level. The impacts of climate change near coastal areas are not entirely known, though inland drought frequency may play a significant role in saltmarsh ecosystems changes.

9.6 Stage Six: Open Water

As water inundation continues, the site transitions to a fully aquatic ecosystem. The characteristics of different types of marine ecosystems in shown in table 18. In the southeast Atlantic Coast, roughly 44 km^2 (10,873 acres) of dry land and wetlands were converted to open water from 1996 to 2011.[40] From 1985 to 2010, Louisiana's coast lost an average of 42.99 km^2 (10,623 acres) of land per year to open water.[41] Depending on the topography, tides, fresh- and saltwater water input ratios, and other factors, the area could range from slightly brackish to seawater. Management of this newly created marine ecosystem is beyond the scope of this guide.

Table 18—Characteristics of different types of marine ecosystems

Classification	EC in dS m^{-1}	EC in uS cm^{-1}	mM NaCl	ppt	ppm	mg Cl L^{-1}
Freshwater	0.8	800	8	0.5	500	280
Slightly brackish	1.7	1700	17	1	1000	600
Medium brackish	1.7 - 8	1700 - 8000	17 - 80	1 - 5	1000 - 5000	600 - 2800
Brackish	8 - 25	8000 - 25000	80 - 250	5 - 15	5000 - 15000	2800 - 9000
Strong brackish	25 - 58	25000 - 58000	250 - 580	15 - 35	15000 - 35000	9000 - 18000
Seawater	58	58000	580	35	35000	18000
Brine	> 58	> 58000	> 580	<35	>35000	>18000

Saltmarsh. (Photo courtesy of Needpix)

APPENDIX I

Useful Tools and Resources

Resources

NC State tool useful for cost-revenue analysis of implementing SRWC within North Carolina
https://projects.ncsu.edu/project/bioenergy/SR_Hardwoods.html

Factsheet guidance from Mississippi State Extension on SRWC
http://extension.msstate.edu/sites/default/files/publications/publications/p3019.pdf

BioSAT
Host of tools and factsheets on SRWC cost assessment and suitability

Suitability Index: http://www.biosat.net/index.html

Factsheets: http://www.biosat.net/FactSheets.html

Harvesting and Transportation cost tools: http://www.biosat.net/Toolset.html

NOAA Sea Level Rise Map Viewer
Useful large-scale map viewer showing sea-level rise, marsh migration, high-tide flooding potential, and population vulnerability for the United States

https://coast.noaa.gov/slr/#/layer/slr/0/-11581024.663779823/5095888.569004184/4/satellite/none/0.8/2050/interHigh/midAccretion

Union of Concerned Scientists SLR Fact Sheet
A factsheet detailing causes and measurement of sea-level rise along with vulnerable land areas and populations
https://www.ucsusa.org/sites/default/files/legacy/assets/documents/global_warming/Causes-of-Sea-Level-Rise.pdf

Smithsonian SLR
Smithsonian sea-level rise resource on impacts and measurement
https://ocean.si.edu/through-time/ancient-seas/sea-level-rise

U.S. Climate Resilience Toolkit
Shows sea-level rise estimates from 2020–2100 corresponding with emission/climate change scenarios. Provides NOAA's interactive relative sea-level trends map
https://toolkit.climate.gov/

Coastal Salinity Index
Developed by USGS in cooperation with NOAA and National Integrated Drought Monitoring System (NIDIS)
https://www2.usgs.gov/water/southatlantic/projects/coastalsalinity/home.php

Noninsured Crop Disaster Assistance Program (NAP): provides financial assistance to producers of uninsurable crops when low yields, loss of inventory, or prevented planting occur due to natural disasters
https://www.fsa.usda.gov/programs-and-services/disaster-assistance-program/noninsured-crop-disaster-assistance/index

Regional Variability in Alternative Crop Markets

Advice on alternative crop systems and markets—University of Maryland

https://extension.umd.edu/agmarketing/alternative-enterprises

Alternative Crop Resource—USDA

https://www.nal.usda.gov/afsic/list-alternative-crops-and-enterprises-small-farm-diversification

Alternative/Specialty Crop Marketing—NCSU

https://newcropsorganics.ces.ncsu.edu/specialty-crops/specialty-crops-marketing/

Crop Selection and Market Implications—UGA

https://extension.uga.edu/publications/detail.html?number=B1398&title=Nursery%20Crop%20Selection%20and%20Market%20Implications

Halophytes

http://www.biosalinity.org/halophytes.htm#Why_Halophytes_Economic_&_Environmental_

Food and Agriculture Organization of the United Nations Factsheet/Portal

http://www.fao.org/agriculture/crops/thematic-sitemap/theme/spi/scpi-home/managing-ecosystems/integrated-crop-livestock-systems/en/SARE Presentations

https://www.sare.org/Learning-Center/Conference-Materials/2014-National-Conference-on-Cover-Crops-and-Soil-Health/Grazing-Cover-Crops-and-Benefits-for-Livestock-Operations

USDA NRCS Pennsylvania

https://www.nrcs.usda.gov/wps/portal/nrcs/detail/pa/soils/health/?cid=nrcseprd1204610

APPENDIX II

Native Plant Species Salt Tolerances by Condition

Plant species have varying tolerance levels to salt spray, soil saturated with saltwater, and infrequent flooding of brackish water. In table A1, the more tolerant species are denoted by "X" and "*" denotes low/medium tolerance species. Plant species can be tolerant to direct salt spray or indirect/infrequent salt spray. The tolerance of plant species to soil saturated with saltwater and flooding with brackish water is based on the salinity (ppt) they can withstand.

