Propagation of *Spartina alterniflora* for Substrate Stabilization and Salt Marsh Development

by

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Techniques were developed for propagation of *Spartina alterniflora* Loisel., smooth cordgrass, in the intertidal zone on dredge spoil and eroding shorelines. Both seeding and transplanting methods were successful. Transplants proved to be more tolerant of rigorous conditions such as storm waves and blowing sand, but seeding was more economical and was successful on protected sites. Vegetative development of seeded and transplanted areas was rapid with primary production equal to that of a long established marsh by the second growing season. At the end of the first growing season,

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more plant cover was produced from seeding at the rate of 100 viable seeds per square meter than from transplanting single-stem plants on a 0.9-meter spacing.

The relationship of mineral nutrition to productivity of *S. alterniflora* was determined. Plants and soils in natural stands were sampled and analyzed for productivity interrelationships using multiple regression techniques. Salinity of the soil solution, plant and soil manganese concentrations, and plant sulfur concentrations were negatively associated with aboveground production. Variables positively associated with production included phosphorus concentration in the plant tissue and in the soil. Fertilizer experiments showed that the production of a natural stand of *S. alterniflora* growing on sand was increased significantly by additions of nitrogen and increased threefold when both nitrogen and phosphorus were added. The production of natural marsh growing on finer-textured sediments doubled when nitrogen was added, but there was no response to phosphorus. Nitrogen and phosphorus fertilizers also enhanced growth of transplants and seedlings on sandy dredge material.

PREFACE

This is a report of research started in November 1969 with support from the U.S. Army, Coastal Engineering Research Center (CERC) through Contract DACW72-70-C-0015, and continued through Contract DACW72-72-C-0012. This effort has also received support from the North Carolina Sea Grant Program, Office of Sea Grant, National Oceanographic and Atmospheric Administration, Department of Commerce, Grant No. GH-78, GH-103, 2-35178 and 04-3-158-40; North Carolina Coastal Research Program; and the North Carolina Agricultural Experiment Station.

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NOTE: Comments on this publication are invited.

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Colonel, Corps of Engineers
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PROPAGATION OF *SPARTINA ALTERNIFLORA* FOR SUBSTRATE STABILIZATION AND SALT MARSH DEVELOPMENT

by

W.W. Woodhouse, Jr., E.D. Seneca, and S.W. Broome

I. INTRODUCTION

1. General.

Natural tidal marsh has become recognized as a valuable resource (Gosselink, Odum, and Pope, 1974). Marshes serve as a nursery ground or as a source of energy or both, for a large number of sports and commercial fishery species (Odum, 1961; Teal, 1962; Odum and de la Cruz, 1967; Cooper, 1969; Williams and Murdoch, 1969). Under suitable conditions, dry-matter production in these marshes may exceed that of the major food crops of the world grown under the best conditions (Odum, 1961). Tidal marshes are also important in the storage and transfer of mineral nutrients between sediments and surrounding estuarine waters (Pomeroy, et al., 1969; Williams and Murdoch, 1969). Further, in many situations these marshes stabilize shorelines and afford protection to developed areas during storms by absorbing and dissipating wave energy, and by storage of water.

In many parts of the world intertidal marshes have been prime targets of reclamation for agricultural, industrial and commercial development for a long time. Some Dutch polders are believed to have been reclaimed from marshes over 1,000 years ago. Until recently, marshes along much of the Atlantic coast of the United States have been viewed as wasteland suitable for conversion to other land uses by dredge and fill operations and as a place to dump waste materials. Consequently, the coastal marsh areas have decreased markedly in many regions causing concern, particularly along the Atlantic coast of the United States.

Although dredging for development and for navigation has destroyed substantial amounts of marsh over the years, much of the marsh that has developed in recent times arose on dredge spoil deposits in and around estuaries. Dredging continues to be essential to the maintenance of navigation, and it seems likely to increase in importance. The stabilization of dredged materials will often be desirable. If this activity could be successfully combined with marsh creation, substantial multiple benefits should be possible. This is a report of a study started in the fall of 1969, to explore the possibility of stabilizing dredged material in the intertidal zone and the concomitant establishment of estuarine marsh plants under conditions existing along the North Carolina coast (Woodhouse, Seneca, and Broome, 1972; Broome, 1973; Broome, Woodhouse, and Seneca, 1974).

Efforts were concentrated primarily on the perennial salt marsh grass, *Spartina alterniflora* Loisel. (smooth cordgrass). At the start of this study, little was known about establishing new stands of this plant, although natural stands had been investigated extensively for a long time. Marsh planting of a closely related species, *S. townsendii* H. & J. Groves (Ranwell, 1967) has been practiced in northern Europe primarily for the purposes of land reclamation.

2. Biology of *Spartina alterniflora*.

Spartina alterniflora is the dominant flowering plant in regularly flooded intertidal marshes along the Atlantic and Gulf coasts from Newfoundland to Texas. These low marshes are almost pure stands of *S. alterniflora*, and constitute what is generally considered the most valuable type of estuarine marsh. Although the shoots of the grass are often covered with algae that may be grazed by the salt marsh periwinkle, *Littorina irrorata* (Say), only a small part of the annual production of the grass itself is consumed by other organisms (mainly insects and birds) while the plant is living. After the aboveground parts of the plant die and fragment, small suspended particles called detritus with associated decomposing microorganisms are exported into the estuary. The detritus is utilized by fish and invertebrate animals which may be permanent or temporary inhabitants of the estuary. In estuaries where high turbidity reduces light penetration which lowers phytoplankton production, marsh grasses account for most of the primary production by the system.

Primary production of marshes dominated by *S. alterniflora* varies with latitude and also within any given marsh. An increasing annual production trend from north to south has been described by the combined work of Good (1965) and Durand and Nadeau (1972) in New Jersey, Keefe and Boynton (1973) in Maryland-Virginia, Stroud and Cooper (1968) and Williams and Murdoch (1969) in North Carolina, Smally (1959) in Georgia, and Kirby (1971) in Louisiana. This production trend may be partially due to a latitudinal gradient of increasing length of growing season from north to south. Production also varies a great deal within a particular marsh due to height of the grass which varies from about 0.5 to 3.0 meters. Three distinct height forms described as short, medium, and tall are generally recognized (Teal, 1962; Adams, 1963; Stroud and Cooper, 1968). Based on their study in Brunswick County, North Carolina, Stroud and Cooper reported differences in annual net production of the short, medium, and tall height forms as 280, 471, and 1,563 grams per square meter per year, respectively.

There is some disagreement about whether the difference in growth habit and production among the height forms is due to genetic differences between the short and tall height forms or if the size difference is the result of environmental factors. Chapman (1960) suggests that the stunted *S. alterniflora* is actually a genetic variety which is inherently smaller than the closely associated taller form. Data reported by Stalter and Batson (1969) from a transplant experiment suggest that there are two forms of *S. alterniflora*, one which is inherently dwarf and one which is inherently tall. However, the period over which the transplants were observed was too short to be conclusive. The most obvious environmental factor to which zonation in salt marshes may be related is the relationship between tide and elevation and the amount of inundation to which a particular area is subjected (Johnson and York, 1915; Hinde, 1954; Adams, 1963). Reed (1947) pointed out that individual *S. alterniflora* plants reached their best development halfway between the low and high tide levels and decline in height and luxuriance both seaward and shoreward. Bourdeau and Adams (1956) found that salinity increased markedly from the tall to the short height zone. Results of a greenhouse study by Mooring, Cooper, and Seneca (1971) conducted with North Carolina plants indicated no differences in seedling response to various levels of substrate salinity due to height form of the parent plant. Based on seedling biomass and height response, these researchers postulated that differences in height forms were not genetic and may result from exposure to environments differing in salinity. Biochemical evidence based on total soluble proteins and enzyme patterns, along with field transplant studies of tall and short height forms from Connecticut, also led Shea, Warren, and Niering (1972) to conclude that the two height forms were due to environmental conditions at a given site and not to genetic differences.

In established stands, the primary means of reproduction is vegetative by means of extensive belowground hollow cylinders of stem tissue called rhizomes. Along intertidal creeks and in newly established stands of the grass, sexual reproduction often occurs. In these areas, the aboveground stems, which are often called culms in grasses, reach their tallest height. Flowers emerge at the terminal end of culms to form elongate flowering heads or inflorescences. Flowering (anthers available for pollination) occurs earlier in more northern populations along the Atlantic coast, often in July, and becomes progressively later in southern populations (Seneca, in press). Pollen is usually transported by the wind, and following fertilization, seed development proceeds. Seeds reach maturity from September to November depending on latitude, and they shatter shortly thereafter.

The plant can grow in a wide range of substrate textures, from coarse sands to silty-clay sediments. The grass appears well-adapted to the anaerobic substrates characteristic of most salt marshes, because of its oxygen transport system. Large, hollow, air-filled tissue called aerenchyma extend from openings (lacuna) in the leaves down the shoot to the rhizomes and roots (Teal and Kanwisher, 1966; Anderson, 1974). Thus, belowground tissues in the anaerobic substrate are able to receive necessary supplies of oxygen.

Although *S. alterniflora* does not usually reach its maximum growth in higher salinity (35 parts per thousand) areas, it is well-adapted to and can outcompete most other flowering plants in these regularly flooded saline habitats. The plant tolerates salinity by taking salt up through its roots and excreting it through special structures in the leaves called salt glands. Because the species can tolerate salt but is not restricted to highly saline areas, it has been termed a facultative halophyte. In some brackish to freshwater tidal marshes *S. alterniflora* and a related species, *S. cynosuroides* (L.) Roth (giant cordgrass), occur together but can be distinguished by the occurrence of a prominant midrib on the leaf of the latter species and its total absence on *S. alterniflora*.

3. Characteristics of the North Carolina Coast.

The North Carolina coast is about 530 kilometers (330 miles) long, lying between about 33.5° and 36.5° N. latitude. The outer coast is made up of a chain of low, sandy, barrier islands. These are separated from the mainland by large bodies of water along the northern half of the coast from Cape Lookout to the Virginia line -- Core, Pamlico, Albemarle and Currituck Sounds. These sounds are generally shallow with sandy bottoms. South of Cape Lookout, the sounds narrow as in Bogue Sound or disappear altogether leaving only tidal creeks and marshes between the islands and the mainland as from Southport southward.

The state is drained by four principal rivers that reach the sea directly or indirectly within North Carolina. These are the Roanoke, Pamlico, Neuse, and Cape Fear Rivers. Only the latter empties directly into the Atlantic Ocean; the other three enter the sounds at distances of 50 to over 100 kilometers from the nearest inlet. The inlets, really "outlets," between the barrier islands are shallow, narrow and unstable.

Tide range along the outer coast is lowest (mean about 1.1 meters) near the Virginia-North Carolina border and increases to about 1.4 meters near the North Carolina-South Carolina border. Due to the low water exchange capacity of the inlets and the damping action of the sounds, astronomical tide effects within the sounds are confined to the close proximity of the inlets north of Cape Lookout. However, the long fetches and shallowness of these bodies of water permit large wind setup effects. South of Cape Lookout damping action is greatly reduced, and astronomical tides dominate.

Salt and brackish marshes are distributed throughout the coastal zone of North Carolina. These marshes can be divided roughly into low or regularly flooded, and high or irregularly flooded marshes. There are about 24,000 hectares of the low marshes, primarily *S. alterniflora*, and 41,000 hectares of the high marshes dominated largely by *Juncus romerianus* Scheele (black needlerush).

The amount of silt and clay brought into the lower reaches of the estuaries is low except for the Cape Fear River. Consequently, most substrate materials near the inlets are sandy and during this study there has been little opportunity to work with any other materials, except for one location, The Straits.

II. PROCEDURE

Primary emphasis was placed on field experimentation with support as necessary from laboratory, phytotron (growth chambers), greenhouse, or nursery experiments. Field techniques developed as the work progressed and tended to be a blend and adaptation of agronomic and botanical approaches. Where feasible, variables were tested in replicated trials. Exploratory trials and field-scale plantings generally have been unreplicated, but did extend whenever possible to two or more experimental sites (Tab. 1 and Fig. 1). Site duplication spreads the risk, so that if one site is destroyed not all the information is lost.

Special measures of plant growth response are described for certain experiments, but the following measures generally have been used to obtain estimates of vegetative growth and development in the field:

1. Aerial dry weight - oven dry weight of aboveground growth per transplant (hill) or per unit area.

2. Belowground dry weight (yield of rhizomes and roots) - oven dry weight of belowground plant material (rhizomes and roots) for entire transplant (hill) for first-year transplants; for older plantings usually two cores were taken from each quadrat harvested for aboveground growth. Samples were taken to a depth of 30 centimeters with a stainless-steel coring tube with an inside diameter of 8.5 centimeters. Samples were washed and plant parts separated, weighed, and expressed as belowground growth per transplant (hill) or per unit area.

3. Number of flowers - flowering culms per transplant (hill) or per unit area, gives some measure of vigor.

4. Number of center culms - number of culms (stems) clustered around the original transplant (hill), recorded on first-year transplants only.

5. Number of rhizome culms - number of culms (stems) arising from rhizomes, away from the original transplant (hill), gives some measure of spread, recorded on first-year transplants only.

6. Height - distance from base to tip of culm in centimeters, usually the average of five culms per sample.

7. Basal area - area covered by culms (stems) at ground level as determined by harvesting culms, holding them tightly bunched and measuring their cross sectional diameter, then determining cross sectional area; recorded per transplant (hill) or per unit area.

The exposed locations and unstable conditions of many study sites rendered them more vulnerable to damage or total loss than is typical of upland studies; hence, higher experimental errors are obtained from coastal studies. Compensation for this problem was attempted through duplication of field tests. Major hazards inflicting damage and loss were: storm associated wave action, shifting of channels causing undermining, and burial by windblown sand.

III. PROPAGATION

Spartina alterniflora invades new sites by both vegetative means and by seeds. Pieces of marsh dislodged by water or ice may be deposited on

Table 1. Experimental Sites

Location	Exposure	Fetch (km)	Tidal Regime (meters)	Salinity of Estuarine Water*	Substrate	Use
Oregon Inlet - East of bridge and north of channel	SW Variable for specific test	Variable 0.5 to 5.0	0.2 to 0.3 lunar range with extensive wind effect	20 to 25	Sandy, natural accretion, 97% sand, 1% silt, 2% clay	Preliminary transplanting and seeding tests, 1969, 70, and 71
Old House Channel - Pamlico Sound	Variable SE to NW	Variable 5.0 to 50.0	0.2 to 0.3 lunar range with extensive wind effect	20 to 25	Old and fresh dredge spoil on small, very exposed islands - very sandy	Preliminary transplanting and seeding tests 1970, 71 and 72. Attempts to promote natural invasion through seed patches
Hatteras Inlet - Ocracoke Island	SW	50.0 to 60.0	0.3 to 0.5 lunar range with sustained wind effect	25 to 30	Natural accretion and fresh dredge spoil, 97% sand, 3% clay, trace of silt	Fertilizer response tests, preliminary transplanting and seeding trials, 1971, 72 and 73
The Straits - between Harkers Island and the mainland	E and W	1.0 to 2.0	0.5 to 0.6 lunar range with pronounced wind effect	20 to 33	Very fresh dredge spoil, highly variable in texture. 76 to 93% sand, 2 to 14% silt, 4 to 10% clay	First field scale transplanting. 1970-71
Drum Inlet - north of channel	N-NE	5.0 to 15.0	0.6 to 0.8 lunar range with pronounced wind effect	35	Sandy, fresh dredge spoil, 98% sand, 0.4% silt, 1.6% clay	Variety of small tests of planting materials and methods. 1972-73
South Island - south of channel	S-W-NE	5.0 to 15.0	0.6 to 0.8 lunar range with pronounced wind effect	35	Sandy, fresh accretion around small spoil lump, 98% sand, 0.5% silt, 1.5% clay	Field scale seeding trial and fertilizer tests, 1973

*Parts per thousand (summer)

Table 1. Experimental Sites-Continued

Location	Exposure	Fetch (km)	Tidal Regime (meters)	Salinity of Estuarine Water*	Substrate	Use
Beaufort - north of causeway between Morehead City and Beaufort	NE	0.1 to 10.0	0.9 lunar range with little wind effect	20 to 25	Sandy, fresh spoil, 97.6% sand, 0.7% silt, 1.7% clay	First field scale seeding, nursery, plant digging and handling, 1972-73
Cedar Island - former Lola Naval Facility	NE to SE	10.0 to 30.0	Wind tide only	20 to 25	Eroding shoreline, alternate layers of coarse sand and peat, 89% sand, 7% silt, 4% clay	Preliminary testing of transplants on eroding shoreline, 1972-73
Snow's Cut - in lower Cape Fear Estuary, 15 miles upstream from Southport	NE	1.0 to 3.0	1.2 lunar range with little wind effect	7 to 10	Sandy to fine fresh spoil, 96% sand, 1% silt, 3% clay	Plant sources, time of transplanting and seeding, seeding method tests. Follow-up of marsh development and stabilization and invasion. 1971, 72 and 73
Oak Island - just inside mouth of Cape Fear River	NE	None	1.4 lunar range with little wind effect	28	Old natural marsh on fine textured material. 35.7% sand, 50.5% silt, 13.8% clay	Fertilizer trials on natural stands. 1971, 72 and 73

*Parts per thousand (summer)

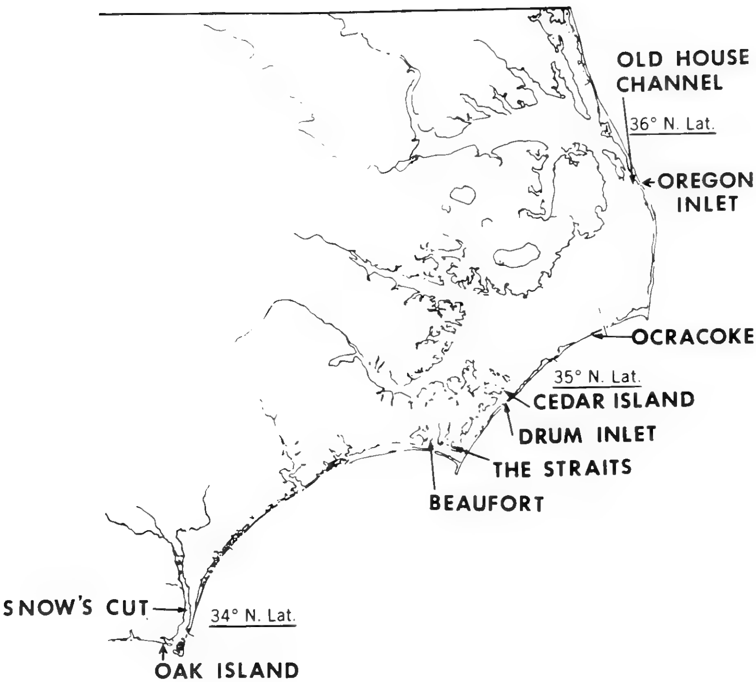

Figure 1. Experimental sites used in propagation studies.

bare areas, take root and spread (Fig. 2); or seeds may drift onto such sites at optimum times, germinate and establish new stands (in Sec. III, see Fig. 11). It has not been unusual to see both means of colonization taking place at the same site. These observations indicate that the species lends itself to propagation by three general methods: transplanting of established plants obtained by digging and dividing mature plants from natural stands or from "nursery" plantings, direct seeding with seeds that have been suitably processed and stored, and transplanting of seedlings produced in the greenhouse or under other controlled or semi-controlled environments (E.W. Garbisch, Jr., personal communication). Attention was devoted to the first two methods, since they seem to have wider application under North Carolina conditions. The third method is technically feasible, but we have not pursued it on a field scale.

Initial emphasis was determined largely by availability of plant material and flexibility in use of this material. Use of field-collected or -produced planting stock has several advantages. Seeds do not have to be collected in advance, and planting stock can be obtained from sites producing few or no seeds. Planting material can be carried over from year to year, or can be held in reserve for unforeseen needs. Further, it requires less initial investment, and seems likely to be more economical than producing plants in the greenhouse. Direct seeding, where feasible, appears to be a rapid and very economical approach. It requires prior planning to ensure adequate quantities of seeds. Greenhouse-grown seedlings may have advantages (as less transplanting shock) under rigorous conditions, but their requirements for prior planning and investment, dependence on suitable seed supplies, and unsuitability for carryover without additional handling may limit their use.

1. Transplanting.

a. Plants. Choice transplants consist of a large, single stem (culm) with small shoots or pieces of rhizomes left attached, or discarded (Fig. 3). Plants were obtained initially by hand digging in natural stands, usually those of recent origin growing on sandy substrates. Planting stock is more difficult to dig and process from older marsh because of the dense root mat. Plants from older marshes are usually smaller, of poorer quality, and tend to be subjected to considerable wear and tear during the digging process.