Table A1—Native plant species salt tolerances by condition

Botanical name	Plant	Salt spray	Saltwater	Flooding
SHRUBS/VINES/GROUNDCOVER				
Amorpha fruticosa	Indigobush		X	*
Arctostaphyllos uva-ursi	Bearberry	*	*	*
Aronia arbutifolia	Red chokeberry		*	*
Aronia melanocarpa	Black chokeberry		*	*
Baccharis halimifolia	Groundsel bush	X	X	X
Cephalanthus occidentalis	Buttonbush		*	*
Clethra alnifolia	Sweet pepperbush	*	*	*
Ilex glabra	Inkberry	*	*	X
Ilex decidua	Possumhaw		*	*
Iva frutescens	Marsh elder	X	X	X
Juniperus conferta	Seashore juniper	X	*	X
Lindera benzoin	Spicebush		*	*
Magnolia virginica	Sweetbay		*	*
Morella pensylvanica	Bayberry	X	*	*
Myrica cerifera	Wax myrtle	X	*	X
Parthenocissus quinquefolia	Virginia creeper	*	*	*
Prunus maritima	Beach plum	X	*	X
Rosa carolina	Pasture rose	*	*	X
Rosa rugosa	Rugosa rose	X	*	X
Rosa virginiana	Virginia rose	*	*	*
Rhus copallina	Winged/Dwarf sumac	*	*	*
Salix discolor	Pussy willow		*	*
Sambucus canadensis	Elderberry		*	*
Vaccinium corymbosum	Highbush blueberry	*		*
Viburnum dentatum	Southern arrowwood	*		*

Botanical name	Plant	Salt spray	Saltwater	Flooding
TREES				
Alnus serrulata	Smooth alder			*
Amelanchier canadensis	Serviceberry/Shadbush	*	*	*
Celtis occidentalis	Hackberry	X		*
Juniperus virginiana	Eastern red cedar	X	*	*
Ilex opaca	American holly	X	*	*
Populus deltoides	Eastern cottonwood	*	*	*
GRASSES/GRASSLIKES				
Ammophila breviligulata	American beachgrass	X	X	X
Distichlis spicata	Saltgrass	X	X	X
Juncus gerardii/roemarianus	Blackgrass/Needlerush	X	X	X
Panicum virgatum	Switchgrass	*	*	X
Panicum amarum	Bitter panicgrass	X	X	X
Panicum amarulum	Coastal panicgrass	X	*	X
Schizachyrium littorale	Seacoast bluestem	X	X	X
Scirpus tabernaemontanii	Hardstem bulrush	*	*	*
Scirpus americanus	Three square	*	*	*
Scirpus robustus	Saltmeadow bulrush	*	X	X
Spartina alterniflora	Smooth cordgrass	X	X	X
Spartina cynosuroides	Giant cordgrass	*	*	*
Spartina pectinata	Prairie cordgrass	*	*	*
Spartina patens	Saltmeadow cordgrass	X	X	X
Tripsacum dactyloides	Eastern gamagrass	*	*	*
Typha angustifolia	Narrow-leaf cattail	*	*	*
FORBS				
Hibiscus moscheutos	Marsh hibiscus	*	*	*
Kosteletzkya virginica	Seashore mallow	X	*	*
Lathyrus maritimus	Beach pea	X	*	*
Solidago sempervirens	Seaside goldenrod	X	X	X

1. Salt spray
X = tolerance to direct salt spray
* = tolerance to indirect/infrequent salt spray

2. Saltwater (soil saturated)
X = strong tolerance (up to 25–35 ppt sodium chloride concentration)
* = low/medium tolerance (up to 10–15 ppt sodium chloride concentration)

3. Flooding tolerance = tolerance to infrequent flooding of brackish water
X = strong tolerance (up to 25–35 ppt sodium chloride concentration)
* = low/medium tolerance (up to 10–15 ppt sodium chloride concentration)

APPENDIX III

Unit Conversions

The following conversions produce approximate total dissolved solids (TDS) and parts per million (ppm) values and should not be taken as absolute and accurate values.

Handy Unit Conversions:

Milligrams per liter (mg/l or mg l^{-1}) equals parts per million (ppm).

Example: 125 mg l^{-1} = 125 ppm.

Percentage multiplied by 10,000 equals parts per million (ppm), or conversely, parts per million (ppm) divided by 10,000 equals percentage (%).

Example: To convert 2% (0.02 x 100) to ppm, multiply 2 times 10,000 to get 20,000 ppm. Do not confuse the fraction 0.02 with 2 percent when converting. However, if the percentage were actually 0.02% (0.02/100 or 0.0002), then the conversion would correctly be 0.02 x 10,000 = 100 ppm.

Milligrams per liter (mg l^{-1}) = parts per million (ppm).

Example: 20 mg l^{-1} = 20 ppm.