A substantial amount of size variability will be encountered among plants from any given site. Thus, in 1972, a test was conducted at Drum Inlet to determine the effect of height and stem robustness of plants on their value for transplanting purposes. Plants dug from a natural stand near Drum Inlet were graded into four groups, transplanted, and later compared (Tab. 2). Both the thin- and large-stemmed tall plants were growing along the open water's edge, but the thin-stemmed plants occurred in more dense stands. The short, large-stemmed plants were from new plants originating from rhizomes invading open areas. The short, thin-stemmed plants came from thick stands 1 to 2 meters behind the tall plants. For most measures of first-year growth (aerial dry weight, number of flowers,

Figure 2. Natural invasion by vegetative means. *S. alterniflora* crown and rhizomes taking root on new site at Snow's Cut, 27 April 1971.

Table 2. Comparison of Growth of Four Transplant Types *S. alterniflora* Collected and Transplanted at Drum Inlet.*

Type of Plant	Aerial Dry Weight (g/plant)	Number of Flowers	Number of Center Culms	Number of Rhizome Culms	Height (cm)	Basal Area (cm^2/plant)	Survival (percent)
Tall, large stems	115.2	1.9	7.7	0.4	62.0	2.6	79.0
Short, large stems	56.1	1.7	6.4	0.0	57.0	1.5	62.0
Tall, thin stems	59.4	1.4	7.3	0.2	57.0	1.2	74.0
Short, thin stems	17.0	0.2	3.4	0.0	35.0	0.3	57.0
LSD† 0.01	32.1	1.2	2.4	‡	17.0	0.9	13.0
0.05	23.7	0.9	1.8	‡	12.0	0.6	10.0
CV§ (percent)	39.3	72.2	29.7	346.4	24.0	48.2	14.9

*Transplanted 31 May 1972; harvested 3 October 1972. Randomized complete block design with three blocks; three samples of individual plants were taken from each plot.

†Least significant difference.

‡Not significant.

§Coefficient of variation.

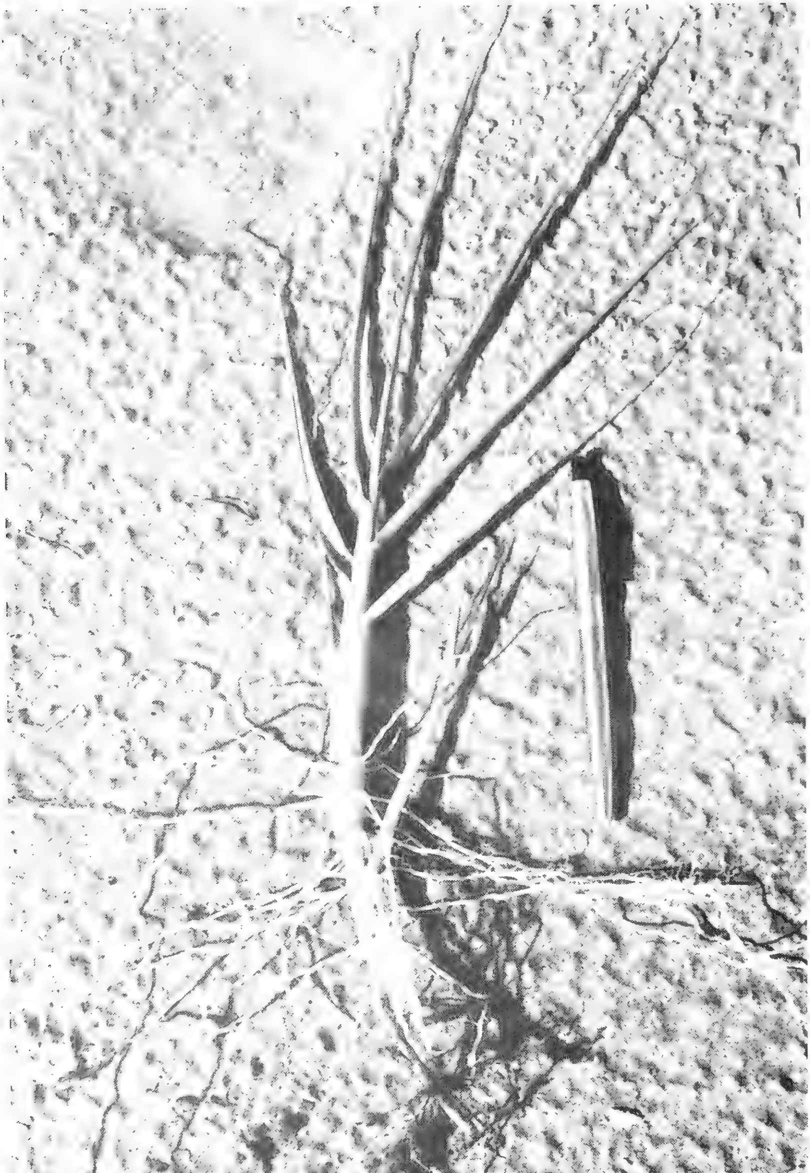

Figure 3. Typical transplant, Oregon Inlet, 8 May 1970.

number of center culms, height and basal area) the short, thin-stemmed plants were inferior to the other three types of plants. There was somewhat less difference in survival. It appears from this test that the larger, plumper stems, which probably contain the most food reserves, are preferable for transplanting purposes. However, even the very small plants are not worthless and may be used if limited sources are available.

It is advantageous to establish nursery plantings at locations within the intertidal zone accessible by tractor-mounted equipment which facilitates digging. These plantings can be established by either seeding or transplanting in 1 year, and planting stock can be dug from them the next spring. Plants grown in this manner are more uniform and generally of better quality than those obtained from natural marshes. Certainly, this method offers substantial savings in time spent in searching and moving between different patches of desirable natural stands. Marsh recovery following digging is rapid, making it feasible to take plants from the same site year after year as long as the growth does not become so dense that the stand loses vigor.

Nursery production has also been tested on upland sites under irrigation. This type of production was done first on the North Carolina State University (NCSU) Clayton Research Farm in 1971. Transplants were grown under sprinkler irrigation on a very sandy substrate. First-year growth was roughly comparable with that on sites of intermediate productivity on the coast. Weed control was the most difficult problem. Frequent irrigation coupled with the very sandy soil tends to nullify the effect of herbicides while encouraging rapid germination of weedy annuals following cultivation. Consequently, frequent cultivation was required, which discouraged the lateral spread of the *S. alterniflora*.

Another approach, under flood irrigation, was undertaken in 1972 on a nearby field with a less pervious subsoil. A low dike was constructed around the area, transplants from several locations were introduced on a 0.61-meter spacing, and several hundred viable seeds per square meter from one source were broadcast. The area was flooded intermittently by supplementing rainfall with water pumped from an irrigation pond. This effort was more successful than the planting under sprinkler irrigation (Figs. 4, 5). The weed problem was greatly reduced, but not eliminated, as there was still some invasion by freshwater marsh species (*Typha* sp., cattail) and other plants tolerant of flooded conditions. Survival and production by large and medium transplants from Drum Inlet, the large transplants from Snow's Cut, and both transplants and seedlings from Oregon Inlet were good (Tab. 3). Aerial yields were considerably lower for short and medium transplants from Snow's Cut and short and tall ones from Beaufort, as was the case in the field trial in the Core Sound estuary at Drum Inlet. Since the flooding periods on this field were days to weeks in length rather than hours and, thus, vaguely simulated wind setup (referred locally as wind tide), it might be expected that transplants and seeds from wind setup areas, in this case Oregon Inlet and Drum Inlet, would do relatively well. The yield from seedlings was greater than from transplants because the heavy application rate of seeds resulted

Figure 4. Flooded nursery, Clayton, North Carolina. Transplanted 5 May 1972 on 0.61-meter centers; photo taken 8 August 1972.

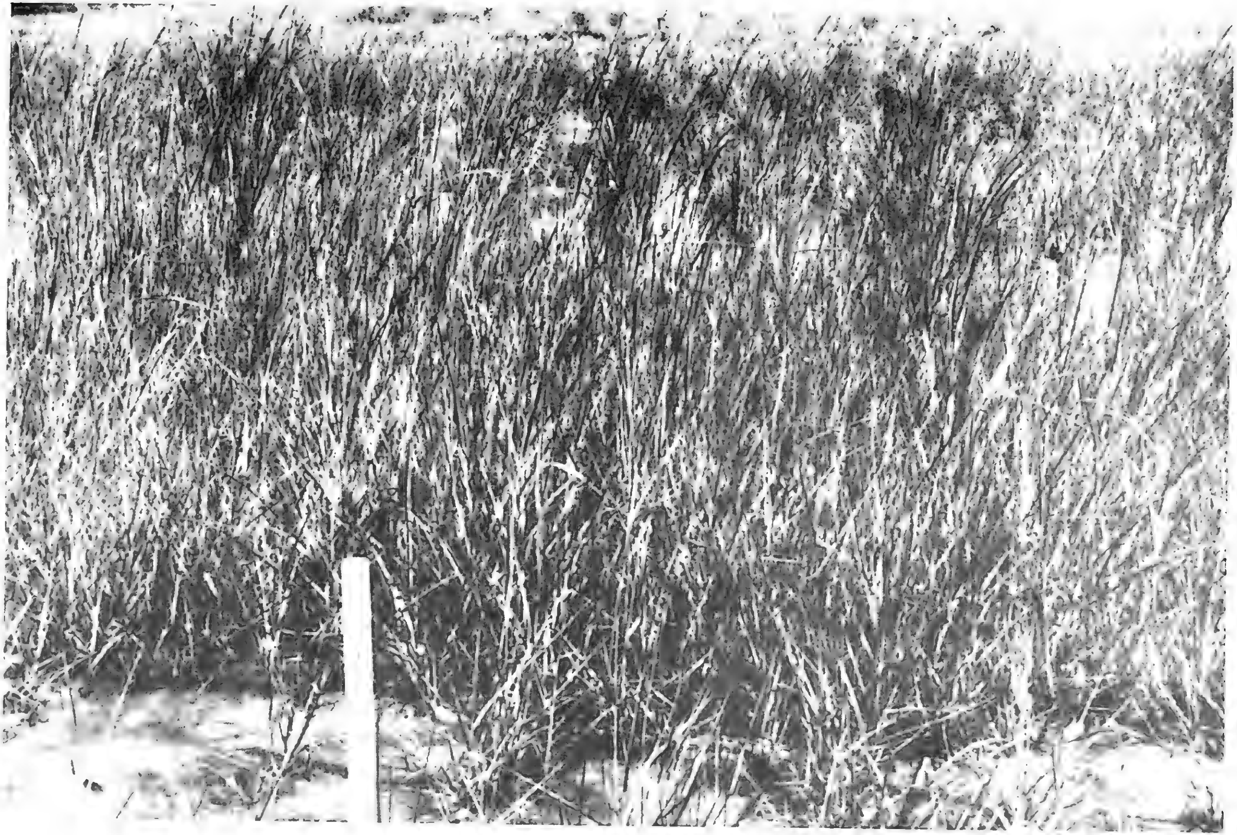

Figure 5. Flooded nursery. Seeded 4 May 1972; photo taken 8 August 1972.

Table 3. First-Year Aerial Yield of *S. alterniflora* Transplants from Four Locations Grown in a Flooded Nursery, Clayton, North Carolina.*

Source of Plants	Propagule Description	Aerial Yields† (kg/ha)
Oregon Inlet‡	Plants	2,314
	Seedlings§	5,786
Drum Inlet‡	Small	1,776
	Medium	3,310
	Large	3,014
Snow's Cut‡	Small	619
	Medium	807
	Large	2,018
Beaufort‖	Short	915
	Tall	646

*Single stems transplanted on 61-centimeter centers, May 1972; harvested October 1972.

†Comparable yield under sprinkler irrigation in 1971 was 1,695 kg/ha. Means of three samples (individual plants for transplants and 0.25 m^2 areas for seedlings).

‡Plants harvested from one location and graded into large, medium and small size culms.

§Seed broadcast

‖Tall and short height forms

in a denser stand than those produced from transplanting on a 0.61-meter spacing.

Using an upland nursery is a technically feasible method, but certainly not as easy or economical as nursery plantings in the intertidal zone. It does offer a practicable alternative when intertidal sites are not available. Also, mechanical digging might be easier since the field could be drained beforehand.

b. Digging and Processing. Plants can be dug from natural stands manually with shovels or mechanically with a small back-hoe. Nursery plantings can be loosened by tractor-drawn tillage and lifted by hand (Fig. 6). The uprooted material should be separated into single stem (culm) propagules or "plants." Small shoots or short pieces of rhizome may be left attached or discarded if damaged or broken. Small single stems are not usually satisfactory transplants (Tab. 3). Survival of rhizomes solely, i.e. not attached to culms, that were planted at 10- to 15-centimeter depths was unsatisfactory. Pruning of shoots to facilitate machine planting may be necessary, but experience suggests that severe defoliation should be avoided. The leaves may be necessary for satisfactory rate of survival, possibly for supplying oxygen to the roots.

Plants to be transported to planting sites may be stacked roots down in tubs, baskets or boxes if moisture loss is prevented. Storage in this manner is satisfactory for a few days. For longer period of storage, plants should be heeled-in in trenches within the intertidal zone.

Two plant storage trials were conducted in 1973. One test site was adjacent to the nursery area at Beaufort. There was little difference in growth or survival between the freshly dug and the heeled-in plants for all five planting dates (Tab. 4). As might be anticipated, the later plantings of both types of transplants produced markedly less first-year growth than those plantings made earlier in the season.

Table 4. Survival and Growth of Freshly Dug Transplants and Heeled-In Transplants at Beaufort, 1973.*

Planting Date	Aboveground Dry Wt. (g/m^2)†		Survival (percent)	
	Freshly Dug	Heeled-In‡	Freshly Dug	Heeled-In‡
7 May	62	89	72	86
14 May	66	32	75	69
28 May	43	36	76	73
11 June	31	23	65	59
10 July	13	9	59	59

*Harvested 10 September 1973
†Means of three samples (individual plants)
‡Dug and heeled-in 26 April 1973

Figure 6. Lifting planting stock, Beaufort, 10 April 1972.

The other trial, at Drum Inlet, covered only three planting dates, but used plants from both Beaufort and Drum Inlet. Growth and survival were lower and more erratic at Drum Inlet than at Beaufort (Tab. 5). This differential response is believed due to the occurrence of salt buildup several times during the growing season at Drum Inlet. However, the relative performance of freshly dug versus heeled-in transplants in the two trials was similar, which suggests that it is feasible to dig and store planting stock of *S. alterniflora* for at least several months.

Survival figures of heeled-in plants for the later planting dates may be somewhat misleading. Some selection probably occurs as they are removed from the trench. Plants that initially appeared as acceptable transplants may have withered during the storage period and would be rejected at this time as nonusable transplanting material. Consequently, there can be some decrease in transplant numbers during storage.

c. Sources. The growth habit and vigor of *S. alterniflora* varies widely along the North Carolina coast. Whether this variability is genetic or environmental or both is still in doubt. Thus, a question arises about the range of adaptation of the transplant material as it is moved from one site to another. This question was examined in several experiments. The first and most comprehensive trial was started at Snow's Cut, 7 April 1971. This trial included plants from five locations ranging from regular tides to mostly wind setup and with salinities ranging from about 10 parts per thousand to nearly sea strength (Tabs. 1 and 6). The material from nearby, labeled "Snow's Cut," most closely resembled an intermediate height form. The Beaufort tall was definitely a tall height form from a tidal creek bank in the Beaufort marshes. Plants from Oregon and Ocracoke Inlets were intermediate in height and were growing on sites exposed to substantial wind setup. The Beaufort short came from the short height zone well away from the creeks, under a regular tide regime and salinities near sea strength.

All five sources grew well the first year (Fig. 7). Some morphological differences were still apparent at the end of the growing season, as well as the characteristic north to south flowering sequence. In addition, there were differences in aerial dry weight, height, number of flowers, number of rhizome culms (an indication of the rate of spread), and total number of culms (Tab. 6).

While growth of transplants from all five sources was satisfactory, the local type, Snow's Cut, appeared to be superior. This source had more aboveground production and a greater rate of spread (rhizome culms) than transplants from other sources, and was intermediate in number of center culms and height. The following spring (1972), new shoots populated the entire area of all plots so that individual hills and rows were indistinguishable (discussed later in Sec. IV, Fig. 39). Vegetative cover and yield increased several fold over that of the first year (Tabs. 6 and 7). Some differences between transplants from different sources were still distinct with Beaufort short definitely shorter than the other sources, and Beaufort tall having produced fewer flowers and

Table 5. Survival and Growth of Freshly Dug Transplants and Heeled-In Transplants at Drum Inlet, 1973.*

Planting Date	Beaufort		Drum Inlet	
	Fresh	Heeled-In‡	Fresh	Heeled-In§
	Aboveground Dry Wt. (g/m^2)†			
29 May	6.4	11.3	13.9	16.7
11 June	13.3	9.7	18.0	10.3
10 July	5.2	2.7	7.1	2.1
	Survival (percent)			
29 May	52.0	57.0	25.0	32.0
11 June	52.0	40.0	51.0	82.0
10 July	40.0	58.0	67.0	81.0

*Harvested 12 September 1973
†Means of three samples
‡Dug and heeled-in 26 April 1973
§Dug and heeled-in 10 May 1973

Figure 7. Beaufort tall transplanted at Snow's Cut.

Table 6. First-Year Performance of *S. alterniflora* Plant Sources at Snow's Cut.*

Source	Aerial Dry Wt. (kg/ha)	Height (cm)	Number of Flowers/ Hill	Rhizome Culms/ Hill	Center Culms/ Hill
Oregon Inlet	1,592.0	138.5	34.2	50.1	38.7
Ocracoke	2,049.0	151.4	21.2	26.2	32.9
Beaufort short	1,424.0	109.1	18.4	57.2	28.2
Beaufort tall	2,365.0	172.0	12.1	34.2	17.6
Snow's Cut	2,723.0	139.3	26.4	66.0	29.9
LSD† 0.05	86.0	10.9	10.8	18.2	11.8
0.01	116.0	14.7	14.6	24.6	15.9
CV‡ (percent)	44.2	8.0	50.0	46.8	41.7

*Harvested 14 September 1971. Three row plots, 91-centimeter spacing, randomized complete block design with three blocks. Three samples (individual plants) taken from each plot in the elevation zone of maximum growth.

†Least significant difference

‡Coefficient of variation

culms than the other sources. Material from Ocracoke and from Snow's Cut was the most productive (in dry weight), but differences in production during the second year were less marked than differences recorded the first year. The north to south flowering sequence (characteristic of the original sites) was still apparent. Adequate sampling of root and rhizome production is difficult (Coefficient of Variation = 57 percent) and differences would have to be quite large to be detectable. However, data on this variable give an indication of the belowground biomass and related soil-binding capability of this vegetation (Tab. 7).

This trial was followed through the third growing season, but comparisons made for the 1971 and 1972 data do not appear valid for the 1973 season. By 1973, the higher elevations of the plots were extensively invaded by fresh and brackish water marsh species plus some common inland weeds (Tab. 8). Furthermore, there were visual indications of some mixing by the plant material from the five sources. Therefore, while data are presented elsewhere on stand maturation, sediment accumulation, and colonization by other organisms, the individual plots were not distinct after the second growing season.

It seems reasonable to conclude, from the first 2 years of this trial, that plants from any of the five sources tested would be satisfactory for initial stabilization of this site. However, this site with its regular tide (1.15 meters) and low salinity (8 to 10 parts per thousand) does not represent the most rigorous test of the range of adaptability of the plant material.

Table 7. Second-Year Performance of Plant Sources at Snow's Cut, 1972.*

Source	Aerial Dry Wt. (kg/ha)	Root and Rhizome Yield (kg/ha)	Height (cm)	Number of Flowers/ m^2	Total Culms/ m^2
Oregon Inlet	9,281.0	14,461.0	132.0	28.5	79.1
Ocracoke	12,626.0	19,651.0	152.0	25.1	72.2
Beaufort short	9,233.0	20,977.0	117.0	23.2	89.9
Beaufort tall	9,723.0	22,132.0	158.0	16.9	50.9
Snow's Cut	12,336.0	22,671.0	143.0	25.6	68.7
LSD† 0.05	2,967.0	‡	11.2	6.0	12.5
0.01	‡	‡	15.0	8.0	16.7
CV§ (percent)	33.9	56.9	9.6	30.4	72.2

*Data collected and plants harvested 19 September 1972. Means of four 0.25 m^2 samples per plot taken from four elevation zones.

†Least significant difference

‡Not significant

§Coefficient of variation

A similar trial was conducted in 1972 at Drum Inlet (Tab. 9). Growth was slow and erratic, due presumably to the salt buildup on this site which occurs periodically during the summer. Differences between sources were small except for the low survival of the Snow's Cut plants. This response would appear reasonable in view of the low salinity at Snow's Cut if it were not for the fact that the Clayton plants were also plants from Snow's Cut which were grown under freshwater irrigation before being transplanted to Drum Inlet.

A small test comparing Snow's Cut plants with Oregon Inlet plants was conducted in 1971 at Oregon Inlet (Tab. 10). In this case Snow's Cut material performed poorly when moved to a location with high salinity and significant wind setup.

The above results suggest that within a latitudinal region such as the North Carolina coast there are naturally occurring populations of *S. alterniflora* that are distinctly different in several respects, including adaptation to specific sites, vigor, morphology, and flowering dates.

Extending beyond this immediate region, seeds of this species were collected from populations from New England to Texas (Seneca, in press). Germination response of these populations was examined in 1972, and some of the seedlings produced were transplanted at the Snow's Cut field site

Table 8. List of Flowering Plants Invading the *S. alterniflora* Planting During the Second and Third Years Following Transplanting in 1971

Scientific Name	Year Recorded	
	1972	1973
Aeschynomene indica L.	x	
Alternanthera philoxeroides (Mart.) Griseb.	x	x
Amaranthus cannabinus (L.) J.D. Sauer	x	x
Aster subulatus Michx.	x	x
Aster tenuifolius L.	x	x
Atriplex patula L.		x
Borrichia frutescens (L.) DC.	x	x
Cyperus polystachyos var. *texensis* (Torr.) Fern.	x	x
Cyperus strigosus L.	x	x
Daubentonia punicea (Cav.) DC.	x	x
Echinochloa walteri (Pursh) Heller	x	
Erianthus giganteus (Walt.) Muhl.		x
Fimbristylis spadicea (L.) Vahl.	x	x
Iva frutescens L.	x	x
Juncus roemerianus Scheele	x	x
Panicum dichotomiflorum Michx.	x	x
Panicum virgatum L.		x
Phragmites communis Trin.		x
Pluchea purpurascens (Sw.) DC.		x
Polygonum pensylvanicum L.		x
Sabatia stellaris Pursh		x
Scirpus americanus Pers.		x
Scirpus robustus Pursh	x	x
Scirpus validus Vahl.	x	x
Spartina patens (Ait.) Muhl.		x
Suaeda linearis (Ell.) Moq.	x	
Vigna luteola (Jacq.) Benth.		x

Table 9. First-Year Performance of *S. alterniflora* Plant Sources at Drum Inlet.*

Transplant Source	Survival (percent)	Aerial Dry Wt. (kg/ha)	Height (cm)	Rhizome Culms/ Hill	Total No. Culms/ Hill
Oregon Inlet	71.0	1,840	91.0	1.2	18.9
Clayton	80.0	1,186	71.0	1.8	8.6
Ocracoke	74.0	1,464	75.0	6.4	13.6
Drum Inlet	78.0	1,288	74.0	4.7	9.7
Snow's Cut	50.0	1,320	69.0	4.7	9.3
LSD† 0.05	11.0	‡	15.4	3.6	7.0
0.01	14.8	‡	‡	‡	‡

*Transplanted 30 May 1972; harvested 3 October 1972. Three row plots, randomized complete block design with three blocks; three samples per plot (individual plants).

†Least significant difference

‡Not significant

Table 10. First-Year Performance of Plant Sources at Oregon Inlet.*

Transplant Source	Aerial Dry Wt. (g/plant)	Survival (percent)	Height (cm)	Rhizome Culms/ Plant	Total No. Culms/ Plant	Number Flowers/ Plant
Snow's Cut	6	27	50	1	7	0
Oregon Inlet	23	65	96	11	12	5

*Transplanted 31 March 1971, samples 31 August 1971. Means of three samples (individual plants).

on 19 May. Aerial dry matter production data for 1972 and 1973 suggest that there are major differences in adaptation within populations of this species (Tab. 11). The latitudinal population grouping nearest North Carolina grew best the first year but the South Atlantic and Gulf coast population groupings forged ahead the second year. Production by the New England material was definitely less both years. These results imply that there may be serious risks in producing seeds or transplants from any single population for planting far away from the site of origin without first testing for adaptation. However, within an area such as the North Carolina coast, it appears that populations may generally be moved with no great difficulty except for extremes, such as from Snow's Cut to Oregon Inlet. Further, it appears that populations having broad adaptation within a region might be found, as in the case of the Oregon Inlet and Ocracoke populations in North Carolina. Propagation of such populations could have real practical application in nursery production of material that might be used for stabilization purposes on a variety of sites. This is one area of study that warrants additional attention.

Table 11. Mean Aboveground Biomass for Two Growing Seasons for Four Geographic Population Groupings Grown on Dredge Spoil at Snow's Cut, North Carolina.*

Population Grouping	Aerial Dry Wt. (kg/ha)	
	1972	1973
New England (Massachusetts, Rhode Island, and Connecticut populations)	150	1,140
Mid-Atlantic (New York, Virginia, and North Carolina populations)	560	3,430
South Atlantic (Georgia and Florida populations)	350	14,190
Gulf (Mississippi and Texas populations)	160	11,340

*Transplanted 19 May 1971; harvested in September of 1972 and 1973.

d. Transplanting Method. Hand planting is more appropriate on small, irregularly shaped areas where access for equipment is difficult. Planting is done by opening a planting hole with a dibble or shovel, inserting a plant to a depth of 10 to 15 centimeters, and firming the soil around it. The team approach is best with men working in pairs; one opening holes and the other planting. This can be done while the soil surface is under water, if the soil is pressed firmly around the plant before it floats out of the hole. However, due to the tendency of plants to float free, transplanting while the surface is exposed is preferred.

Planting depth was not investigated due to the impracticality of keeping holes open long enough for insertion of plants to depths greater than 13 to 15 centimeters. Further, planting depth appears unimportant under these conditions, provided that the plant is anchored until it takes root and becomes established. Drying of roots near the surface is not a problem as it is in dune grass establishment.

Machine planting is feasible on many sites and is preferable on larger areas. It can be done with any of several commercial transplanters designed to transplant cultivated plants such as peppers, tomatoes, and tobacco. A standard farm tractor can be used through the addition of dual wheels and high flotation tires (Fig. 8). With care, this equipment can be operated on surfaces that barely support hand planting.

For machine transplanting, the surface must be exposed and not under water. With the equipment presently available, it is not feasible to time the closing of the furrow precisely after the release of the plant to prevent its floating out.

e. Spacing. Early in the study, it became apparent that with plants on 0.91-meter (3 feet) centers, cover was nearly complete by the following spring. It did appear likely that closer spacing would be helpful on some of the more exposed sites during the first growing season, and spacing tests were established, at Drum Inlet in 1972 and again in 1973 (Tabs. 12 and 13). Unfortunately, second year observations were not possible on the 1972 test due to excessive deposition of sand by the "February blizzard" in early February 1973. Although the data from both experiments are variable, the cover produced by the end of the first growing season was roughly proportional to the spacing. Mean aboveground dry weights for the two trials are 25.2 grams per square meter for 0.46-meter (1.5 feet) spacing, 15.0 grams per square meter for 0.61-meter (2 feet) spacing, and 7.5 grams per square meter for 0.91-meter (3 feet) spacing. There was no test in either year of the value of this from the standpoint of stabilization. It seems reasonable to expect that under some circumstances the higher density planting would be helpful, but this would depend a great deal on the timing and the nature of the disturbance to which the planting is exposed. The denser spacings should have some advantage in the case of erosive action on the substrate occurring after the initial establishment period. Dense spacing appears to offer little protection during the first 60 days after transplanting or against heavy sand deposition such as occurred on the 1972 experiment.

Spacing of transplants is important and needs further clarification since it greatly affects planting costs. It is difficult to evaluate under field conditions due to the unpredictability of storm events and their effects on a specific site. If a spacing trial is placed on a fairly stable site, the trial probably will not be subjected to enough stress to provide any measure of effectiveness. On the other hand, locating a test on a more exposed site will likely result in severe damage and little or no usable data. In the meantime, we are inclined to continue with spacing of about 0.9 by 0.9 meters for most purposes.

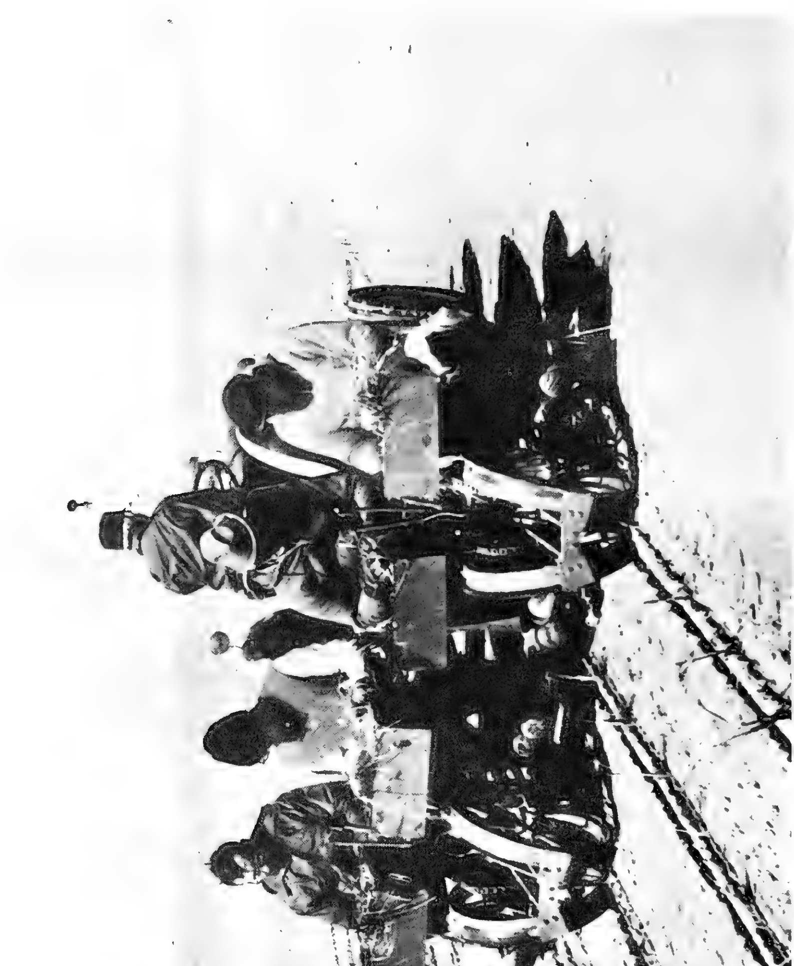

Figure 8. Transplanting.

Table 12. Effect of Spacing on First-Year Growth of *S. alterniflora*, Drum Inlet, 1972.*

Spacing (ft.)	Aerial Dry Wt. (g/m^2)	Height (cm)	Number Flowers/ m^2	Total No. Culms/ m^2	Basal Area (cm^2/m^2)
1.5 x 1.5	20.7	77	6.0	32.3	5.9
2.0 x 2.0	9.7	64	3.6	13.3	2.3
3.0 x 3.0	8.3	69	2.3	11.0	2.8

*Transplanted 31 May 1972; harvested 3 October 1972. Means of three samples (individual plants).

Table 13. Effect of Spacing on First Year Growth of *S. alterniflora*, Drum Inlet, 1973.*

Spacing (ft.)	Aerial Dry Wt. (g/m^2)	Number Flowers/ m^2	Total No. Culms/ m^2	Basal Area (cm^2/m^2)
1.5 x 1.5	29.7	10	39	8.4
2.0 x 2.0	20.4	7	23	4.7
3.0 x 3.0	6.8	2	9	1.9

*Transplanted 8 May 1973; harvested 12 September 1973. Means of six samples (individual plants).

f. Date. Time of transplanting can be critical for many plant species, and particularly for perennials. Consequently, planting date was one of the first points examined in our study. Planting date experiments were started in early November 1969, and some observations have been obtained each year from then on. The data on survival and first-year aboveground dry matter production are plotted in Figures 9 and 10. Although these data are not all strictly comparable, particularly for yield, since some sites tend to be more productive than others, these illustrations seem to be the most useful way to examine the information.

In general, these results indicate survival to be good from midwinter to early summer (Fig. 9). The very poor survival of December and January plantings in 1970-71 is believed due to excessive wave action on an exposed site. Aboveground growth has been satisfactory from about December through May, dropping off sharply in the summer months, due presumably, to the shortness of the growing season remaining at that time (Fig. 10). Both survival and growth have been poor from November plantings; this probably can be attributed to the difficulty in identifying suitable planting stock at that season and the long period of exposure to winter weather before more favorable conditions for growth.

S. alterniflora can be transplanted with considerable success almost the year round. The desirable planting season depends greatly on the particular situation. The late fall and winter period is likely to be risky for exposed sites due to the probability of rough weather. The April-May period seems ideal, coming after the period of high storm frequency, but early enough to take full advantage of the length of the growing season. Summer plantings produce little cover to go into the first winter. However, if they survive the winter, these late plantings can provide full cover early in the next growing season, and there are circumstances in which they would be warranted. For these reasons, it appears unwise to state any rigid rules, but rather to suggest that planting date should be adjusted to each particular set of circumstances, keeping in mind the limitations described above.

g. Costs. The following are mean production figures taken from several short periods of digging, processing, and transplanting over the last 2 years. No allowance is made for travel time, machinery movement, weather, and tides, or for management and overhead.

Harvesting and processing plants

By hand	180 to 200 plants per man per hour
Backhoe (natural stands)	300 plants per man per hour
Lifted by plow (nursery planting)	400 plants per man per hour

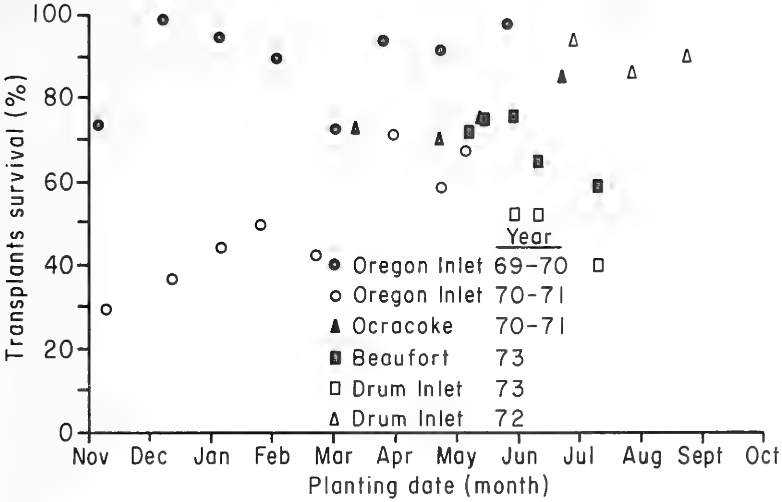

Figure 9. Effect of transplanting date on survival of *S. alterniflora*.

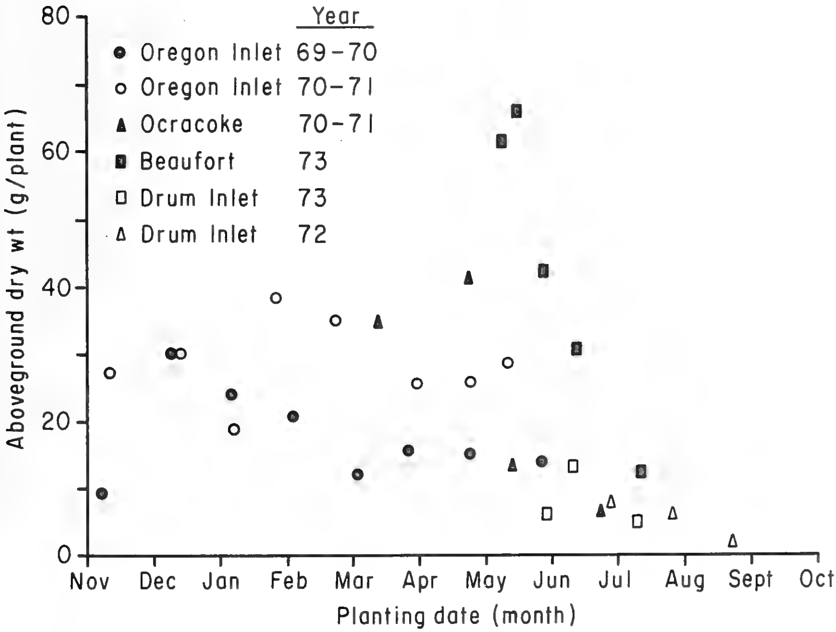

Figure 10. Effect of transplanting date on first-year growth of *S. alterniflora*.

Transplanting

By hand - men working in pairs	180 hills per man per hour
Machine - tractor; two-row planter with six-man crew (one on tractor, four on planter, and one supplying plants)	360 hills per man per hour

Requirements on hectare basis

For 0.91 by 0.91-meter spacing	12,000 hills per hectare or approximately 111 hills per 1,000 sq ft
Hand digging and planting	134 man-hours per hectare
Machine digging from nursery area and machine planting	63 man-hours per hectare

These estimates may reflect higher productivity per man-hour than would be realistic for large-scale operations. On the other hand, we feel the digging operation could be speeded up appreciably with experience in handling larger volumes, and by further development of harvesting equipment.

2. Seeding.

There are reports in the literature that *S. alterniflora* produces very few viable seed (Chapman, 1960; Larimer, 1968), and that seeds are not as important as rhizomes in spreading this grass. However, early in the studies, seedlings appeared to be the primary means of natural colonization of *S. alterniflora* on freshly deposited sediments in the intertidal zone in North Carolina estuaries (Fig. 11). Seed germinate in March and seedlings grow rapidly through the summer, producing flowers and seed by the end of the growing season (October). Seedlings are often numerous in the debris of drift lines at high water and may also be present at lower elevations, particularly in protected areas.

If natural seeding is an important means of spreading *S. alterniflora*, it seems logical that direct seeding would be a suitable method for artificial propagation. This method would have substantial economic and labor-saving advantages over transplanting. To use direct seeding, efficient techniques for harvesting, processing, storing and planting seed had to be developed.

a. Seed Production. The amount and quality of seed available for harvest varies from location to location and from year to year. As would be expected, the most vigorous plants produce the best seed supply. Such plants are generally found in areas recently colonized by *S. alterniflora*,

Figure 11. Natural invasion by seeds. Dense stand of seedlings adjacent to 2-year transplant block, Snow's Cut, 11 May 1973.

and seed production is rather uniform over the entire area. In older marshes, there is little flowering and seed production in thick stands of the short-height zone, but some seed are produced by the tall form along creek banks. In such places, harvesting seed is inefficient because the total area is small.

Since the quality and quantity of seed is variable, inspection of potential harvest sites is necessary each year. Variations in rainfall and other climatic conditions apparently affect seed production. Infestation by flower beetles (family Moredellidae) may also reduce the seed crop in some areas.

b. Harvesting and Processing. An adequate supply of seed for small-scale experiments can be obtained by simply cutting the seed heads by hand. For large field plantings, a more efficient means of harvesting large quantities is desirable. To accomplish this task, a mechanical harvester was developed which consists of a sickle bar blade, a reel, and a canvas bag or tray for catching the seed heads. The apparatus was mounted on a two-wheel garden tractor (Fig. 12). The machine works best in large areas of seed heads of uniform height. After cutting, seed heads were wrapped in burlap sheets and returned to the laboratory where they were stored temporarily in a cold room (2° to 3° Centigrade) until they could be threshed. A threshing machine, previously used for small-grain plot work, was used to separate the spikelets from the straw. This leaves nearly all seeds still in the spikelets (glumes, lemma, and palea). The threshing procedure reduced the storage space required for keeping the seed over winter (Figs. 13 through 16). Germination studies indicate that seed should be harvested as near maturity as possible, but it is often necessary to compromise on complete maturity since many seed may be lost due to natural shattering if harvesting is delayed too long.

c. Storage and Laboratory Testing. A study by Mooring, Cooper and Seneca (1971) showed that 52 percent of *S. alterniflora* seed germinated when subjected to a 18° to 35° Centigrade diurnal thermoperiod after storage in sea water at 6° Centigrade for 8 months. Seed stored dry during the same period did not remain viable. In the beginning of our studies, we tested the effect of several storage treatments on germination. Seed of *S. alterniflora* were collected from five locations along the North Carolina coast (Fig. 17) and samples from each location were subjected to the following storage treatments: (1) submerged in estuarine water at 2° to 3° Centigrade, (2) submerged in distilled water at 2° to 3° Centigrade, (3) suspended over water on screen wire at 2° to 3° Centigrade, (4) frozen dry, (5) frozen in estuarine water, and (6) freeze-dried. Salinity of the estuarine water was between 20 and 25 parts per thousand.

Germination was tested in February 1970 by placing 50 seeds, which were disinfected by soaking in a 25 percent Clorox solution for 15 minutes, on moist filter paper in a petri dish. Three replicates of seed from each treatment and location were prepared with a replicate consisting of a petri dish of 50 seeds. Careful selection was made to be reasonably sure a seed was present within each spikelet. The petri dishes containing the

Figure 12. Seed harvester. Cutter bar, reel, tray and motor mounted on two-wheel tractor.

Figure 13. Threshing seed. Thresher in center foreground; seed heads in burlap sheets at left foreground and right background.

Figure 14. Seed in spikelets mixed with pieces of stems, and seed heads coming from thresher.

Figure 15. Seeds being separated from broken stems and unthreshed seed heads using a motorized screening device.

Figure 16. Threshed and cleaned seeds in plastic containers; containers ready for filling with salt-water and storing in the cold room.