Electrical Conductivity (EC) x 640 = Total dissolved solids (TDS) of lesser saline soils
Electrical Conductivity (EC) x 800 = Total dissolved solids (TDS) of highly saline soils

Example: the TDS of a very slightly saline soil with an EC of 2.5 dS cm^{-1} can be approximated by multiplying 2.5 X 640 = 1,600 ppm or 0.16 percent or 0.0016.

Electrical Conductivity (EC) Testing Laboratories by State

Alabama—Special Soil Analysis	https://ssl.acesag.auburn.edu/anr/soillab/
Delaware—Soluble Salts Test	https://www.udel.edu/canr/cooperative-extension/environmental-stewardship/soil-testing/
Florida	http://edis.ifas.ufl.edu/ss186
Georgia	http://aesl.ces.uga.edu/
Louisiana—Optional Soil Test	https://www.lsuagcenter.com/portals/our_offices/departments/spess/servicelabs/soil_testing_lab
Maryland	https://extension.umd.edu/hgic/topics/soil-testing
Mississippi—only measures TSS	http://extension.msstate.edu/lawn-and-garden/soil-testing
New Jersey	https://njaes.rutgers.edu/soil-testing-lab/
North Carolina—only gives soluble salt index (10-5 mho/cm)	http://www.ncagr.gov/agronomi/uyrst.htm
South Carolina—same as NC	https://www.clemson.edu/public/regulatory/ag-srvc-lab/soil-testing/index.html
Virginia—same as NC	https://www.soiltest.vt.edu/fees-and-forms.html

LEFT: Soil pH test kit. (Photo courtesy of CSIRO Forestry and Forest Products, Wikimedia Commons; CC BY 3.0 license);
RIGHT: Well testing. (Photo courtesy of USDA Photo Library)

APPENDIX V

Conservation and Farm Bill Programs

The following programs can be used in most of the salinization stages. To find programs available in your area, contact your local NRCS field staff. Conservation and Farm Bill programs should be discussed with your local NRCS field staff. NRCS field office staff are more knowledgeable on these programs and work with producers and landowners to determine which one(s) are more feasible depending on farm-specific resource concerns and farmer objectives.

Conservation Programs Administered by the Natural Resources Conservation Service

On the public side, the U.S. Government has established financial incentive programs intended to preserve wetlands and other ecosystems that promote compensation, not avoidance or minimization. The Agricultural Conservation Easement Program (ACEP) and the Conservation Reserve Program/Conservation Reserve Enhancement Program (CRP/CREP) are the NRCS's two main wetland programs.

Agricultural Conservation Easement Program (ACEP)

The Agricultural Conservation Easement Program replaced the Wetlands Reserve Program (WRP) in 2014 under the new Farm Bill. The wetlands portion of ACEP is a continuation of the WRP, now referred to as the WREP (Wetland Reserve Enhancement Partnership). The WREP/ACEP is specifically intended to assist landowners in protecting, restoring, and enhancing wetlands on their property. The WREP/ACEP is a joint effort between the USDA-NRCS and State and local governments. The WREP/ACEP encompasses three different enrollment options—permanent easements, 30-year easements, and restoration cost-share agreements. Most easements fall into the first category and are protected for perpetuity.

Agricultural Management Assistance Program (AMA)

The Agricultural Management Assistance program helps agricultural producers manage financial risk through diversification, marketing, or natural resource conservation practices. NRCS administers the conservation provisions while the Agricultural Marketing Service and the Risk Management Agency implement the production diversification and marketing provisions.

Environmental Quality Incentives Program (EQIP)

The Environmental Quality Incentives Program provides financial and technical assistance to agricultural producers to address natural resource concerns and delivers environmental benefits. The objectives include improving water and air quality, conserving ground- and surface water, increasing soil health, reducing soil erosion and sedimentation, improving or creating wildlife habitat, and mitigating against increasing weather volatility.

Mangroves. (Photo courtesy of James St. John; CC BY 2.0 license)

Conservation Stewardship Program (CSP)

The Conservation Stewardship Program helps agricultural producers maintain and improve their existing conservation systems and adopt additional conservation activities to address priority resource concerns. Participants earn CSP payments for conservation performance—the higher the performance, the higher the payment.

CSP Grasslands Conservation Initiative

This new initiative helps producers protect grazing land use, conserving and improving soil, water, and wildlife resources; and achieving related conservation values by conserving eligible land through grassland conservation contracts. Eligible lands are limited to cropland for which base acres have been maintained under the Farm Service Agency's Agricultural Risk Coverage/Price Loss Coverage and were planted to grass or pasture, including idle or fallow, during a specific period. Enrolled acreage must be managed consistently with a grassland conservation plan. Producers will have a single opportunity to enroll eligible land in a 5-year contract.

Healthy Forests Reserve Program (HFRP)

The Healthy Forests Reserve Program helps landowners restore, enhance, and protect forest land resources on private and tribal lands through easements and financial assistance. Through HRFP, landowners promote the recovery of endangered or threatened species, improve plant and animal biodiversity, and enhance carbon sequestration.

Regional Conservation Partnership Program (RCPP)

The Regional Conservation Partnership Program promotes coordination between NRCS and its partners to deliver conservation assistance to producers and landowners. NRCS provides support to producers through partnership agreements and RCPP conservation program contracts.