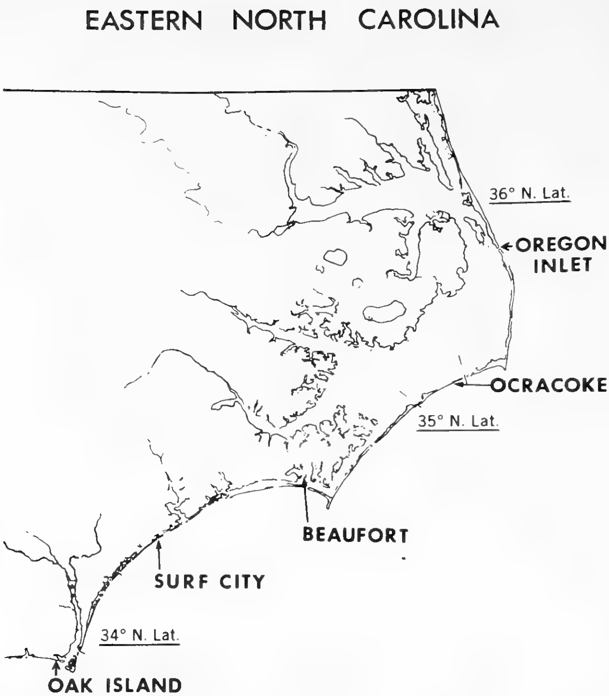

Figure 17. Location of seed collections in North Carolina.

seeds were placed in canisters to exclude light, and were subjected to an alternating thermoperiod of 7 hours at 35° Centigrade and 17 hours at 18° Centigrade in a growth chamber. Germinating seed, indicated by the emergence of the epicotyl, were counted after 5, 7, 9, 21 and 30 days. Since none of the seeds subjected to freeze-drying germinated, the results of this treatment were deleted from the statistical analysis. Germination failure of freeze-dried seed is consistent with the findings of Mooring, Cooper, and Seneca (1971), and showed *S. alterniflora* seed must remain moist to retain viability.

Results of the effect of storage treatment on germination indicate that freezing, either dry or in estuarine water, was clearly detrimental to germination of seeds from all locations (Fig. 18). Freezing was particularly harmful to seed from Surf City and Oak Island. Germination of seed from Oregon Inlet, Ocracoke and Beaufort, which were stored frozen was fair; however, germination was delayed. This indicates that the after-ripening or development process of the seed was retarded while the seed were frozen.

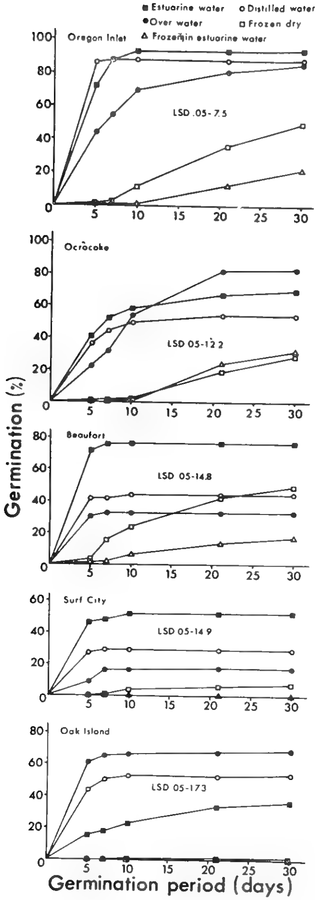

Figure 18. Effect of storage treatments on germination of *S. alterniflora* seed from five locations.

The effects of storage of seed in estuarine water, distilled water or over water on germination were more variable between locations. Seed from Oregon Inlet showed no statistical difference in percent germination of seed among these three treatments at the end of 30 days. Germination of seed stored over water did lag for the first 10 days of the germination period. Storage over water produced the best germination percentages for seed from Ocracoke and Oak Island, while storage in estuarine water was significantly better than any other treatment for seed from Beaufort and Surf City.

The explanation for the variable response to storage treatment of seeds collected from different locations is probably due to the degree of maturity of seed at the time of harvest. *Spartina alterniflora* seed apparently are never dormant but continue development during an afterripening period. The degree of seed development at the time of harvest, as well as the environment in which the afterripening proceeds, probably influences viability of the seed. Although there is variation in seed maturity even within a particular stand, flowering and seed maturity occur earlier along the northern coast of North Carolina with about a 3-week span from north to south.

The seed collections from the different locations used in the experiment were made within 3 days; therefore, seed from the northern coast, e.g., Oregon Inlet, were more mature than those from the southern coast, e.g., Oak Island. Consequently, the difference in the effect of storage in estuarine water, distilled water or over water on germination was least in the seed collected from Oregon Inlet. Storage over water was advantageous for seed collected at Ocracoke and Oak Island. Apparently these seed were less mature at harvest and storage in a saturated atmosphere, but not submerged, was more conducive to the afterripening process.

This study of germination indicates that seed should be harvested as near maturity as possible and that storage in estuarine water or possibly freshwater at 2° to 3° Centigrade is an acceptable and relatively easy way to maintain viability over winter. However, it is often necessary to compromise on complete maturity, since many seed may be lost due to natural shattering if harvesting is delayed too long. At Oregon Inlet the best harvest period has been from about 20 September to 20 October. The best harvest date is later farther south.

The effects of date of harvest, length of afterripening period, and storage in distilled or estuarine water were evaluated with seed collected in 1971. Seed harvested on 28 September 1971 at Oregon Inlet had a significantly higher germination percentage than those harvested 1 week earlier (Fig. 19). However, seed harvested on 21 September were threshed and stored in estuarine water within a few days of harvesting, while those harvested on 28 September were stored in burlap sheets in a cooler for 3 weeks before threshing and storing in estuarine water. Subsequent experience indicates that storing the seed at 2° to 3° Centigrade for several weeks before submerging in water enhances the germination percentage.

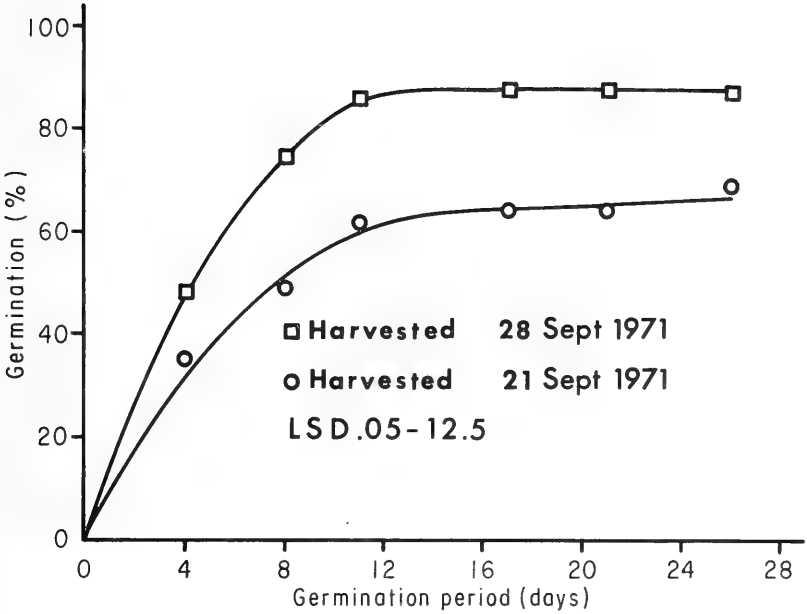

Figure 19. Effect of harvest date on germination of *S. alterniflora* seed stored in estuarine water. Seeds were harvested at Oregon Inlet; the germination period began 17 February 1972.

Results of a study on the effect of length of storage on germination indicate that immediately after harvest, seed were slow to germinate, requiring about 24 days to reach 50 percent germination (Fig. 20). By February, 50 percent of the seed sample germinated within 4 days. The results suggest that an afterripening process occurs that speeds germination and increases the germination percentage as the length of storage increases. Similar results were obtained by Van Shreven (1958) in a study of *S. townsendii* seed. It is difficult to evaluate the effects of length of storage on germination beyond 6 or 7 months since the epicotyl of a large percentage of seed emerges even though stored in salt water at 2° to 3° Centigrade. Experience has indicated that seed stored longer than 1 year do not retain their viability. A study to develop techniques to increase longevity of storage could prove beneficial.

Samples of seed harvested 21 September 1971 at Oregon Inlet were used to compare storage in estuarine water with distilled water. After 2 months storage, there was no difference in germination between the storage treatments (Fig. 21). However, after 5 months, when the after-ripening process was apparently complete, seed stored in estuarine water had a significantly higher germination percentage than those stored in distilled water. At least in some cases, storage in salt water enhances seed germination.

d. Planting Methods for Field Experiments. Several methods of planting and incorporating seed have been used. In the first field experiment with seed (1970), the plots consisted of three rows of seed planted in furrows 1.0 meter apart and 15.2 meters long. Since the seedlings were confined to narrow rows, little growth per unit area was produced during the first growing season (Tab. 14). The results of this initial experiment indicated that seed could be successfully used to establish *S. alterniflora* and that seed should be distributed evenly over an area to give a better plant cover during the first growing season.

In 1971, comparisons were made between the performance of seed applied to the surface in a clay slurry (attapulgite) and seed broadcast by hand and incorporated 1 to 4 centimeters into the substrate. At Oregon Inlet, seed applied to the surface in the clay slurry produced a greater amount of aboveground growth than those which were covered (Tab. 15). The seed in the clay slurry germinated earlier and got off to a faster start since temperatures on the surface were probably higher and the seedlings did not have to emerge through a layer of sand. However, at Snow's Cut, seed planted in the clay slurry produced almost no seedlings. There is a greater tide range at Snow's Cut, and due to the regular flooding the clay slurry containing the seed did not remain in place long enough for germination and rooting to occur. In adjacent plots, where seed were thoroughly mixed with the substrate by raking to a depth of 1 to 4 centimeters, there was a good stand of seedlings which produced very good growth (Tab. 15). It appears that broadcasting the seed and covering to a depth of 1 to 4 centimeters is the best method to ensure a good stand of *S. alterniflora* seedlings over a wide range of conditions.

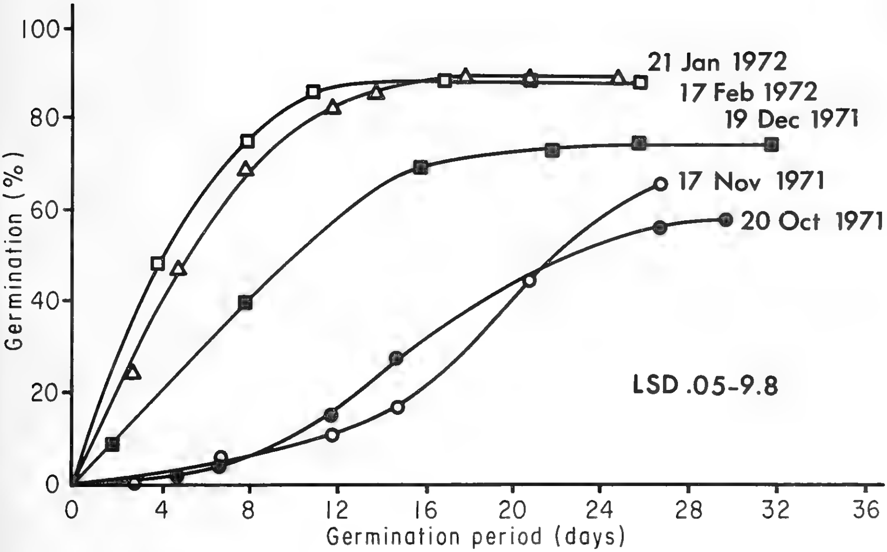

Figure 20. Effect of afterripening of *S. alterniflora* seed stored for various lengths of time. Seed harvested 28 September 1971 at Oregon Inlet and stored in estuarine water until germination was begun on the dates indicated.

Table 14. Mean Standing Crops Produced from *S. alterniflora* seed in Two Growing Seasons.*

Plant Component	Dry Weight (g/m^2)†	
	22 Sept. 70	8 Sept. 71
Shoots	17.5	273.3
Rhizomes	7.0	‡
Roots	17.5	‡

*Planted in rows 1 meter apart at Oregon Inlet, 21 April 1970.

†Means of three samples

‡No data taken

Table 15. A Comparison of Growth Measurements of *S. alterniflora* Seedlings from Two Seeding Methods.

	Aerial Dry Wt. (g/m^2)	Number Flowers/m^2	Total Culms/m^2	Height (cm)
Oregon Inlet* (seeded 22 Apr., harvested 1 Sept. 1971)				
Clay slurry	101.2	72.0	208.0	41.3
Raked	60.0	25.2	173.2	30.3
Snow's Cut (seeded 24 Mar., harvested 15 Sept. 1971)				
Raked (Plot 1)	1,236.8	260.0	480.0	116.0
Raked (Plot 2)	685.6	120.0	388.0	116.0

*Means of three replications

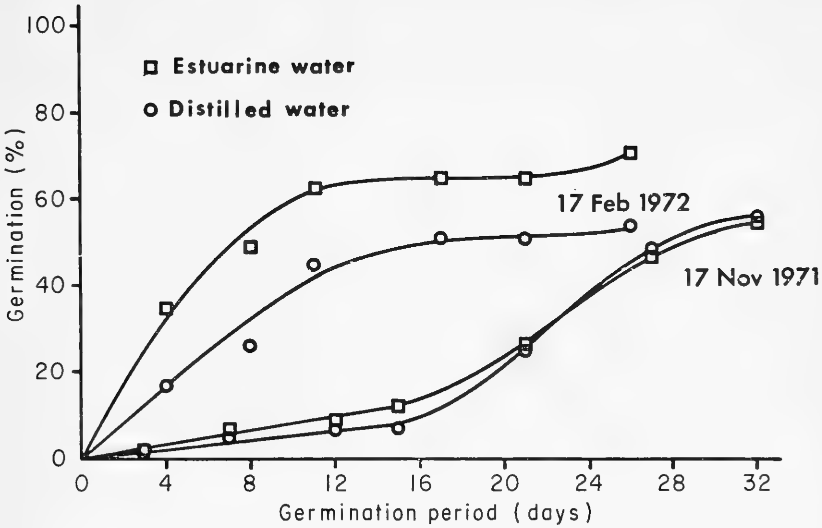

Figure 21. Comparison of germination of *S. alterniflora* stored in estuarine water and distilled water.

Several methods of incorporating seed were used to replace raking for larger scale plantings. Where access is available, a farm tractor may be used. We have used a standard farm tractor equipped with dual wheels for added flotation and traction. Seed were broadcast by hand on the surface and covered by six narrow sweeps mounted on the tool bar of the tractor, followed by a spiked-tooth harrow (Fig. 22). Seed were also incorporated without the spiked-tooth harrow by going over the area with the sweeps, broadcasting the seed (Fig. 23) and plowing again with the sweeps.

Mechanization of distribution of the wet seed would be difficult. However, spreading by hand works very well. Seeds placed in tubs or buckets should be drained of excess water and sufficient dry sand mixed with them to cause the individual seeds to separate (Fig. 24). They are then ready to be broadcast.

Many areas are not accessible to a full-sized tractor. Two portable mechanical methods have been utilized in these areas. For small areas, seed may be broadcast (Fig. 25) and incorporated with a rototiller (Fig. 26),

Figure 22. Farm tractor incorporating seed on dredge spoil near Beaufort, North Carolina.

Figure 23. Broadcasting seed after preparing a seedbed with tractor and cultivators.

Figure 24. Mixing dry sand with wet seed to improve distribution when broadcasting.

Figure 25. Broadcasting seed and sand mixture on a small experimental plot on a dredge island near Snow's Cut, North Carolina.

Figure 26. Incorporating seed with a rototiller.

but this technique is too slow for larger plantings. A faster method was developed which utilized the same two-wheel garden tractor, equipped with dual wheels, which was used for harvesting seed to pull a cultivator that consisted of six small sweeps about 25 centimeters apart (Fig. 27). Furrows were opened with the sweeps, seed were broadcast and covered by a second trip over the seeded area.

e. Seeding Date. Seed germination under natural conditions begins as early as March on the North Carolina coast. However, when seeding *S. alterniflora*, delaying the planting date until mid-April lessens the chance of damage due to weather. The probability of storms which produce damaging wave action decreases later in the spring. Earlier plantings produce more growth by the end of the growing season, but a compromise must be made between early planting and increasing the risk of being washed out or buried by wave action.

A comparison of two planting dates was made at Beaufort in 1972. About 0.5 hectare was seeded 11 April, but part of the seedlings were washed out by a storm in May. A second seeding was made 21 June. Samples of aboveground and belowground standing crops harvested 5 October 1972 from an area about in the middle of the tide range, indicate that the April seeding was more productive the first growing season (Tab. 16 and Fig. 28). After the second growing season, differences were less striking.

Table 16. Mean Aboveground and Belowground Standing Crops Produced from Two Seeding Dates at Beaufort, North Carolina in 1972

Seeding Date	Aboveground Standing Crop (g/m^2) by Year		Belowground Standing Crop (g/m^2) by Year	
	5 Oct. 1972	11 Sept. 1973	5 Oct. 1972	11 Sept. 1973
11 April 1972	354	644	541	1,077
21 June 1972	56	527	176	869

Three seeding dates were compared in the spring of 1972 at Snow's Cut. Seed were planted on 16 March, 10 April, and 10 May; yields of shoots were 388, 304 and 116 grams per square meter, respectively. These results indicate that there is very little difference in growth between the March and April seeding; therefore, risk of weather damage can be reduced by delaying planting until April without sacrificing growth potential. Delaying until May reduced first season growth greatly.

f. Seeding Rate. Since the number of viable seed produced varies from year to year and between locations, it is desirable to estimate the number of viable seed per unit volume for each lot of seed that is available for planting. This can be done by simply measuring a small volume of seed, germinating them, and counting the number of seedlings produced.

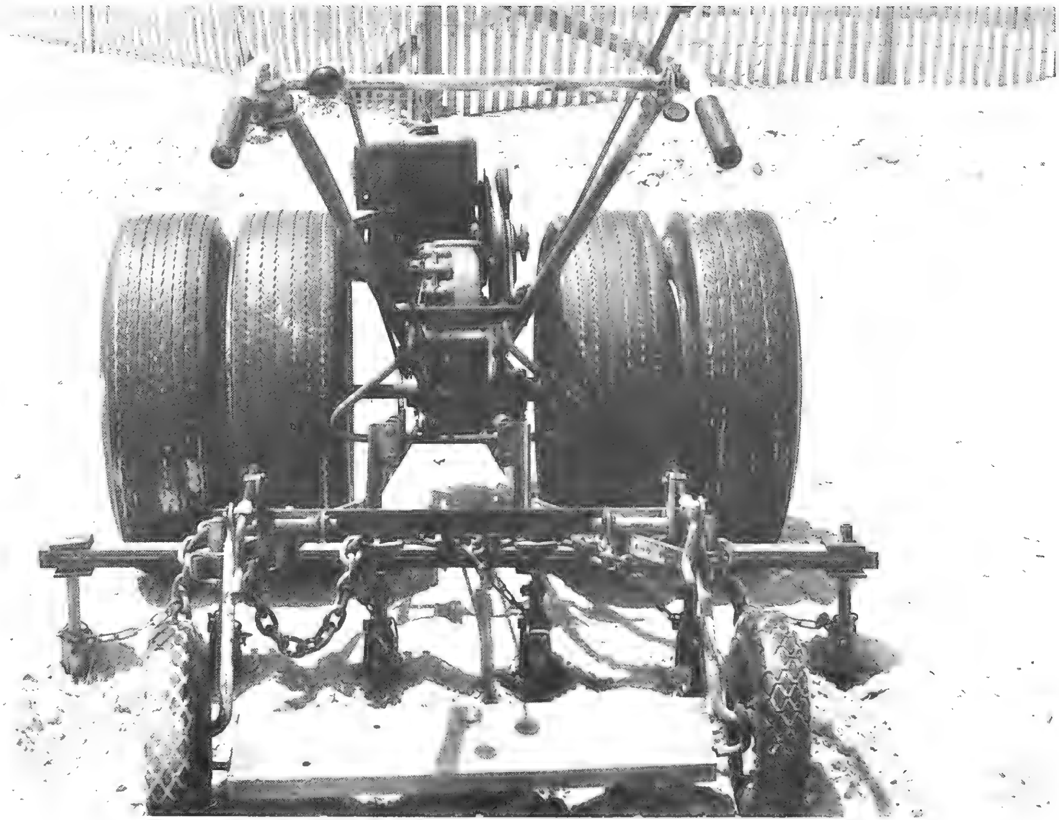

Figure 27. Garden tractor used in seeding at locations not accessible to the farm tractor.

Figure 28. *S. alterniflora* seeded 21 June 1972 (left); 11 April 1972 (right). Photo taken 11 November 1972. Compare with Figure 22.