Conservation Programs Administered by the Farm Service Agency (FSA)

Biomass Crop Assistance Program (BCAP)

The Biomass Crop Assistance Program provides incentives to help farmers grow bioenergy feedstocks, i.e., crops well suited for conversion to energy such as warm-season grasses and woody trees and shrubs.

Conservation Reserve Program (CRP)

The CRP was established in 1985 as part of the Farm Bill and is managed by the USDA's Farm Service Agency in collaboration with State agencies. The CRP assists landowners in taking farmland out of agricultural production. Farmers receive funding from the CRP to establish native vegetation on these lands and implement various land management practices that enhance the ecosystem services of the land as a natural habitat. Land can be enrolled in a 10- to 15-year CRP contract. CRP designates different conservation practices that target specific environmental outcomes and specify which vegetation types must be planted and maintained. The CRP is federally funded only. The CREP, a program within the CRP, is a partnership between the Federal Government and State governments. Other non-governmental groups may also contribute funding to CREP. Landowners receive payments for part of the cost of establishing the conservation measure and annual rental payments while the land is enrolled in the program. When the contract expires, the land can be placed back into agricultural production, or the contract can be renewed for another 10–15 years with State approval. This program does not guarantee that these restored ecosystems remain in perpetuity. Research has shown that the number of acres enrolled in this program fluctuates with the crop price market, and farmers will take marginal lands out of CRP if they feel the payments are too low. **However, farmers are not likely to attempt to put lands heavily affected by saltwater intrusion back into agricultural production.** CRP/CREP may provide a right way for farmers to transition their lands out of production and into a more permanent conservation easement.

Emergency Conservation Program (ECP)

The ECP provides funding and technical assistance for farmers and ranchers to restore farmland damaged by natural disasters and for emergency water conservation measures in severe droughts.

Emergency Forest Restoration Program (EFRP)

The EFRP provides funding to restore privately owned forests damaged by natural disasters.

Tree Assistance Program (TAP)

The TAP provides financial cost-share assistance to qualifying orchardists and nursery tree growers to replant or rehabilitate eligible trees, bushes, and vines damaged by or lost due to a natural disaster.

Salinization Manual Glossary

Adsorb, Adsorption: The process by which atoms, molecules, or ions are taken up from the soil solution or soil atmosphere and retained on the surfaces of solids by chemical or physical binding.

Adaptation: The alteration or adjustment of land management strategies to better function under new environmental stressors.

Alkali Soil**:** *See Sodic Soil.*

Altered Drainage: Soils that have had some modification to their natural drainage condition.

Alkalinity: Refers to the ability or inability of water to neutralize acids. The *alkalinity* of the soil is measured by pH *(potential hydrogen ions).*

Alkalinization: The process of becoming alkaline, i.e, increasing in pH.

Anions: An element or molecule with a negative charge. This negative charge occurs when the number of electrons in the atom or molecule exceeds the number of protons.

Anthropogenic: The influence of human beings on nature.

Atmospheres (atm): The force exerted by the atmosphere measured at sea level. *One atmosphere* equals 14.7 pounds per square inch, or one *bar.*

Available Water Capacity (AWC): The portion of water in a soil that can be readily absorbed by plant roots of most crops, expressed in inches per inch, inches per foot, or total inches for a specific soil depth. AWC is the amount of water stored in the soil between field capacity (FC) and permanent wilting point (WP). AWC is typically adjusted for salinity (electrical conductivity) and rock fragment content. Also called available water holding capacity (AWC).

Available Soil Water: The difference between the actual water content of soil and the water held by that soil at the permanent wilting point.

Bars: One bar equals 0.9869 atmospheres of pressure. For field use, the units of bars and atmospheres are interchangeable.

Biochar: Charcoal produced from partially burned plant matter and stored in the soil as a means of adding organic matter to the soil.

Brine: Precipitates left after highly saline water has evaporated.

Capillary Water: Water held in the capillary or small pores of the soil, usually with soil water pressure (tension) greater than 1/3 bar. Capillary water can move in any direction.

Capillary Action: Flow of water through soil micropores in unsaturated soil due to adhesive and cohesive forces. Capillary action is the process by which most soil water moves to plant roots. *(See Capillary Forces*)

Capillary Forces: The two types of forces that cause capillary flow are adhesion and cohesion. Adhesion is the attraction of liquid (water) molecules to solid (soil) surfaces. Cohesion is the attraction of liquid (water) molecules to each other. Adhesive forces act in the direction from wet soil to drier soil in unsaturated conditions. In unsaturated soils, if the adhesive forces in the upward direction exceed the force of gravity, water molecules are able to move upward. In saturated soils, adhesive forces are zero, and water moves under the influence of gravity.

Cation Exchange Capacity (CEC): The sum of exchangeable cations (usually Ca, Mg, K, Na, Al, H) that the soil constituent or other material can adsorb at a specific pH, usually expressed in centimoles of charge per Kg of exchanger (cmol Kg^{-1}), or milliequivalents per 100 grams of soil at neutrality, or pH=0.7 (meq $100g^{-1}$). There are several laboratory procedures by which CEC is estimated.

Cations: An isotope, or a compound with a positive charge.

Cohesive Forces: The attractive force between the molecules of the liquid.

Conservation Practices: Specific land management practices that control runoff of sediment and nutrients and protect soil and water quality. Also referred to as best management practices (BMPs).

Crop Rooting Depth: Crop rooting depth is typically taken as the soil depth containing 80 percent of plant roots, measured in feet or inches.

Datum: A base elevation used as a reference point. In soil-plant-water relations, the datum is a horizontal reference. The datum is usually set at a depth below the root zone such that the downward movement of water within the root zone always results in a decrease of potential.

DeciSiemens Per Meter (dS m^{-1}): A unit for electrical conductance used in evaluating soil salinity. One deciSiemen per meter is equivalent to one millimho per centimeter. Millimhos per centimeter were formerly used as the unit for reporting electrical conductance of soils.

Deep Percolation (DP): Water that moves downward through the soil profile below the plant root zone and is not available for plant use. It is a major source of groundwater pollution in some areas.

Degradation: Displacement of soil material by water and wind; *in-situ* deterioration by physical, chemical, and biological processes. This process describes human-induced phenomena which lower the current and/or future capacity of the soil to support human life.

Electrical Conductivity (EC): A measure of the ability of the soil water to transfer an electrical charge. Used as an indicator for the estimation of salt concentration, measured in mmhos cm^{-1} (dS m^{-1}), at 77 °F (25 °C).

Emitter: A small device that controls the irrigation water flow going to the soil. Emitters (also known as "drippers") come in many different flow rates and styles.

Epidermal Cells: The outer layer of cells. On a leaf, the epidermis is covered with a waxy substance to prevent water loss.

Equivalent, *or* Equivalent Weight: The *atomic weight* or *formula weight* of a substance divided by its valence. The amount of a substance in grams numerically equivalent to its equivalent weight is one gram equivalent weight. *(See Milliequivalents)*

Evaporation: The physical process by which a liquid is transformed to the gaseous state, which in irrigation generally is restricted to the change of water from liquid to vapor. This process occurs from the plant leaf surface, ground surface, water surface, and sprinkler spray.

Evapotranspiration (ET): The combination of water transpired from vegetation and evaporated from soil and plant surfaces. Sometimes called consumptive use (CU).

Exchange Capacity: The total ionic charge of the absorption complex active in the adsorption of ions. *See Cation Exchange Capacity (CEC).*

Exchangeable Cation: A positively charged ion held on or near the surface of a solid particle by a negative surface charge of a colloid, and which may be replaced by other positively charged ions in the soil solution.

Exchangeable Sodium Percentage (ESP): The fraction of the cation exchange capacity of a soil occupied by sodium ions, expressed as a percentage: exchangeable sodium (meq 100 gram soil^{-1}) divided by CEC (meq 100 gram soil^{-1}) times 100. ESP is unreliable in soil containing soluble sodium silicate minerals or large amounts of sodium chloride.

Fallow: The 6- to 18-month process of replenishing soil moisture by not planting field crops or disturbing the soil.

Field Capacity (FC): The amount of water retained after saturated soil has drained freely by gravity. FC can be expressed as inches, inches per inch bars suction, or percent of total available water.

Free Water: The water in the soil that is not held by adhesive forces. Also called *gravitational water*, it is the water in the soil between *saturation* and *field capacity*.

Free Drainage, or Free Water Drainage: Movement of *free water* by gravitational forces through and below the plant root zone. This water is unavailable for plant use except while passing through the soil. *(See Deep Percolation)*

Fugitive Dust: A nonpoint source air pollution—small airborne particles that do not originate from a specific point such as a gravel quarry or grain mill. Fugitive dust originates in small quantities over large areas. Significant sources include unpaved roads, agricultural cropland, and construction sites.

Geomorphology: The academic study of features found and processes operating upon the surface of the Earth.

Glycophytes: Non-halophytic plants or plants that do not grow well when the osmotic pressure of the soil solution rises above 2 bars.

Gravitational Water: Water in the soil that moves under the force of gravity. Gravitational forces exceed the adhesive forces that attract water to the soil. Generally, the water in a soil with a matric potential greater than negative 1/3 bar (water with matric potential between that for field capacity and full saturation).

Gravity Potential, or Gravitational Potential: Potential energy of water expressed as a distance above or below a reference line or datum. The gravitational component of soil-water potential acts in a downward direction and is the major component of soil-water potential for saturated conditions.

Groundwater: Water occurring in the zone of saturation in an aquifer or soil.

Gypsum: A rock-forming mineral chemically comprised of calcium sulfate dihydrate ($CaSO_4$ $2H_20$). Available commercially, this product can be used to reduce sodium (Na^+) by replacing soil exchange sites with Ca^{++}, which is a plant nutrient.

Halophytes: Defined as rooted seed-bearing plants (i.e., grasses, succulents, herbs, shrubs, and trees) that grow in a wide variety of saline habitats from coastal dunes, saltmarshes, and mudflats to inland deserts, salt flats, and steppes. Halophytes can sequester sodium ions in vacuoles (pockets) within the cell by active transport mechanisms and intracellular pumps that help maintain constant levels of salt within the cytoplasm. This inhibits ion toxicity and helps maintain cell turgor (rigidity) while slight accumulations of water, potassium, and manufactured organic proteins (i.e., proline, mannitol, sucrose, and glycine betaine) keep the cell sap from dehydrating and allow for the proper function of essential metabolic processes. Increased protein production, which requires additional carbon synthesis, is a direct response to the increased salt content and changing osmotic requirements of the cell.