Experience has shown the number of viable seed per liter varies from as low as 500 to as high as 27,000. A rule-of-thumb estimate generally used is 10,000 viable seed per liter (10 per milliliter). When planting, the volume of seed applied per unit area can be adjusted according to the results of the germination studies. The rate used as standard is 100 viable seed per square meter. This rate can be adjusted up or down, depending on amount of seed available and the exposure of the site. Fewer seed are necessary in a protected area; heavy seeding rates increase the chances of successfully establishing seedlings in areas exposed to wave action.

g. Elevation. The elevation range over which seeding is an effective means of establishing new stands of *S. alterniflora* is less than the elevation range of transplants. Seedlings are not as hardy as transplants and are not as able to tolerate the rigorous conditions of inundation and wave action characteristic of the lower elevations of the intertidal zone. Observations at Beaufort and Snow's Cut illustrate this point in a quantitative manner.

At Beaufort, an average elevation of several points along the edge of a natural marsh near the seeding experiment, indicated the lower limit of growth to be 0.43 meter above MLW (mean low water). However, seedlings produced by planting 11 April survived only as low as 1.02 meters above MLW. The elevation of the upper edge of the natural marsh was 1.15 meters above MLW. Therefore, the part of the elevation range normally occupied by *S. alterniflora* which was effectively colonized by seeding was between 1.02 meters and 1.15 meters or a range of 0.13 meter. This amounts to about 19 percent of the 0.72 meter elevation range of the grass at Beaufort. Tide tables list the mean tide range at Beaufort as 0.76 meter. Seedlings produced from seed planted 21 June had an average lower limit of survival of 0.93 meter above MLW. The area colonized represents about 31 percent of the elevation range of *S. alterniflora*. Apparently the late-planted grass was able to survive at the lower elevation because it was not subjected to storm-induced wave action as was the earlier planting.

Seedlings were successfully established over a larger part of the elevation range on a dredge island in the Cape Fear River near Snow's Cut, tide range 1.2 meters. Transplants survived from 0.25 to 1.41 meters above MLW or a range of 1.16 meters. Seedlings survived down to 0.79 meter above MLW which is a range of 0.62 meter or about 54 percent of the elevation range at this location.

h. Protection from Blowing Sand. Covering of seedlings by windblown sand appears to be a primary cause of failure of natural *S. alterniflora* on sandy dredged material. If there is sandy material above the intertidal zone, sand can be blown from these higher elevations until it becomes armored with shell or covered with vegetation. When establishing *S. alterniflora* on these sites by seeding, it is necessary to protect the area with a sand fence, a vegetation strip such as *Ammophila breviligulata* Fern. (American beachgrass), *S. patens* (Ait.) Muhl. (saltmeadow cordgrass), *Panicum* sp., or preferably a combination of fencing and vegetation.

The experimental planting site at Beaufort was on the northeast side of a large sandy dredged pile. Consequently, southwest winds periodically moved large amounts of sand onto the planting site. Sand fences were erected to prevent the planting from being smothered (Fig. 29). After the first fence (1.2 meters high) was completely filled, it was necessary to erect a second (Fig. 30) and finally a third fence. A strip of *Panicum amarulum* Hitchc. & Chase (silver bunchgrass) was also seeded to intercept the blowing sand. (Seed were provided by the U.S. Department of Agriculture, Soil Conservation Service, Cape May Plant Materials Center, Cape May Court House, New Jersey.)

A similar seeding on the southwest side of a large dredged pile on the Ocracoke side of Hatteras Inlet was completely destroyed by drifting sand. This was seeded 13 and 14 April 1972 in the same manner as the Beaufort planting; by mid-May, the seedling stand appeared comparable to that at Beaufort. However, no sand fence was installed on this site before the storm of 24 to 27 May, and the entire seeding was smothered by the deposition of 15 centimeters of sand. Failure to protect seedings from drifting sand can be critical under circumstances such as described for these two sites. This experience emphasizes the potential of wind erosion in transporting sand from dredge material back into the estuary. By stabilizing the dredge material above the tidal zone with vegetation, a significant amount of refilling of the estuary may be prevented.

Sand deposition or erosion by waves or currents are also major threats to seedling survival on exposed sites. If suitable structures could be devised to protect such sites from wave action during the establishment period, seeding might be feasible in many more locations than it is now.

i. Introducing Natural Seed Sources. The encouragement of natural invasion of new areas through establishment of small "seed patches" might be the most economical approach in some situations. Both seedlings and transplants of *S. alterniflora* almost invariably produce seeds the first year and large numbers of seedlings have been observed among transplants during the spring of the second growing season (Fig. 31).

Small plantings were made for this purpose at several locations. The most successful was on a large (2 or 3 hectares) dredge island near Old House Channel. A small area was transplanted in May 1971 on the shoreward edge of a flat on the southeast shore of the island (Fig. 32). There were no other plants of this species evident on this or the adjoining islands at that time. About 26 months later, *S. alterniflora* occupied an area of about 0.5 hectare, on each side of and shoreward from the original planting (Fig. 33), which could no longer be identified. This method of colonization may be appropriate where resources are limited or where rapid coverage is not required.

j. Large-Scale Seeding. An island, (which we call South Island), comprising in excess of 10 hectares, has been developing for the last 18 months just south of Drum Inlet and several hundred meters west of the barrier island. This island appears to result from sand coming in the

Figure 29. The first of three sand fences erected at Beaufort to protect seedlings from blowing sand. Erected 15 April 1972; photo taken 15 August 1972.

Figure 30. By 12 April 1973 the first fence was completely full and a second fence had been erected.

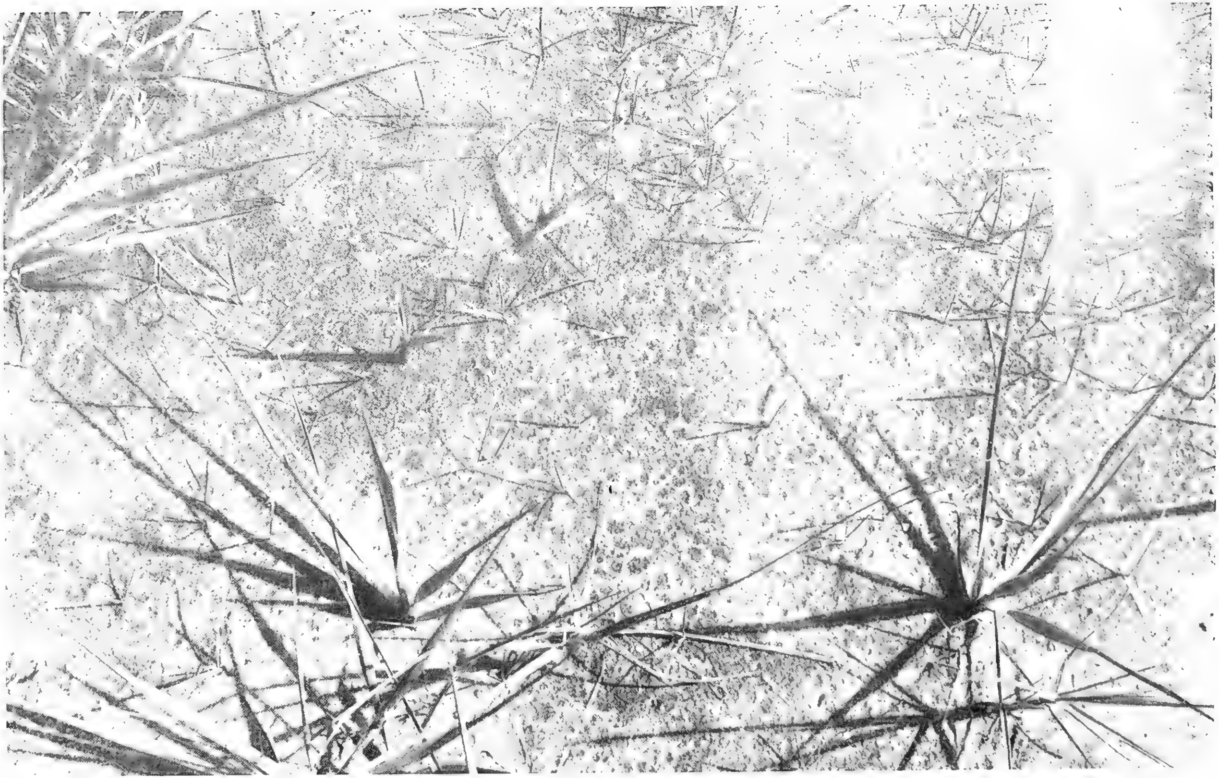

Figure 31. Seedlings (April 1973) among second year rhizome growth in an area near Drum Inlet which was transplanted 15 April 1972 on 0.91-meter centers. Seeds were produced by the transplants the first growing season.

Figure 32. Transplanting *S. alterniflora* near Old House Channel, Pamlico Sound on 11 May 1971. View is west.

Figure 33. The surrounding area was seeded after 26 months (23 July 1973). View is south.

inlet and accumulating around a small (1 hectare or less) spoil island deposited during the course of opening the original channel. An island in this vicinity was seeded in early May 1972, and the resulting seedlings destroyed in the storm of 24 to 27 May of that year.

By early April 1973, an estimated 6 to 7 hectares of South Island lay within the upper half of the tide range, the elevation zone in which we have found seeding of *S. alterniflora* to be feasible. This situation presented a unique opportunity to: (1) undertake field-scale seeding using our portable equipment under the type of conditions for which it was designed, and (2) test the feasibility of seeding a very exposed area where little opportunity for natural invasion by marsh species seemed likely in the immediate future. The low elevation and closeness to the inlet subjects the area to frequent flooding and strong turbulence. The probability of seeds drifting onto this site at the appropriate time for germination and subsequent seedling establishment seems rather remote.

Seeding was delayed until the week of 16 April to reduce storm hazards. About 4 hectares were seeded on 17 and 18 April using the two-wheel tractor with cultivator. The area to be seeded was cultivated before seeding and again immediately after seeding. Seed were broadcast by hand as previously described. On 2 May, a second area of about 1 hectare was seeded in the same manner. Germination and emergence were excellent over most of the area; by late May, an adequate stand of seedlings had survived over an area of 3 to 4 hectares. However, the island continued to grow and many seedlings were smothered by sand that moved over the island during the summer. By the end of the growing season a 2-hectare block lying roughly across the westerly one-fourth of the island still retained an adequate stand with scattered plants remaining over another 1 or 2 hectares.

Rainfall was below normal for much of the summer in this region which when coupled with the low, flat nature of the island, made the seeded area vulnerable to salt injury (see discussion in Section 3c on Salt Damage). Salt damage was believed to be the cause of both the stand thinning and the slow rate of top growth of this planting. An area near the center of the 2-hectare block (Fig. 34), devoted to a fertilizer test, was sampled 8 November 1973 and the data are presented and discussed later in Section VI and Table 43. Top growth was quite restricted, much less than that of the seeding of 21 June 1972 at Beaufort (Tab. 16). However, root and rhizome production was equal to or better than the Beaufort planting. These results suggest that the periodic salt-induced dieback observed aboveground is not necessarily matched by losses in underground growth. This does not seem too surprising since the large mass of succulent roots and rhizomes underneath established stands probably plays a significant role in their tolerance to salt buildup.

This planting was in good condition on 8 March 1974. The island is still growing to the south and east with some erosion along the northwest side. Additional sand has been deposited over most of the seedlings,

Figure 34. Rhizome culms from a seeding on South Island. Seeded 18 April 1973; photo taken 8 March 1974.

but many of them are already sending new shoots through it. Unless drastic shifts in erosion or deposition rates occur within the next 2 or 3 months, an adequate stand of well established vegetation is expected over the area this spring. This is interpreted to be moderately successful and to indicate that seeding under such conditions offers promise of rapid and economical stabilization in some cases.

k. Cost. The cost of propagating *S. alterniflora* from seed is reasonable and not unlike that of agricultural crops, except for difficulties in gathering seed, and for access of equipment to some planting sites. The time required to harvest a known amount of seed was determined at Oregon Inlet in September 1972. One man operated the harvester, while two others removed the cut seed heads from it at the end of each round. Three sample areas were harvested (Tab. 17) to quantify yield of seed per unit area and time required for harvesting. The variability of yield is demonstrated by comparing the first sample area to the other two sample areas. The volume of seed per unit area was about five times greater on the first sample area than on the others, even though it was much smaller. Variability of this magnitude in the seed crop of *S. alterniflora* is common. Consequently, it is difficult to predict the resources necessary to harvest seed at different locations or years or even different areas within the same stand. In the sample, about 5 man-hours were needed to harvest enough seed to plant 1 hectare.

The harvested seed were threshed to reduce the space necessary for storage. Threshing required about one-half as many man-hours as harvesting. The cost of storage was negligible, since refrigeration facilities were available.

The amount of time required for planting depends on the equipment available. Using a two-wheel garden tractor for preparing the seedbed and covering the seed after they were broadcast by hand, 4 hectares were seeded by 3 men in about 10 hours. This amounts to 7.5 man-hours per hectare.

In addition to the times listed there are other variable costs for transportation to the sites, fuel, etc., which are difficult to estimate. Fixed costs (equipment) are also difficult to estimate. In this case, most of the equipment used was modified from that already owned by the Soil Science Department, North Carolina State University.

3. Site Requirements.

a. Elevation and Tide Range. For propagation of salt marshes by either seeding or transplanting, care must be taken in selecting or preparing sites which meet the requirements of the species used. The interactions of such factors as tide range, elevation, slope and salinity determine the species of plants present and influence their vertical zonation in marshes. The vertical range of *S. alterniflora* is generally stated to occur from about mean sea level to mean high tide. There are many exceptions to this generalization. Variations in vertical

Table 17. Seed Harvest from Three Sample Areas at Oregon Inlet in September 1972

Harvested Area	Volume* (liters)	Yield (1/ha)	Weight* (kg)	Time (Manhours)	Approximate Number of Viable Seed	Area which could be Seeded (ha)
0.08 (0.2 ac)	80.0	1,000	16.6	4.5	800,000	0.8 (2.0 ac)
0.28 (0.7 ac)	53.3	190	11.6	3.0	530,000	0.5 (1.2 ac)
0.30 (0.75 ac)	60.0	200	12.8	3.0	600,000	0.6 (1.5 ac)
Total						
0.66 (1.65 ac)	193.3	----	41.0	10.5	1,930,000	1.9 (4.7 ac)

*Volumes and weights are for threshed seed prior to emersion in water for storage.

range occur in North Carolina estuaries where tidal fluctuations are dominated by wind direction and velocity and where salinities are low. At our Snow's Cut experimental site the salinity ranges from 7 to 10 parts per thousand. Under this low salinity, freshwater plants have become mixed with the *S. alterniflora* from about half way in the intertidal zone upward. In completely freshwater, plant species adapted to freshwater would probably become dominant.

In several North Carolina estuaries the range of periodic tides is quite low because of few, narrow inlets and the large area of the estuaries. In such estuaries, surface fluctuations are greatly affected by wind direction and velocity, and consequently, changes in surface levels occur irregularly. This complicates the relationship between tide range and the elevation zone occupied by *S. alterniflora*. In many locations, *S. alterniflora* occurs as a narrow fringe at the water's edge. When planning marsh restoration, it is best to take elevation readings of the upper and lower limits of nearby natural marshes and plan to plant within this zone. In preparing a site, the area available for planting can be increased by making the slope as gentle as practicable without ponding of water. The more gentle the slope the larger the area which will be alternately flooded and drained.

b. Substrate Texture. Several substrate-related factors affect propagation of *S. alterniflora*. Texture of the substrate as it affects bearing capacity is an important practical consideration. Substrates with high proportions of silt and clay are not suitable for conventional planting equipment. The Straits test site is the only place where this problem was found. Most of the dredged material in North Carolina estuaries is composed mostly of sand, and consequently has excellent physical properties. Additional opportunities to experiment with propagation methods on finer textured materials will be welcome.

Sandy substrates are not without limitations. Sandy materials are inherently less fertile than silt and clay since fewer mineral nutrients are adsorbed. Experiments with fertilizers have produced increased growth through applications of nitrogen and phosphorus at locations where the substrate is sandy, such as Drum Inlet and Ocracoke Island. An exception is the Snow's Cut location where the substrate is sand, but nutrients are apparently supplied by the large amount of silt and clay sediments carried by the Cape Fear River and deposited in the marsh on each tidal cycle. At Ocracoke and Drum Inlet little deposition of fine materials has been observed.

c. Salt Damage. Another substrate-related factor is salinity. Although *S. alterniflora* is exceptionally well adapted to growth and survival under saline conditions, it can suffer serious salt damage. This damage we observed in several instances during the field studies. All observations were in the Pamlico and Core Sound region on sites subject to wind setup. Salt damage may occur in such areas any time that extended periods of low water coincide with periods of warm, clear weather. Under these conditions surface salinities build up rapidly and can be particularly severe on seedlings and young transplants. Established plants seem to be able to tolerate much higher salinities at least for short periods of time.

Core Sound and the southern part of Pamlico are particularly vulnerable to this phenomena since the southwesterly winds normally prevailing here during the warm part of the year result in low water levels. It occurs also in northern Pamlico where low water results from northeasterly winds. Heavy salt concentrations, even to the extent of a white crust on the soil surface, have been observed. This condition develops at Oregon Inlet, particularly in April and early May when northeasters of several days duration are not uncommon. At such times the effect on young seedlings is quite severe.

While seedling stands are occasionally killed completely by salt damage, the more frequent effect is a temporary dieback, thinning and stunting. The less severe effect may be due to an intermediate salt concentration or to shortening or interruption of the buildup period by rain showers or wind shifts. This probably happened at the field-scale seeding on South Island (Drum Inlet) during the 1973 growing season. Early seedling emergence on most of this site was good, and by early May a very dense stand seemed ensured. However, by early July many seedlings had died and the remaining plants were stunted and exhibited the general appearance we associate with salt damage -- dead leaves and varying degrees of tip burn of living leaves. Spot checks of salinity were made on about every site visit throughout the summer. All readings were approximately sea strength, although plant appearances suggested that some additional salt damage had occurred, probably on more than one occasion. When the planting was sampled 5 November for estimates of aboveground and belowground production, salinity determinations were made at each sample site. The mean for the 48 samples was 40 parts per thousand (sound water = 35 parts per thousand in this vicinity).

Stand losses that appear to be related to salt buildup have also been observed in well established plantings, occurring as small irregular spots. These have been identified at The Straits on recently dredged material, highly variable in texture, and at Drum Inlet on recently dredged material containing a high proportion of sand.

The damage always appeared the year after transplanting, and was first observed at The Straits in the summer of 1971. Five sampling stations were established and these were sampled three times (Tab. 18).

Wherever salinities of the soil solution exceeded 45 parts per thousand, dieback of *S. alterniflora* leaves was observed; in more severe cases, entire plants were dead.

A similar pattern appeared at Drum Inlet in the spring of 1973 on plots transplanted to *S. alterniflora* in May 1972. Eight sampling stations were established in May and followed through August (Tab. 19).

Table 18. Soil Solution and Sound Water Salinity Measurements* in Dieback Spots at The Straits

Date	Salinity†	
	Sound Water	Soil Solution‡
28 July 1971	28	32 to 58
9 Sept. 1971	32	35 to 80
29 Oct. 1971§	12	35 to 55

*Salinity determined in field with hand-held refractometer.

†Parts per thousand

‡Range among five stations

§Immediately after period of heavy rains

Table 19. Soil Solution Salinity - Drum Inlet, 1973

Station	Salinity*					Vegetation Condition
	May 5	June 12	July 11	Aug. 16	Elevation MLW†	16 Aug.
1	75	60	55	84	1.0	Dead, soil bare
2	35	45	44	38	0.4	Normal
3	70	84	85	110	1.4	Dead, soil bare
4	36	45	40	38	0.4	Normal
5	50	30	40	42	1.2	Dead, soil bare
6	45	48	48	55	0.9	Normal
7	40	35	42	35	0.9	Normal
8	25	10	8	20	1.3	Normal

*Parts per thousand
†Mean low water

At The Straits, it was theorized that the high salinity spots were related to the interlayering of very fine and coarse sediments that occurred at that site. This theory was abandoned when similar phenomenon appeared at Drum Inlet, a site containing almost no fine material. At Drum Inlet, the toxic areas were confined to the higher intertidal elevation within these plantings. This would be the zone left exposed most often, and it was exposed for days at a time during the summer. This does not account for the localized nature of the high salinity spots within this zone.

Station 8 at Drum Inlet is in the "high" elevation zone, but appears very much out-of-place with salinities well below all other stations (Tab. 19). This station is immediately adjacent to a part of the island lying 1 meter or more above the intertidal zone. It is sandy and big enough to develop a freshwater bubble, such as occurs under dunes (Berenyi, 1966), and seepage from this elevated area into the vicinity of Station 8 continually dilutes the soil solution at this location.

Freshwater seepage from sandy spoil piles can significantly reduce soil solution salinities in the intertidal zone. This could be important for plant establishment and survival in this zone in regions having substantial wind setup. On South Island the absence of any area high enough to permit the retention of freshwater was a handicap to the initial establishment of a seedling stand.

IV. MARSH DEVELOPMENT

The ultimate objective of planting *S. alterniflora* will usually be the initiation of a marsh, which has as one of its functions stabilization of the substrate material. Consequently, the rate at which a planting is able to achieve this objective is of interest. An area at Snow's Cut has been followed since planting 7 April 1971. Planting was by hand, one stem (culm) per hill, 0.91-by 0.91-meter spacing, using transplants dug from nearby natural stands. Their development has been monitored by sampling, counts, and measurements made annually in September, near the end of the period of major aboveground growth. A photographic record has been maintained, and elevation cross sections have been surveyed.

The developmental pattern of such a planting can probably be best seen, through the early stages, in the pictorial record. The developmental sequence over the first 12 months for this planting is shown in Figures 35 through 39.

Following spring transplanting, there were a few weeks during which the transplants developed new roots and new shoots emerged from the base (Fig. 35). This stage was followed by a period of rapid aboveground growth, as seen by the proliferation of new stems (center culms) around the original transplant, extension of rhizomes, and emergence of new stems from rhizomes (rhizome culms) at various distances from the transplant (Fig. 36). This stage lasted a little past midsummer after which flowering began and the season's aboveground growth approached maturity (Fig. 37).

Figure 35. Transplanted 8 April 1971; photo taken 2 June 1971. New plants well established and putting on new growth in the eighth week.

Figure 36. Five weeks later on 8 July 1971. Rapid expansion during this period.

Figure 37. Near end of first growing season, 14 September 1971. Note rhizome culms and seed heads.

Figure 38. First-year growth from a single stem transplant.

Figure 39. Starting the second growing season, 10 April 1972. Rows have disappeared.

By late September, seeds were mature and aerial growth had decreased. At this point, the stand consisted of large clumps of stems, 20 to 50 or more, centered around the original transplant with rhizomes of various lengths radiating from them and sending up new stems (rhizome culms) (Fig. 38). At this stage, the substrate was partially stabilized by roots and rhizomes but the cover was still quite open, leaving much of the surface bare.

Seeds shattered rapidly following maturation in late September through mid-October, and aerial growth took on the color of straw and became susceptible to being broken and exported to the estuary by winter storms. Belowground growth continued as evidenced by new rhizome shoots emerging at the surface through the fall. Although not studied, it is evident from observations that a substantial amount of root and rhizome expansion goes on under these stands during the winter.

By March of the second growing season, new shoots so populated the surface that the original hills and rows were no longer identifiable (Fig. 39). Following the flush of spring growth, the site appeared to be fully stabilized, or very close to it, as far as vegetative cover could go.

Developmental data of this planting at Snow's Cut over the 3-year period are presented in Table 20.

In September 1971, three fairly distinct zones of growth consisting of about the upper 25 percent of the vegetated slope, the center 50 percent, and the lower 25 percent were visible. Growth was best in the center of the slope and much poorer at both extremes. Consequently, the planting was divided into these three zones for sampling purposes for 1971. However, at the end of the next growing season, it appeared that four zones would be preferable and sampling afterward was done accordingly. It became evident, after 2 years, that for most measures the two center zones could be combined with little loss of information. Visually there is some difference, but this is primarily in the number of invading plants, and these are numerous enough to sample only in the original upper zone.

A large increase in plant cover developed between the end of the first growing season and the end of the second. This is reflected particularly in number of culms and in both aboveground and belowground dry-matter production, with increases ranging from 3- to 10-fold. These results probably indicate a concomitant increase in substrate stabilization and resistance to wave action of the planted area.

By the end of the third growing season, some additional aboveground development was recorded (Fig. 40), but the real change was belowground (Tab. 20). While top growth increased noticeably at the higher elevations, root and rhizome production increased dramatically throughout. Such increase in root and rhizome mass should substantially increase the stability of the area. Although the belowground plant material was not separated by species, it was nearly all *S. alterniflora* except in the

Table 20. Growth and Development of an *S. alterniflora* Planting at Snow's Cut over Three Growing Seasons*

Period Inundated Mean Hr/day	No. Culms/m^2		Flowers/m^2	Basal Area (cm^2/m^2)	Height (cm)	Below-ground Yield† (kg/ha)	Aboveground Yield (kg/ha)	
	Center	Rhizome					Spartina	Invaders
14 September 1971								
‡0.0 to 3.6	17	11	5	9.6	95	183	280	None
3.6 to 13.0	48	42	18	40.1	147	920	2,275	
13.0 to 16.6	10	5	1	4.5	97	106	240	
19 September 1972								
‡0.0 to 3.6	179		80	58.0	101	4,348	3,260	§
3.6 to 8.9	237		82	86.0	148	7,176	7,850	
8.9 to 13.0	324		104	81.0	125	13,647	7,910	
13.0 to 16.6	232		71	49.0	138	3,837	5,740	
18 September 1973								
‡0.0 to 3.6	273		7	173.0	131	32,949	9,296	442
3.6 to 8.9	419		84	110.0	136	20,918	10,760	§
8.9 to 13.0	448		79	95.0	142	21,673	10,856	§
13.0 to 16.6	361		45	75.0	132	7,406	5,460	§

*Transplanted 8 April 1971
†All species
‡Barely covered by spring tides
§Too few invaders to sample

Sample Size

1971 samples were three individual plants from three elevation zones.

1972 samples were four, 0.25 m^2 samples from each of four elevation zones.

1973 samples were three, 0.25 m^2 samples from each of four elevation zones.

Figure 40. Approaching full vegetative productivity for this site, 11 May 1973.

upper zone. Based on the first 3 years of stand development on this site, it is evident from the standpoint of vegetative cover, substrate stabilization, and primary productivity, that marsh development following transplanting can be quite rapid. Productivity was 7,000 kilograms per hectare the second year and reached 10,000 kilograms per hectare in the third year which compares with 5,100 and 16,000 for the short and tall height forms in the long established natural marshes of Oak Island (discussed later in Section VI, Tab. 40). Cover, as reflected in number and size of stems, and production increased between the second and third year, but the rate of increase slowed. Belowground growth expanded much more than did top growth during the third year. However, these data may be deceptive, since this may mean an accumulation of another season's growth added to that of the first 2 years. If this is the correct interpretation, the annual rate of production belowground appears to be slowing also. There may be further increases in vegetative material in the root zone, but it is difficult to comprehend how it can continue to expand at the present rate without much deeper penetration into the substrate. We have seen no evidence of change in this respect from the first year.

Distribution of roots and rhizomes by depths was examined at Snow's Cut in 1972. It was feasible to take cores to a depth of about 30 centimeters, but only at low tide. There was little penetration of roots and rhizomes below this depth, and no adequate method of sampling below 30 centimeters was found. Cores almost invariably broke off at the point of sharp decrease in belowground growth which occurred around 25 to 30 centimeters below surface.

Cores collected in 1972 were divided into the 0 to 10- and 10 to 30-centimeter depth segments, and the roots separated from rhizomes. The depth division was selected because belowground plant material was more dense in the upper 10 centimeters. About two-thirds of the roots collected are distributed in the upper 10 centimeters; the remainder occurring in the 10-to 30-centimeter zone (Tab. 21). Rhizomes were more evenly distributed between the two zones. There was a distinct tendency toward less total belowground growth as the period of inundation increased.

Sampling variation is high with coefficients of variability of 37.5 to 84.3 percent. Consequently, differences would have to be quite large to be detectable.

Estimates of rate of spread were obtained at Snow's Cut at the end of the third growing season. The lateral rate of spread was from 0.9 to 1.5 meters per year (Tab. 22; Fig. 41). Data on downslope spread were available from only one plant source (Ocracoke) at one elevation. Since lateral spread for all plantings at this location was uniform across the four zones of inundation and of the same general magnitude as the single downslope expansion determination, we assume that the latter would be very similar to the lateral spread at all elevations within this range (2 to 12 hours inundation).

Table 21. Distribution of Belowground Growth* by Depths, Snow's Cut 1972

Inundation Zones (hr/day)	Dry Weight (kg/ha) Roots (cm)		Dry Weight (kg/ha) Rhizomes (cm)	
	0 to 10	10 to 30	0 to 10	10 to 30
0.0 to 3.6	3,093.0	1,499.0	6,734.0	4,015.0
3.6 to 8.9	2,831.0	1,783.0	5,695.0	4,261.0
8.9 to 13.0	2,553.0	1,304.0	3,987.0	3,990.0
13.0 to 16.6	2,318.0	934.0	3,664.0	2,723.0
LSD† 0.05	‡	‡	‡	‡
CV § %	37.5	73.2	84.3	73.9

*Samples were four core samples (8.5 cm in diameter and 30 cm deep) from each elevation zone. One core was taken from each 0.25 m^2 sample area.

†Least significant difference

‡Not significant

§Coefficient of variation

Table 22. Rate of Spread (meters per year) of *S. alterniflora* at Snow's Cut, 8 April 1971 to 27 November 1973

Lateral Spread				Downslope Spread
Ocracoke Plants	Snow's Cut Planting Stock			Ocracoke Plants
Along Edge of Large Block	From Single Isolated Row	Along Edge of Large Block	Planted on Old, Very Compact Soil	in 12 hr/day Inundation Zone
1.0	1.6	1.3	1.5	1.3

Figure 41. Lateral spread of Ocracoke plants at Snow's Cut, 5 March 1973. Beginning of third growing season.

Rate of spread of such plantings is useful in estimating the time required for stands, established by seeds in the upper part of the tide range, to advance downslope to the lower limit of growth for this species. For example, direct seeding was successful at Snow's Cut down to 0.79 meters above MLW (inundated 5.7 hours daily); transplants survived downslope to 0.25 meters above MLW (inundated 16.6 hours daily). The horizontal distance between these two points on this site was 39 meters. Assuming an annual rate of spread downslope (1.31 meters) equal to that measured for the transplanted area, 30 years would be required for the seeded stand to spread to the lower limit. This is one of the strong justifications for transplanting where early stabilization of the entire slope is desired.

Development of a transplanted stand at Drum Inlet has been followed over a 2-year period (Tab. 23). This stand was one that escaped serious damage from the February 1973 storm and from salt buildup during the summer. Second-year development was equal or somewhat superior to that at Snow's Cut in terms of plant cover, primary production, and belowground growth (Tab. 20). This growth response took place under conditions that varied substantially from those at Snow's Cut. Salinity was much higher (close to sea strength); tide range was lower and erratic due to wind effect, and there appeared to be much less movement of fine grained sediments. The rapid development of *S. alterniflora* on this site is further evidence of its ability to perform well under a wide range of conditions and suggests the Snow's Cut data may be representative of the development process.

Table 23. Development of Transplanted *S. alterniflora* at Drum Inlet

Year	Culms/m^2		Height (cm)	Flowers/m^2	Basal Area (cm^2/m^2)	Yield kg/ha	
	Center	Rhizome				Below-ground	Above-ground
1972*	29	21	122	10	19	†	856
1973‡	473		122	113	124	15,038	9,413

*1972 samples were seven individual plants (means are expressed in the table) for aboveground growth.

†Not sampled

‡1973 samples were six, 0.25 m^2 plots. Belowground samples were two cores from each of the aboveground sampling areas.

Another aspect of marsh development has been followed at the Drum Inlet and Snow's Cut sites. Invertebrate species were sampled by taking core samples of the substrate material, screening, and identifying those present (Tab. 24).

Table 24. Invertebrate Species Found at Drum Inlet and Snow's Cut from March to November 1973

Natural Marsh	Dredged Material
Drum Inlet	
Annelida	Annelida
Heteromastus filiformis	*Paraonis fulgens*
Laeonereis culveri	*Magelona papillicornis*
Eteone heteropoda	
Scoloplos fragilis	Arthropoda
Streblospio benedicti	*Uca pugilator*
Glycera sp.	*Acathohaustorius millsi*
Nereis succinea	
Paranais litoralis	Nemertea
Henlea ventriculosa	*Tubulanus pellucidus*
Tubificidae (*Limnodriloides medioporus*?)	
Arthropoda	
Dolichopodidae	
Ephydridae	
Stratiomyidae	
Insect adult A	
Insect adult B	
Neomysis americana	
Uca pugilator	
Ocypode quadrata	
Mollusca	
Gemma gemma	
Mya arenaria	
Tagelus plebius	
Arcuatula (= *Modiolus*) *demissa*	
Snow's Cut	
Annelida	Mollusca
Heteromastus filiformis	*Tellina* sp.
Laeonereis culveri	*Arcuatula* (= *Modiolus*) *demissa*
Scolocolepides viridens	
Nereis succinea	Nemertea
Enchytraeus albidus	Unidentified
Arthropoda	
Dolichopodidae	
Ephydridae	
Lepidactylus dytiscus	
Cyathura polita	
Uca pugilator	

The invading species, in general, appeared to be the most widely adapted of the typical salt marsh species. Common at both Drum Inlet and Snow's Cut were the polychaetes *Laeonereis* and *Heteromastus* in the creeks, and Dipteran larvae and *Uca pugilator*, the fiddler crab, in the marsh itself. The polychaetes are deposit feeders; the others feed mainly on the growth of algae and diatoms at the marsh surface. In time, it is expected that these species will become less important as other less common species invade, but that they will still be among the dominant invertebrate fauna.

V. SHORE PROTECTION AND SUBSTRATE STABILIZATION

Stabilization was a major objective of the study, but one for which we were unable to develop satisfactory evaluation procedures. The problem is the lack of unaffected or unbiased controls. For example, at the Snow's Cut site, the original experimental plantings were divided into three blocks, 45 to 60 meters wide, that extended roughly from the high spring tide line, downslope to about MLW. These blocks were spaced 30 to 60 meters apart, leaving the intervening strips unplanted and undisturbed. Dominant tidal currents are across the slope (parallel slope contours). Erosion and deposition were monitored in two ways: (1) by cross-sectional surveys started in 1971 through the planted blocks (Figs. 42 through 45) and (2) by cross sections established in early 1972 through the unplanted strips (Figs. 42 and 46 through 49). The latter might seem preferable as controls, compared to following elevation changes of the planted blocks over time. However, the protection afforded these unplanted areas by the adjoining vegetated blocks affects the erosion, the deposition and the revegetation occurring on them. Natural revegetation is gradually eliminating these areas as "unvegetated controls."

Even the provision of unplanted blocks or strips appears inadvisable on eroding shorelines such as at Cedar Island since they would likely promote erosion of adjacent areas.

There appears to be no meaningful way to test stabilization effects directly in small-plot field experiments. However, relative values between variables based on vegetative growth may be sufficient at this stage. Beyond that, wave tank tests might be the best approach.

1. Snow's Cut.

As indicated, certain cross sections were monitored at this site from June 1971 (Figs. 43, 44, and 45) and others (Figs. 46 through 49) from April 1972. All three planted blocks have shown a steady gain in elevation over the 30-month period. The northernmost block (Figs. 42 and 43) has trapped the most sediment, averaging close to 30 centimeters over the entire slope with largest gains in about the upper half of the normal tide range (Fig. 50). It appears that more sediment may be coming from the northern or upstream side and this planting may be intercepting material and reducing the amount available to the areas downstream to it.

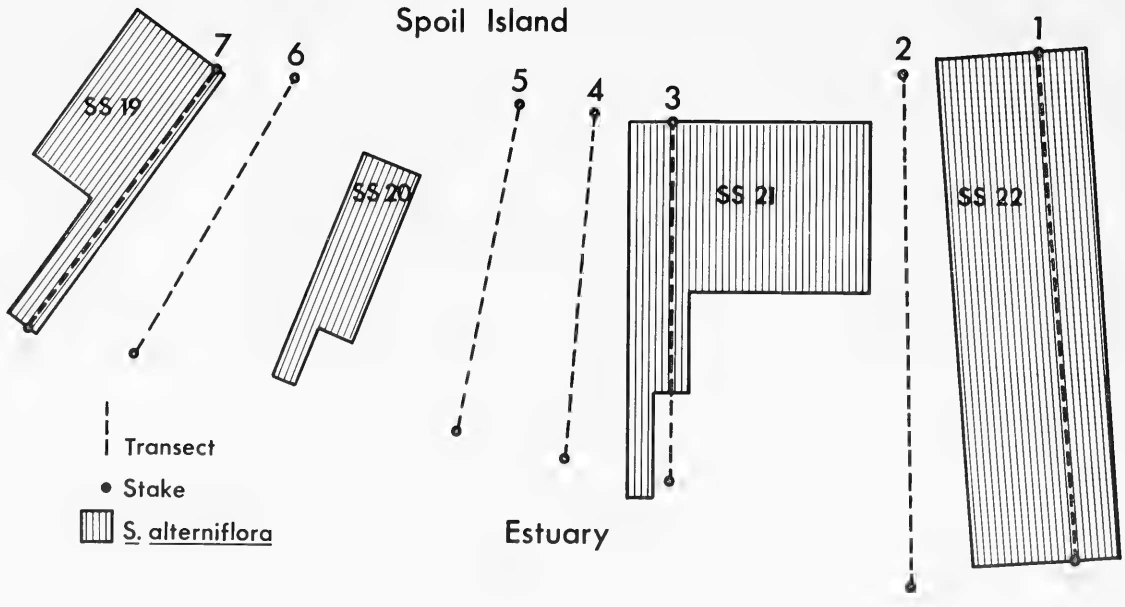

Figure 42. Diagram showing location of transects at Snow's Cut.

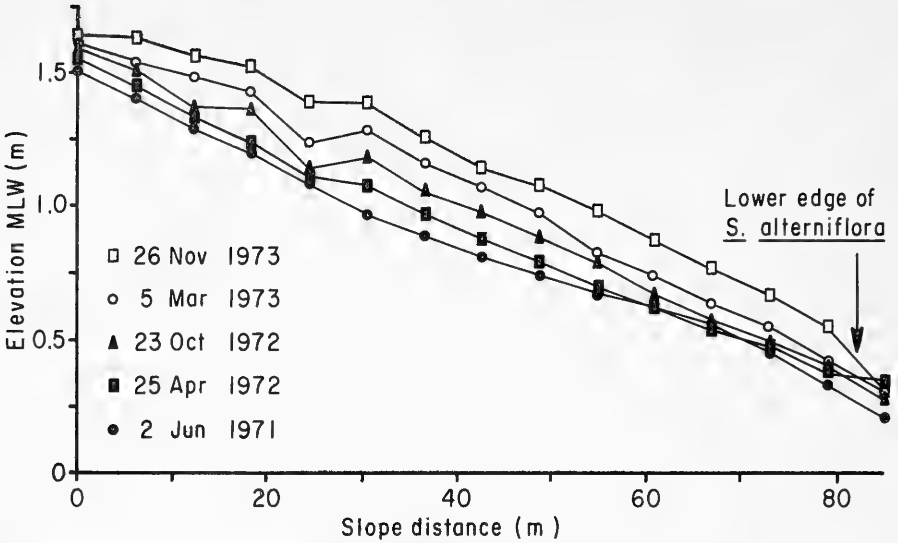

Figure 43. Planted transect, No. 1, Snow's Cut; 2 June 1971 to November 1973.

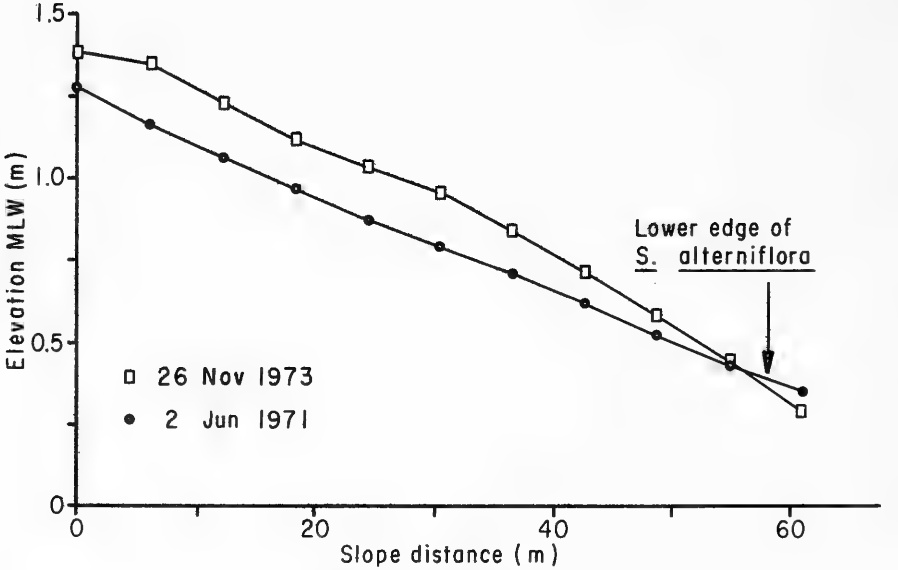

Figure 44. Planted transect, No. 3, Snow's Cut; 2 June 1971 to November 1973.