Hardness: The concentrations of calcium and magnesium ions expressed in terms of calcium carbonate.

Homogeneous: Of uniform structure or composition throughout the material.

Humid Climates: Climate characterized by high rainfall and low evaporation potential. A region generally is considered humid when precipitation averages >40 inches (1,000 mm) per year.

Humus: Organic matter. Decomposed organic compounds in soil excluding undecayed or partially decayed plant and animal tissues and excluding the soil biomass (roots and soil organisms).

Hydraulic Conductivity (K): The ability of a soil to transmit water flow through the soil by a unit hydraulic gradient. Hydraulic conductivity is the coefficient k in Darcy's Law. Darcy's Law is used to express flux density (volume of water flowing through a unit cross-sectional area per unit of time). Hydraulic conductivity is usually expressed in length per time (velocity) units (i.e., cm s^{-1}, ft d^{-1}). In Darcy's Law, where $V = ki$, k is established for a gradient of one. Sometimes called permeability.

Hydrostatic Pressure: The pressure at a specified water depth that is the result of the weight of the overlying column of water.

Hypersalinity: Concentration of dissolved mineral salts such as cations Na, Ca, Mg, K, and the major anions of Cl, SO_4, HCO_3, CO_3, and NO_3, including B, Sr^2, SiO_2, Mo, Ba, and Al. This is measured as mg L^{-1}.

Infiltration, Infiltration Rate: The downward flow of water into the soil at the air-soil interface. Water enters the soil through pores, cracks, wormholes, decayed-root holes, and cavities introduced by tillage. The rate at which water enters soil is called the intake rate or infiltration rate.

Intake Rate: The rate at which irrigation water enters the soil at the surface. Expressed as inches per hour. *(See Infiltration)*

Interception: That fraction of water from precipitation or an irrigation system captured on the vegetation and prevented from reaching the soil surface.

Infiltration: Entry of rainwater or irrigation water into the soil at the soil-atmosphere interface.

Interflow: The flow of groundwater in the lateral direction from one aquifer (usually a perched aquifer) to another aquifer of lower elevation.

Interveinal Chlorosis: A yellowing or bleaching effect of cells in leaf structure between the veins that move photosynthates through the plant.

In-situ: In its original place, unmoved, unexcavated, remaining at the site, or in the subsurface.

Ion: An atom or group of atoms that has an electric charge due to an imbalance in the number of protons and electrons. If protons outnumber electrons, the charge is positive; if electrons outnumber protons, the charge is negative. (*See also Cation and Anion)*

Ionic Concentration: The amount of solute in a water body or water sample. Concentrations of ions are usually expressed in milligrams per liter, milliequivalents per liter, or in parts per million.

Leaching Fraction (L_f): The ratio of the depth of subsurface drainage water (deep percolation) to the depth of infiltrated irrigation water. *(See Leaching Requirement)*

Leaching Requirement: (1) The amount of irrigation water required to pass through the plant root zone to reduce the salt concentration in the soil for reclamation purposes. (2) The fraction of water from irrigation or rainfall required to pass through the soil to prevent salt accumulation in the plant root zone and sustain production. *(See Leaching Fraction)*

Leaching: Removal of soluble material from soil or other permeable material by the passage of water through it.

Macropores: Secondary soil features such as root holes or desiccation cracks that can create significant conduits for the movement of non-aqueous phase liquids (NAPL) and dissolved contaminants, or vapor-phase contaminants.

Matric Potential: A dynamic soil property that will be near zero for a saturated soil. Matric potential results from capillary and adsorption forces. Formerly called capillary potential or capillary water.

Mesophytic: Land plant growing in surroundings having an average supply of water; compare xerophyte and hydrophyte.

Micropore: Smaller soil pores through which water can move by capillary forces. *(See Macropores)*

Milliequivalent: 1/1000 of one gram equivalent weight. *(See Equivalent Weight)*

Millimoles: One one-thousandth of a gram-mole.

Millimhos: Older reference designation of mmhos cm^{-1} of electrical conductivity of soil paste extract.

Milligram Per Liter: A unit of concentration for water quality reports. For water, one milligram per liter is essentially equivalent to one part per million.

Mitigation: Short-term strategy to lessen the impact or damage from environmental stresses such as drought, flooding, saltwater impacts, etc.

Monovalent: An element or compound with an electric charge of plus or minus one. Potassium, hydrogen, and sodium are examples.

Necrosis: Unprogrammed death of cells/living tissue.

Non-Saline Sodic Soil: A soil containing soluble salts that provide electrical conductivity of the saturation extract (ECe) <4.0 mmhos cm^{-1} and an exchangeable sodium percentage (ESP) >15. Commonly called black alkali or slick spots.

Osmotic Potential, or Solute Potential: Arises because of soluble materials (generally salts) in the soil solution and the presence of a semi-permeable membrane. Osmotic potential is the force exerted across the semi-permeable membrane due to differing concentrations of salts on each side.

Orthophotography: The ortho process corrects for distortions caused by the terrain, the orientation of the airplane, and the camera lens. An orthoimage is like a photo that has been draped over the ground over an uneven surface. The ground is represented by an elevation model. Orthophotography is a product that has the geometric accuracy of a map but contains the immense detail of a photograph.