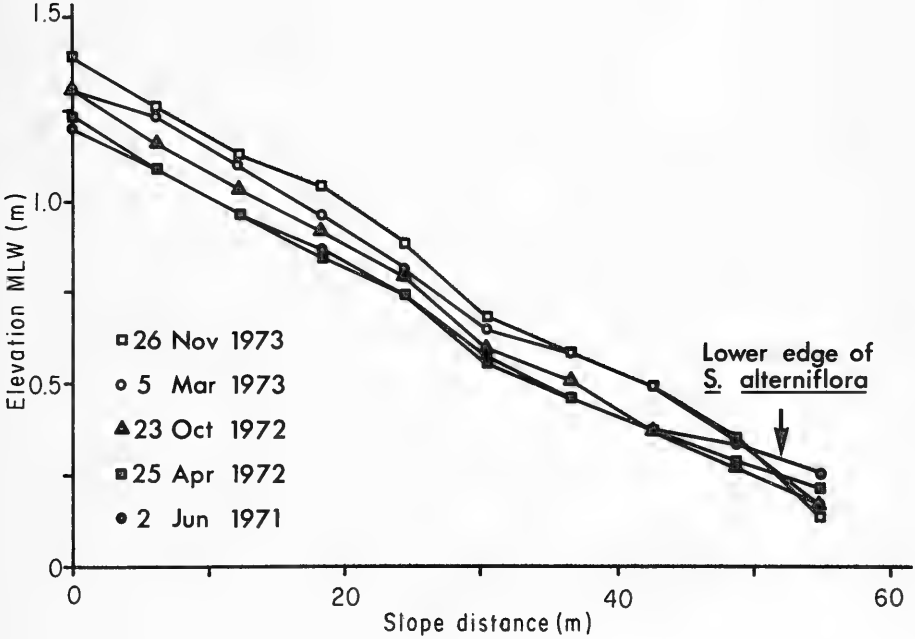

Figure 45. Planted transect, No. 7, Snow's Cut; 2 June 1971 to 26 November 1973.

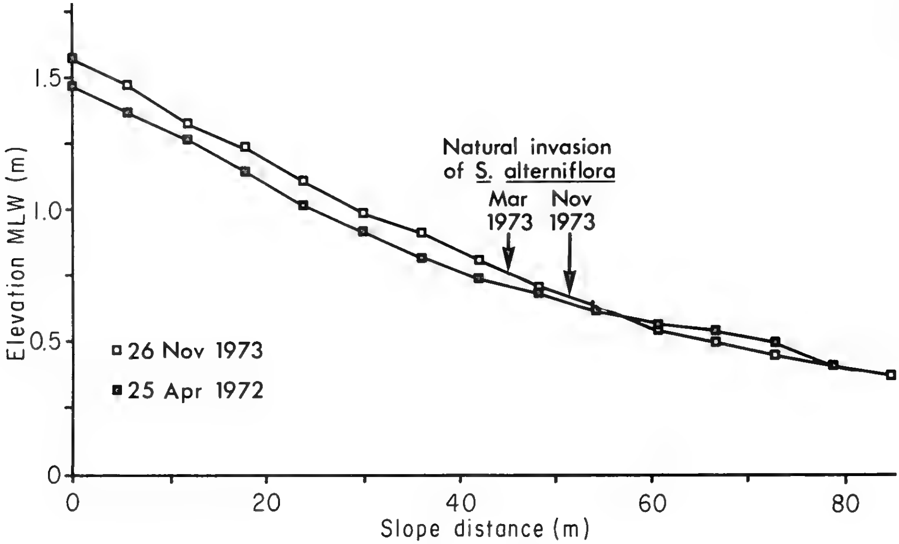

Figure 46. Unplanted transect, No. 2, Snow's Cut; 25 April 1972 to 26 November 1973.

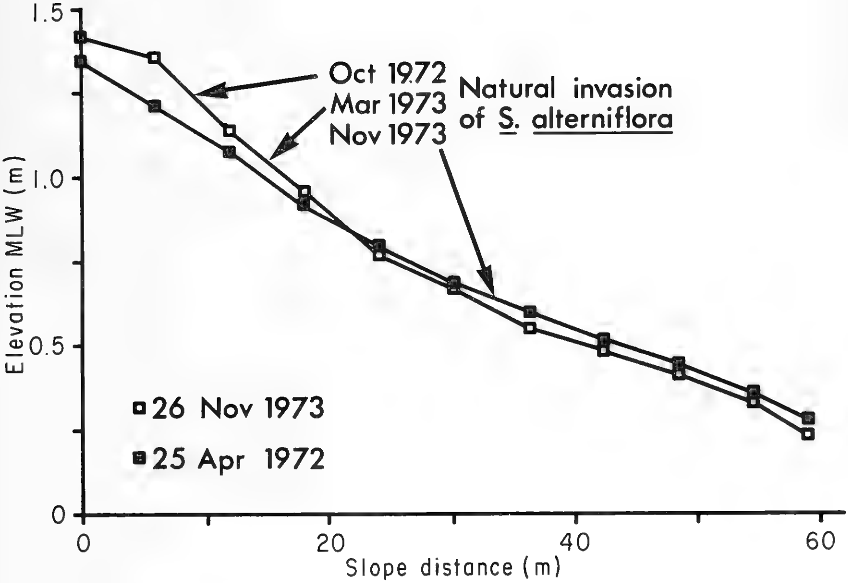

Figure 47. Unplanted transect, No. 4, Snow's Cut; 25 April 1972 to 26 November 1973.

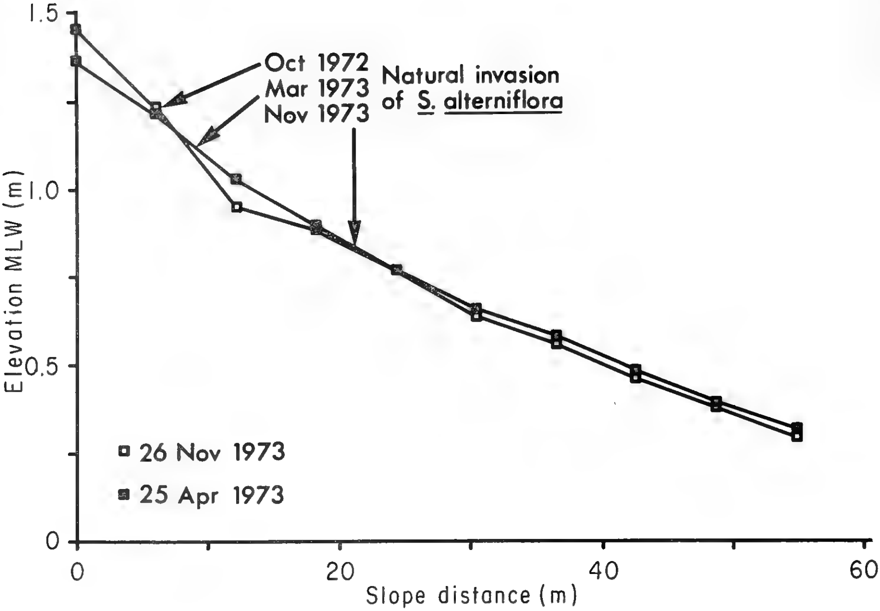

Figure 48. Unplanted transect, No. 5, Snow's Cut; 25 April 1972 to 26 November 1973.

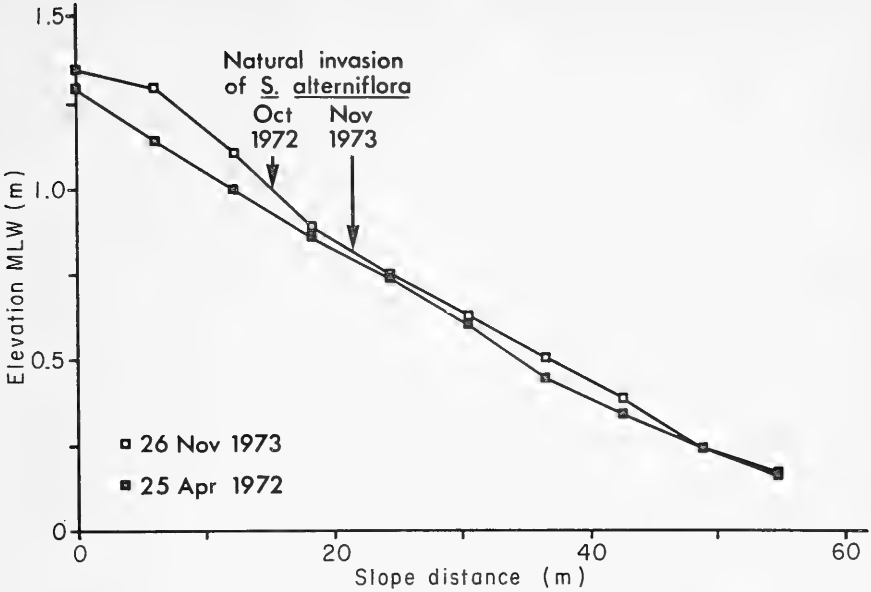

Figure 49. Unplanted transect, No. 6, Snow's Cut, 25 April 1972 to 26 November 1973.

There was little difference in elevation gain between the other two planted blocks; the change on these averaged around 15 centimeters. Sediment accumulation definitely decreased in the zone immediately down-slope of the vegetation.

Records on the four cross sections through the unplanted strips indicate little change in elevation during the period of record (Figs. 46 through 49). Section 2 (Fig. 46) upstream from the others, exhibited the most accumulation. The effect of volunteer seedlings is clearly visible in the most recent survey on all of these unplanted areas. A minor amount of erosion has occurred along these cross sections, largely at the bottom of the slope.

There was no way to predict what elevations would exist along the unplanted cross sections if no *S. alterniflora* were planted in the vicinity. The planted blocks did trap substantial amounts of sediment, and the interpretation is that this, along with the behavior of the unplanted strips is reasonable evidence of a strong stabilizing effect of this vegetation. Also, the slowness with which *S. alterniflora* invaded the unplanted strips appears to indicate that natural colonization of the area would have been extremely slow in the absence of such plantings. No seedlings appeared

Figure 50. Side view of vegetated block showing sediment accumulation.

on the unplanted strips until the second year following the heavy first-year crop of seed on the planted blocks. It seems, therefore, that these areas were both seeded and protected by the planted blocks. It is possible that without this protection, seeds could not remain in place at this location long enough for germination and establishment, and that revegetation would have to come from gradual expansion of vegetation from a more protected part of the island.

2. Cedar Island.

The experimental area is on the former Lola Naval facility situated on a promontory near the southern tip of Cedar Island. It is exposed to a fetch of several miles across Pamlico Sound to the east and northeast and across Core Sound to the south. It appears to be representative of many eroding shorelines in much of the Core and Pamlico Sound region.

This area is believed to have a long history of erosion. On more protected shores nearby, *Juncus* marsh is growing on a thick (0.6 to 1.2 meters) layer of peat well above normal water levels, with the perpendicular face of the peat exposed along the water's edge. Apparently the marsh has grown upward on the surface of the accumulating peat and has long since lost contact with the intertidal zone along this edge. Consequently, the exposed face is quite vulnerable to erosion. This was probably true in front (east) of the Lola facility some years ago, but if so, the thick peat layer has eroded away. This shoreline is steep (10 to 25 percent slope), and is presently composed of coarse sand interlayered with thin lenses of peat. With only wind setup, a narrow area is available, 2 to 4 meters wide, on which *S. alterniflora* could be expected to grow. Before planting in May 1972 there were three or four small eroding patches of *S. alterniflora* along this shore. About 1,900 *S. alterniflora* plants, dug near Drum Inlet, were transplanted by hand on about 0.6-by 0.6-meter spacing along a 0.2-kilometer stretch of shoreline south of the Radar Tower (Fig. 51). Following this planting, the area was subjected to strong northeast winds by a subtropical cyclonic disturbance from 24 to 27 May. A few weeks later, 60 percent of the transplants were washed out and the appearance of the 40 percent remaining was not encouraging. Consequently, this trial was written off as a failure and was not checked again until late in the season. At that time, the surviving plants had made a surprising recovery. When growth emerged the following spring (1973), these plantings were well established, and by fall a high proportion of this stretch of shoreline was effectively stabilized (Fig. 52).

Samples were taken from this area in the fall of 1973 to estimate productivity (Tab. 25). Growth on this site was unusually dense and vigorous. Number of culms and flowers per unit area was quite high, and dry matter production was unusually high. When rechecked in January 1974, the only noticeable change in these plantings was some sporadic sand deposition by storm tides and waves. There was no evidence of stand loss from erosion.

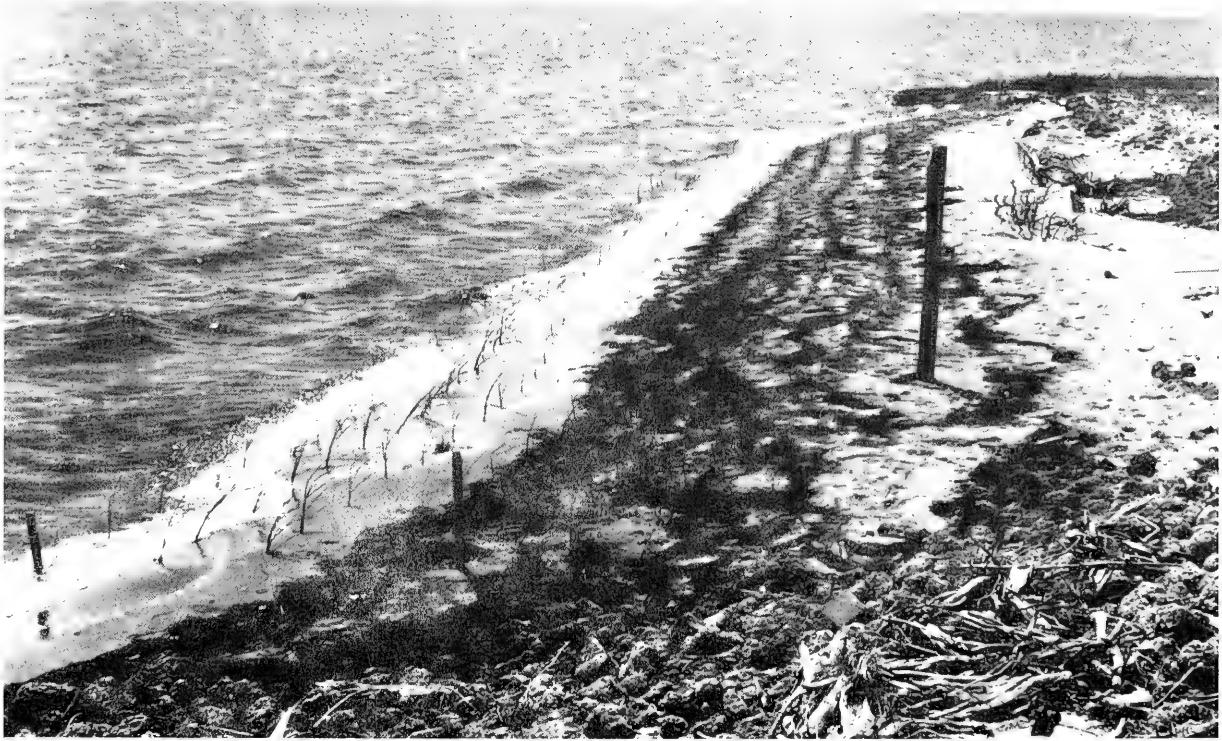

Figure 51. Shoreline at Cedar Island after transplanting, 11 May 1972.

Figure 52. View of the Cedar Island shoreline in the fall of 1973.

Table 25. Second-Year Development of *S. alterniflora* Plantings* - Cedar Island, 13 September 1973

Sample Number	Aerial Dry Weight (kg/ha)	Height (cm)	Number Flowers/m^2	Number Stems/m^2	Basal Area (cm^2/m^2)
1	14,680	128	164	428	81
2	17,680	138	136	425	153
3	16,200	140	112	336	127
4	6,640	118	84	148	46
5	11,920	124	80	372	127
Mean	13,440	130	116	340	107

*0.25 m^2 samples

Another planting of 1,900 transplants was made on five small areas north of the Radar Tower on 11 and 17 May 1973. This shoreline is more exposed to the northeast and is eroding more rapidly than the area used for planting in 1972. Plants were closely spaced, about 0.3 by 0.3 meters. The total frontage covered was about 90 meters long. Erosion has continued on this area with little net recession of the shoreline, but substantial movement of material back and forth so that only about 20 percent of the plants could be identified as surviving in September 1973 (Fig. 53). Fewer were in evidence in January 1974, but some of these had grown quite well, some were buried beneath sand and rubble, and the amount of new growth that would appear in the spring was not predictable. Obviously this planting will not be as successful as the 1972 planting nearby, but it could be better than at present.

Experience in shoreline stabilization suggests that such plantings do have potential for reducing sound-side shoreline erosion in this region. Many eroding sound shorelines are similar to those in the study area at Cedar Island. Any marsh vegetation remaining on them has lost contact with the sound bottom, separated from it by a scarp. The plants can no longer spread back into the bare zone by rhizomes. Further, since turbulence along the shoreline is excessive for seedling establishment, there is little possibility for natural revegetation. It is known from work elsewhere that *S. alterniflora* can be established by transplanting under conditions that are much too rigorous for natural invasion. If vegetation is to be reestablished on these shores, transplanting is the only possibility.

VI. THE RELATIONSHIP OF MINERAL NUTRIENTS TO PRODUCTIVITY OF *SPARTINA ALTERNIFLORA*

The mineral nutrition of *S. alterniflora* was studied to obtain knowledge of the relationship of fertility of the substrate material to

Figure 53. Cedar Island shoreline transplanted 11 May 1973; photo taken September 1973.

productivity of the grass. The role of fertility of the substrate material as it affected starting new marshes by artificial propagation had not previously been investigated.

The productivity of natural marshes varies greatly from one location to another (Cooper, 1969). There is also variation within a given location with three distinct height zones (tall, medium, and short) generally recognized (Teal, 1962; Adams, 1963: Cooper, 1969). In the past, attempts were made to relate differences in productivity to such factors as genetic differences, time of inundation, and salinity. The efforts to relate productivity to nutrients in this study were divided into two phases. The nutrient status of plants and soils was sampled in natural stands from seven locations along the North Carolina coast, and related to yields using regression analysis. The second phase measured growth response to fertilizer applications. Plants in natural stands, transplants, and seedlings were included.

1. Nutrient Status of Natural Stands.

a. Methods. Stands of *S. alterniflora* at seven locations along the North Carolina coast were selected for sampling during the summer of 1970 (Fig. 54). These stands are representative of variations in latitude, in tidal range, and in type of substrate occurring along the North Carolina coast. The Oregon Inlet, Hatteras Village and Ocracoke sites are similar in their location on the sound side of barrier islands where the tide range is 30 centimeters or less. Two important damper effects cause the narrow tide range in estuaries north of Cape Lookout: (1) few inlets through the barrier islands, and (2) a large expanse of water behind the islands. Winds greatly influence the surface levels causing a greater but irregular fluctuation. The Oregon Inlet and Ocracoke marshes are young stands on sandy substrate low in organic matter. The Hatteras Village marsh grows on a substrate containing 10 percent organic matter. The North River marsh is also in a location of low tide, growing on sandy substrate, and consists of a narrow fringe (about 20 meters wide) along the shore.

The Beaufort, Swansboro and Oak Island marshes are in areas of wide tidal range and are more typical of the regularly flooded southeastern tidal marshes described by Cooper (1969). South of Cape Lookout, inlets are numerous and the estuaries are narrow allowing a greater tide range. Texture of the substrate is quite variable between the locations (Tab. 26).

Plant samples were taken from each location and each height zone 17 to 23 June, 5 to 17 August, and 30 September to 2 October. The distinctness of the height zones varied among the locations. The medium height zone was a narrow transition zone which was barely discernable in several locations. Consequently, only samples from the tall and short height zones were included in the statistical analyses. The plant samples, consisting of 0.25-square meter plots, were clipped at ground level from each height zone. The sample plots were selected by establishing a transect across and perpendicular to the height zones. From this line,

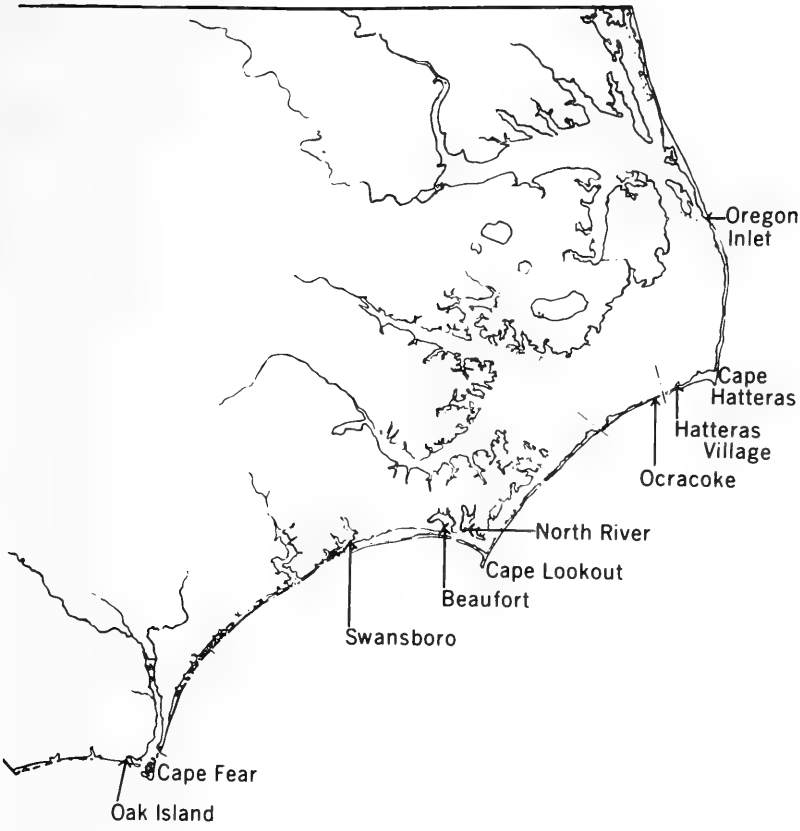

Figure 54. Locations of sampling sites (indicated by arrows).

three points for sampling were randomly selected within each height zone. Sampling was done at low tide when possible. Soil solution salinity was field-determined with a handheld refractometer.