Overburden Potential: The pressure due to the weight the soil exerts on the water in the soil. Overburden potential is zero for unsaturated conditions.

Parts Per Million (ppm): A unit of concentration for water quality reports. For water, one part per million is approximately equivalent to one milligram per liter.

Percolation: Movement of the water through the soil profile. The percolation rate is governed by the permeability or hydraulic conductivity of the soil. Both terms are used to describe the ease with which soil transmits water.

Permanent Wilting Point (PWP): The moisture percentage, on a dry weight basis, at which plants can no longer obtain sufficient moisture from the soil to satisfy water requirements. Plants will not fully recover when water is added to the crop root zone once the permanent wilting point has been experienced. Classically, 15 atmospheres (15 bars), or 1.5 mPa, soil moisture tension is used to estimate PWP.

Permeability: (1) Qualitatively, the ease with which gases, liquids, or plant roots penetrate or pass through a layer of soil. (2) Quantitatively, the specific soil property designating the rate at which gases and liquids can flow through the soil or porous media.

Permeameter: An instrument for rapidly measuring the permeability of a sample of iron or steel with sufficient accuracy for many commercial purposes. A constant head permeameter that measures *in-situ* hydraulic conductivity. The method involves measuring the steady-state rate of water recharge into unsaturated soil from a 2-inch cylindrical hole, in which a constant head of water is maintained.

Piezometer: An open-ended tube inserted into the soil for measuring pressure potential.

Plant Available Water (PAW): Water available in the soil for plant use, the difference between field capacity (FC) and wilting point (WP).

Plant Biomass: The top growth or vegetative (leafy) portion of the plant. This material is grazed by livestock when green (forage) but can be harvested and used after senescence (residue) to create heat from burning, as animal bedding, or as a component of erosion control products.

Pressure Potential: A component of soil-water potential, represented by the distance of submergence. For unsaturated conditions, pressure potential is zero.

Primordial: Having existed from the beginning; in an earliest or original stage or state.

Rhizosphere: The region of the soil immediately surrounding the roots.

Root Zone: Depth of soil that plant roots readily penetrate and in which the predominant root activity occurs. The preferred term is the plant root zone.

Runoff, Runoff Loss: Surface water leaving a field or farm, resulting from surface irrigation tailwater, applying water with sprinklers at a rate higher than soil infiltration and surface storage, overirrigation, and precipitation.

SAR: Measures the relative proportion of sodium ions in a soil or water sample to those of calcium and magnesium. A relation between soluble sodium and soluble divalent cations that can be used to predict the exchangeable sodium percentage of soil equilibrated with a given solution.

Saline Soil: A non-sodic soil containing sufficient soluble salts to impair its productivity for growing most crops. The electrical conductivity of the saturation extract (ECe) is >4 mmhos cm^{-1}, and the exchangeable sodium percentage (ESP) is <15 (i.e., non-sodic). The principal ions are chloride, sulfate, small amounts of bicarbonate, and occasionally some nitrate. Sensitive plants are affected at half this salinity, and highly tolerant ones at about twice this salinity.

Saline-Sodic Soil: Soil containing both sufficient soluble salts and exchangeable sodium to interfere with the growth of most crops. The exchangeable sodium percentage (ESP) is ≥15, and the electrical conductivity of the saturation extract (ECe) is >4 mmhos cm^{-1}. Saline-sodic soil is difficult to leach because the clay colloids are dispersed.

Salinity: The concentration of dissolved mineral salt in water and soil on a unit volume or weight basis. May be harmful or nonharmful for the intended use of the water.

Salinization: The process of a building up of salts in soil eventually to toxic levels.

Saltwater Intrusion: The process of saltwater infiltrating groundwater/aquifer systems.

Saltwater Inundation: Surface water impacts from saltwater related to sea-level rise and coastal storm flooding.

Satiation: To fill most voids between soil particles with water.

Saturation: To fill all (100 percent) voids between soil particles with water.

Saturated Hydraulic Conductivity: A quantitative measure of a saturated soil's ability to transmit water when subjected to a hydraulic gradient. Saturated hydraulic conductivity can be thought of as the ease with which pores of a saturated soil permit water movement.

Solute: The dissolved substance in a solution (water).

Soil Aeration: Process by which air and other gases enter the soil or are exchanged.

Soil Crusting: Compaction of the soil surface by droplet impact from sprinkle irrigation and precipitation. Well-graded, medium textured, low organic matter soils tend to crust more readily than other soils.

Soil Horizon: A layer of soil differing from adjacent genetically related layers in physical, chemical, and biological properties or characteristics.

Soil Moisture Tension: *See Soil-Water Tension.*

Soil Organic Matter: Organic fraction of the soil, including plant and animal residue in various stages of decomposition, cells, and tissues of soil organisms, and substances synthesized by the soil population.

Soil pH: is a measure of the hydrogen ion concentration in soil solution and represents the chemical status of the soil. The soil pH scale ranges from 0 to 14; pH=7 is neutral, pH <7 is acidic, and pH >7 is alkaline or basic. Many arable soils have a pH in the range of 6.0–7.0.

Soil Profile: Vertical section of the soil from the surface through all its horizons.

Soil Resilience: The ability of a soil to maintain some level of productivity after being exposed to negative environmental stressors.

Soil Sealing: The orientation and consolidation of soil particles in the intermediate surface layer of soil so that the layer of soil becomes almost impermeable to water.

Soil Structure: The combination or arrangement of primary soil particles into secondary particles, units, or peds that make up the soil mass. These secondary units may be arranged in the soil profile in such a manner as to give a distinctive characteristic pattern. Principal types of soil structure are platy, prismatic, columnar, blocky, granular, and massive.

Soil Texture: Classification of soil by the relative proportions of sand, silt, and clay present in the soil. USDA uses 12 textural classes.

Soil Water, Soil Moisture: All water stored in the soil. *(See Water Holding Capacity)*

Soil-Water Content: The water content of a given volume of soil. Soil-water content is determined by gravimetric sampling and oven drying field samples (to a standard 105 °C), neutron moisture probes, time-domain (TDR) and frequency domain reflectometry (FDR) devices commonly called RF capacitance probes, tensiometers, electrical resistance blocks, thermal dissipation blocks, and feel and appearance methods.

Soil-Water Deficit or Depletion: Amount of water required to raise the soil-water content of the crop root zone to field capacity. The amount of water is measured in inches.

Soil-Water Potential: Expresses the potential energy status of soil water relative to conditions associated with pure, free water. Total soil-water potential consists of osmotic potential, gravitational potential, and matric potential.

Soil-Water Tension: A measure of the tenacity with which water is retained in the soil. Soil-water tension is the force per unit area that must be exerted to remove water from the soil and is usually measured in bars or atmospheres. Soil-water tension is a measure of the effort required by plant roots to extract water from the soil. Measurements are made using a tensiometer in the field (limited to 1 atm) and a pressure plate apparatus in the laboratory.

Specialty Crop: A unique or locally grown crop, usually grown on smaller acreages, that has a niche market.

Specific Conductance: A measure of how well water can conduct electrical current for a unit length and unit cross-section at a certain temperature. Expressed in units of milliSiemens per centimeter ($mS{\cdot}cm^{-1}$), the conductivity normalized to a temperature of 25 °C.

Subhumid Climate: Climate characterized by a moderate rainfall and moderate to high evaporation potential. A region is usually considered subhumid when precipitation averages >20 inches (500 mm) per year, but <40 inches (1,000 mm) per year.

Sulfidation: A process of increasing sulfide ions in a material or molecule.

Stoma [pl. Stomata]: An opening or pore, usually in plant leaves, that provides access for gaseous exchange between the tissues and the atmosphere.

Tensiometer: Instrument, consisting of a porous cup filled with water and connected to a manometer or vacuum gauge, used for measuring the soil-water matric potential.

Terrestrial Systems: The interactions between soil, water, vegetation, and the atmosphere take place in the unsaturated soil layers.

Soil affected by high salinity. (Photo courtesy of IFPRI; CC BY-NC-ND 2.0 license)

Total Dissolved Solids (TDS): The total dissolved mineral constituents of water.

Translocation: Movement of water from an area other than where the water was applied.

Transpiration: The process of plant water uptake and use, beginning with absorption through the roots and ending with transpiration at the leaf surfaces. *(See Evapotranspiration)*

Unavailable Soil Water: That portion of water in soil held so tightly by adhesion and other soil forces that the water cannot be absorbed by plants rapidly enough to sustain growth without permanent damage. The soil water remaining at the permanent wilting point of plants.

Tortuous Path: The non-straight nature of soil pores.

Total Soil-Water Potential: *See Soil-Water Potential.*

Transpiration: The movement of water through plant tissues and into the atmosphere. *(See Evapotranspiration)*

Unsaturated Soil: Soil in which air exists in the soil pore spaces.

Vadose Zone: The unsaturated zone in a soil where chemical processes are at their most active.

Viscosity: Refers to the quality of a liquid being thick and slow-to-flow. For instance, cold honey has a much higher viscosity than water.

Water Holding Capacity: Total amount of water held in the soil per increment of depth. Water holding capacity is the amount of water held between field capacity (FC) and oven-dry moisture level, expressed in inches per inch, inches per foot, or total inches for a specific soil depth. Soils that are not freely drained because they have impermeable layers can have temporary saturated conditions just above the impermeable layers. This can temporarily increase water holding capacity. Sometimes called total water holding capacity. *(See Available Water Capacity)*

Wilting Point: *See Permanent Wilting Point.*

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Identification, mitigation, and adaptation to salinization on working lands in the U.S. Southeast. Gen. Tech. Rep. SRS-259. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 69 p. https://doi.org/10.2737/SRS-GTR-259.

Key Messages:

- Soil salinization in the coastal Southeastern United States is becoming more prevalent as storm surges increase in frequency, and sea levels rise.
- Salinization reduces the productivity of working lands and can prevent crops from growing.
- Resources are lacking for landowners to understand coastal salinization and how to manage for resilience.
- Action must be taken if the land is to remain profitable as conditions change.

This manual describes the impacts and includes adaptation measures that can be taken to maintain productivity in working lands.

Keywords: Adaptation, agriculture, saline soil, salinity, salinization, sea-level rise.

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