Table 26. Soil Texture and Percent Organic Matter of Tall and Short Height Forms of *S. alterniflora* for Seven Locations

Location	Percent Sand		Percent Silt		Percent Clay		Percent O.M.	
	Tall*	Short	Tall	Short	Tall	Short	Tall	Short
Oregon Inlet	97.3	96.3	0.6	0.8	2.1	2.9	0.1	0.1
Hatteras Village	84.6	71.6	9.1	20.5	6.2	7.9	5.1	10.8
Ocracoke	92.7	96.1	3.7	0.5	3.6	3.3	0.7	0.3
North River	54.9	69.0	30.3	20.6	14.8	10.4	1.6	2.4
Beaufort	47.1	52.4	40.2	34.4	12.7	13.2	5.0	6.0
Swansboro	86.4	93.9	6.2	2.6	7.4	3.5	1.1	0.5
Oak Island	57.3	57.7	30.6	30.3	12.1	11.9	9.3	6.5
LSD 0.05†								
Loc. x ht. zone	10.0		7.9		3.1		1.7	

*Height zone

†Least significant difference
(Main effects are not presented because of significant location by height zone interaction)

Measurements on the grass included dry weight (dried at 70° Centigrade in a forced-air oven), number of stems and their height (the average of five randomly selected stems in each 0.25-square meter plot). The dried samples were chopped with a silage chopper, and subsamples were ground in a Wiley mill in preparation for nutrient analyses of the plant tissue. Determinations of the concentrations of nitrogen, phosphorus, potassium, sodium, calcium, magnesium, sulfur, iron, zinc, manganese and copper were made by the Department of Soil Science, Analytical Service Laboratory at North Carolina State University. Soil samples of the upper 15 centimeters were taken in each height zone at the time of the first plant sampling. These samples were air dried, and screened, and the following determinations were made by the Soil Testing Division of the North Carolina Department of Agriculture using their routine methods: organic matter, calcium, magnesium, phosphorus, potassium, sodium, CEC (cation exchange capacity) and soluble salts. Soil texture was determined by the hydrometer method (Day, 1956).

Regression analysis was the statistical technique used to detect relationships between nutrient levels in the soil, plant tissue, and productivity. After an attempt to use the raw data, yield and height were transformed to their logarithm (base 10) to provide a better fit for the curves, decrease random variation, and normalize the mean square error. There are 48 independent variables in the original data which consisted of the concentration of 11 different mineral nutrients in the plant tissue at each of 3 sampling times, the salinity of the soil solution at each sampling time, and 12 soil chemical and physical properties. The "best" regression model was selected using a combination of the maximum R^2 (multiple correlation coefficient) improvement procedure (Service, 1972), the stepwise regression procedure (Draper and Smith, 1966), and critical examination of the independent variables from an agronomic view. In the stepwise procedure, the single variable model which produces the highest R^2 is selected; then variables are added one by one to the model according to their significance measured by the F-test (0.1 level of significance for entry). At every stage of regression, the variables incorporated in the previous stages are reexamined for significance. A variable entered at an early stage may lose its significance because of its relationship to other variables entering the regression. The maximum R^2 improvement technique developed by J. H. Goodnight (Department of Statistics, North Carolina State University, Raleigh, North Carolina) selects the "best" one-variable model, the "best" two-variable model, etc. according to R^2.

b. Selecting the Dependent Variable. The independent variables were measurements of soil chemical and physical properties and nutrient concentrations in the plant tissue at three sampling dates (Tab. 27). Multiple regression procedures were used as variable screening devices to determine which of these independent variables were related to yield and height of *S. alterniflora*. It was necessary to select two models (one for $\log_{10}$ yield and one for $\log_{10}$ height), because the relationship between height and yield was not as close as might be expected (Fig. 55). Although the relationship between yield and height is highly significant, the R^2 is only 0.26. The R^2 was not greatly improved by transformation to logarithms. Stands are thinnest where the tallest grass occurs; consequently, shorter grass may produce higher yields where stands are thicker. An example is seen by comparing the data for yield and height from the tall height zones at Oregon Inlet and Beaufort (Tab. 28). The average height at Beaufort is much greater than at Oregon Inlet, but the yield at Oregon Inlet is greater. This is attributed to there being nearly twice as many stems per unit area at Oregon Inlet to produce the total biomass. This difference in growth habit may be related to tide range or possibly to genetic difference between the grass from different locations. Shorter grass and thick stands occur at Oregon Inlet, Hatteras Village and Ocracoke where the regular tide range is less than 30 centimeters. At Beaufort, Swansboro, and Oak Island where the tide range is about 1 meter, the grass is taller but the stands are sparse.

There is also a significant difference in the number of stems per unit area between the tall and short height zones. The stands are more dense in the short height zones, but the yields are much less than in the tall

Table 27. Variables Used in Model Building and Their Simple Correlations with Dependent Variables Height and Yield

Variables	Abbreviations	Simple Correlation Coefficient (r)	
		Yield	Height
Soil Properties (Sampled 17 to 23 June 1970)			
Organic matter	S-OM	0.07	0.04
Cation exchange capacity (meq/100 g)	S-CEC	0.09	0.15
Soluble salts (MMho)	S-SALT	-0.07	0.22
Phosphorus (ppm)	S-P	0.06	-0.09
Potassium (ppm)	S-K	-0.02	0.38*
Calcium (ppm)	S-Ca	-0.03	-0.17
Magnesium	S-Mg	-.04	0.22
Manganese (ppm)	S-Mn	-0.19	-0.08
Sodium	S-Na	0.09	0.29
Sand (%)	SAND	0.14	-0.36*
Silt (%)	SILT	-0.15	0.37*
Clay (%)	CLAY	-0.12	0.31*
Salinity of the Soil Solution (o/oo)			
17 to 23 June	AS-SAL	-0.49†	-0.05
5 to 17 August	BS-SAL	-0.23	0.01
30 September to 2 October	CS-SAL	-0.39†	0.00
Nutrient Content of the Plant Tissue			
17 to 23 June			
Nitrogen (%)	AN	0.14	0.04
Phosphorus (%)	AP	0.09	0.39†
Potassium (%)	AK	0.08	-0.08
Sodium (%)	ANa	0.16	0.52†
Calcium (%)	ACa	-0.23	-0.25
Magnesium (%)	AMg	-0.23	0.03
Sulfur (%)	AS	-0.14	-0.52†
Iron (ppm)	AFe	-0.11	0.43†
Zinc (ppm)	AZn	0.25	0.30*
Manganese (ppm)	AMn	-0.24	0.32*
Copper (ppm)	ACu	0.05	0.15

*0.01 $r \geq |0.30|$

†0.05 $r \geq |0.39|$

Table 27. Variables Used in Model Building and Their Simple Correlations with Dependent Variables Height and Yield-Continued

Variables	Abbreviations	Simple Correlation Coéfficient (r)	
		Yield	Height
Nutrient Content of the Plant Tissue			
5 to 17 August			
Nitrogen (%)	BN	0.09	-0.18
Phosphorus (%)	BP	0.23	0.09
Potassium (%)	BK	-0.03	-0.33*
Sodium (%)	BNa	-0.22	-0.08
Calcium (%)	BCa	0.08	0.09
Magnesium (%)	BMg	0.05	0.02
Sulfur (%)	BMg	-0.42†	-0.59†
Iron (ppm)	BFe	-0.11	0.43†
Zinc (ppm)	BZn	-0.13	0.01
Manganese (ppm)	BMn	-0.06	0.24
Copper (ppm)	BCu	0.22	0.16
30 September to 2 October			
Nitrogen (%)	CN	-0.14	-0.27
Phosphorus (%)	CP	-0.23	-0.04
Potassium (%)	CK	-0.32*	-0.38*
Sodium (%)	CNa	-0.18	-0.20
Calcium (%)	CCa	0.06	0.05
Magnesium (%)	CMg	0.07	-0.05
Sulfur (%)	CS	-0.32*	-0.50†
Iron (ppm)	CFe	-0.06	0.40†
Zinc (ppm)	CZn	-0.06	-0.02
Manganese (ppm)	CMn	-0.04	0.16
Copper (ppm)	CCu	-0.17	-0.15

*0.01 $r \geq |0.30|$

†0.05 $r \geq |0.39|$

height zones. Height and yield are more closely related within a given marsh or type of marsh (Williams and Murdoch, 1969). That is, at a particular location the taller grass produces higher yields. In this study, the correlation between height and yield was low enough that it seemed appropriate to create separate models for height and yield.

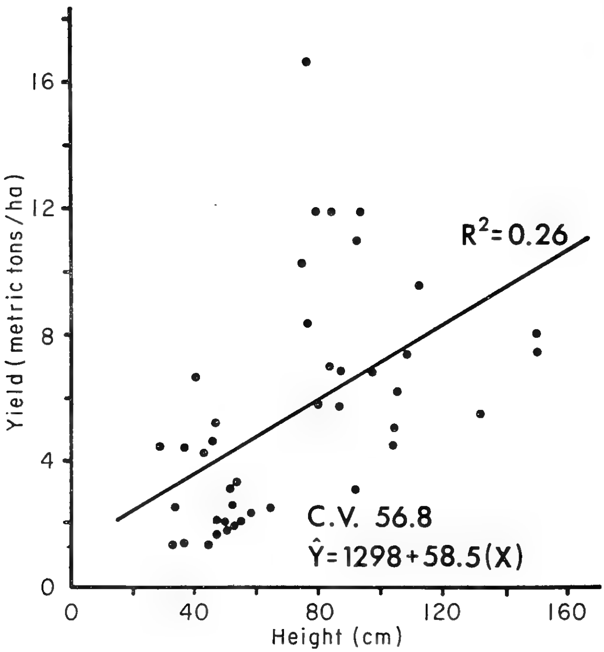

Figure 55. Relationship between height and yield of *S. alterniflora*.

Table 28. Means and Least Significant Differences for Yield, Height and Number of Stems of *S. alterniflora* Samples from the Tall and Short Height Zones of Seven Locations

Location	Yield (kg/ha)			Height (cm)			No. Stems/0.25 m^2		
	Tall*	Short	$\overline{X}$†	Tall	Short	$\overline{X}$†	Tall	Short	$\overline{X}$†
Oregon Inlet	8,253.0	2,213.0	5,233.0	87.0	49.0	68.0	68.0	90.0	79.0
Hatteras Village	12,867.0	5,213.0	9,040.0	76.0	38.0	57.0	144.0	171.0	158.0
Ocracoke	8,800.0	2,013.0	5,407.0	91.0	47.0	69.0	102.0	148.0	125.0
North River	4,200.0	1,707.0	2,953.0	100.0	34.0	67.0	30.0	59.0	44.0
Beaufort	6,973.0	2,253.0	4,613.0	144.0	58.0	101.0	35.0	46.0	40.0
Swansboro	7,800.0	4,613.0	6,207.0	83.0	42.0	62.0	62.0	131.0	96.0
Oak Island	7,893.0	2,360.0	5,127.0	105.0	37.0	79.0	37.0	61.0	49.0
$\overline{X}$†	8,112.0	2,910.0	-------	98.0	45.0	-----	68.0	100.8	-----
LSD‡ 0.05:									
Loc.		2,149.0			8.0			22.0	
Ht. zone		1,149.0			4.0			12.0	
Loc. x ht. zone		§			11.0			§	

*Height zone
†Main effects
‡Least significant difference
§Not significant

c. The Model Building Process. There were 47 independent variables in the original model. Silt was omitted since the percent sand, silt and clay always sums to 100 percent. This causes any two of these variables to correlate perfectly with the third; therefore, only two of the variables can be used in a regression equation. The number of variables in the original model was reduced with the stepwise regression procedure and the maximum R^2 improvement procedure. By regression techniques, two sets of variables most likely to be related to yield (Tab. 29) and height (Tab. 30) were selected. Each model contains 11 variables with an R^2 of 0.90. Thus, about 90 percent of the variation in yield and height is explained by the independent variables in each regression equation. The variables in these models represent a subset of variables which can be used to explain differences in yield and height; however, they may not be the most important variables affecting plant growth in the salt marsh system. Other subsets may produce similar R^2 values, but the two presented were considered the most agronomically feasible. Some models with fewer variables also produced satisfactory R^2 values (Tab. 31). Regression equations with more independent variables produced higher R^2 values, but beyond 11 variables there was very little increase in the regression sum of squares or reduction in the error mean square and the coefficient of variation.

d. Interpretation of the Yield Model. As would be expected in a natural ecological system, an examination of the correlation matrix for the 11 variables in the model revealed that there was some intercorrelation of variables. When there is a correlation between independent variables in a model, the regression coefficients (b's) may not be reliable (Draper and Smith, 1966). However, by considering the regression model in combination with the simple correlations of each independent variable with yield (Tab. 27) and the means and Least Significant Differences obtained by analysis of variance, some insight as to the effect of each variable on yield variation may be obtained. The partial sum of squares are a measure of the relative importance of the variables in a regression equation and the variables may be ranked on this basis (Tab. 29) (Draper and Smith, 1966).

The potassium content of the plant tissue at the fall sampling data (CK) is the variable which accounts for the highest amount of yield variation in the regression equation. At five of the seven locations, potassium concentrations were greater in plants taken from the short height zone (Tab. 32). The trend of lower potassium concentrations in higher yielding plants is probably an indication of a greater dilution of potassium in the plant tissue where higher yields occur.

Sodium concentration of the plant tissue at the first sampling date (ANa) is positively related to yield. Significant differences in sodium concentrations occur between height zones and locations (Tab. 32). Plants from the tall height zones had higher concentrations than those from the short height zones. The explanation for this is not apparent, particularly since higher salinities of the soil solution (AS-SAL) were clearly related to decreased yields (Tab. 27). High salinity of the soil

Table 29. Analysis of Variance Table, Regression Coefficient and Statistics of Fit for Dependent Variable Log_{10} Yield

Source	df	Sum of Squares	F-Value	R^2	C.V. (%)
Regression	11	3.3090	23.29*	0.90	3.1
Deviations	30	0.3876	-----	----	---
Total	41	3.6966			

Source	Regression Coefficient (b)	Partial Sum of Squares	F-Value
Intercept	3.7428	-----	----
CK	-0.9873	0.619	47.9*
ANa†	0.3197	0.309	23.9*
CCa†	1.3632	0.238	18.4*
AS-SAL	-0.0161	0.233	18.1*
BMn†	-0.0095	0.177	13.7*
S-Mn	-0.0046	0.174	13.4*
AP	3.4720	0.155	12.0*
AMn	-0.0116	0.145	11.3*
BP†	3.2208	0.091	7.1*
S-P	0.0005	0.085	6.6*
AS†	-0.3368	0.033	2.6‡

*0.01 level of significance
†Variables which also appear in the height equation
‡0.10 level of significance

Table 30. Analysis of Variance Table, Regression Coefficients, and Statistics of Fit for Dependent Variable Log_{10} Height

Source	df	Sum of Squares	F-Value	R^2	C.V. (%)
Regression	11	1.3301	25.54*	0.90	3.8
Deviations	30	0.1420	----	---	---
Total	41	1.4722			

Source	Regression Coefficient (b)	Partial Sum of Squares	F-Value
Intercept	1.0822	-----	----
BS	-0.3408	0.250	52.8*
ANa†	0.2177	0.110	23.3*
BMg	1.4944	0.100	21.2*
AFe	0.0001	0.093	19.7*
AMg	-1.3985	0.057	12.1*
CN	-0.3963	0.052	11.0*
AN	0.4167	0.048	10.2*
CCa†	0.6428	0.040	8.4*
BP†	1.8244	0.031	6.5‡
BMn†	-0.0028	0.019	4.0‡
AS†	-0.2340	0.018	3.7§

*0.01 level of significance
†Variables which also appear in the yield equation
‡0.05 level of significance
§0.10 level of significance

Table 31. Selected Models for Predicting Log_{10} of Yield and Height

No. in Model	Model	R^2	C.V. (%)
	Yield		
1	BS	0.26	7.2
2	BS, BMn	0.46	6.2
3	BS, BMn, AS-SAL	0.55	5.8
5	AS-SAL, BMn, BS, ANa, S-Mn	0.70	4.8
7	BMn, BS, AS-SAL, ANa, BCa, S-Mn, ACu	0.76	4.4
11	CK, ANa, CCa, AS-SAL, BMn, S-Mn, AP, AMn, BP, SP, AS	0.90	3.1
	Height		
1	BS	0.36	8.4
2	BS, ANa	0.59	6.9
3	BS, ANa, CCa	0.67	6.2
5	BS, CCa, ANa, BFe, AS-SAL	0.78	5.2
7	BS, CCa, ANa, BFe, BMn, S-Ca	0.84	4.6
11	BS, ANa, BMg, AFe, AMg, CN, AN, CCa, BP, BMn, AS	0.90	3.8

Table 32. Means and Least Significant Differences for Variables which appear in Regression Equations for Yield and Height

Location	Percent/Parts Per Thousand/Parts Per Million								
	Tall*	Short	$\overline{X}$†	Tall*	Short	$\overline{X}$†	Tall*	Short	$\overline{X}$†
	AS-SAL (°/oo)			AN (%)			AP (%)		
Oregon Inlet	15.7	27.7	21.7	1.06	1.04	1.05	0.13	0.11	0.12
Hatteras Village	16.0	18.3	17.2	0.99	1.03	1.01	0.11	0.10	0.10
Ocracoke	30.0	37.0	33.5	1.08	1.12	1.10	0.10	0.09	0.09
North River	31.7	40.3	36.0	0.83	0.76	0.80	0.10	0.11	0.11
Beaufort	35.0	36.3	35.7	1.01	1.07	1.04	0.14	0.12	0.13
Swansboro	35.0	36.3	35.7	0.98	0.98	0.09	0.12	0.12	0.11
Oak Island	30.0	25.0	27.5	0.92	0.89	0.91	0.19	0.13	0.16
$\overline{X}$†	27.6	31.6	----	0.98	0.98	----	0.12	0.11	----
LSD‡ 0.05:									
Loc.		2.6			0.08			0.01	
Ht. zone		1.4			§			0.01	
Loc. x ht. zone		3.6			§			0.02	
	ANa (%)			AS (%)			AMg (%)		
Oregon Inlet	2.00	1.83	1.92	0.31	0.46	0.38	0.23	0.30	0.27
Hatteras Village	2.53	2.13	2.33	0.54	0.60	0.57	0.25	0.25	0.25
Ocracoke	2.20	2.23	2.22	0.48	0.68	0.58	0.29	0.31	0.30
North River	2.67	2.33	2.50	0.42	0.46	0.44	0.32	0.30	0.31
Beaufort	2.97	2.60	2.78	0.30	0.53	0.41	0.28	0.27	0.27
Swansboro	2.43	2.37	2.40	0.48	0.44	0.46	0.33	0.32	0.32
Oak Island	2.73	2.53	2.63	0.25	0.36	0.31	0.33	0.28	0.31
$\overline{X}$†	2.50	2.29	----	0.40	0.51	----	0.29	0.29	----
LSD‡ 0.05:									
Loc.		0.25			0.09			0.03	
Ht. zone		0.13			0.05			§	
Loc. x ht. zone		§			§			0.04	

*Height zone †$\overline{X}$ = main effects ‡Least significant difference §Not significant

Table 32. Means and Least Significant Differences for Variables which appear in Regression Equations for Yield and Height-Continued

Location	Percent/Parts Per Thousand/Parts Per Million								
	Tall*	Short	$\overline{X}$†	Tall*	Short	$\overline{X}$†	Tall*	Short	$\overline{X}$†
	AFe (p/m)			AMn (p/m)			BP (p/m)		
Oregon Inlet	89.0	121.0	105.0	32.0	31.0	31.7	0.14	0.13	0.13
Hatteras Village	96.0	113.0	104.3	22.0	25.0	23.3	0.11	0.07	0.09
Ocracoke	460.0	131.0	295.3	29.0	40.0	34.7	0.08	0.09	0.09
North River	940.0	380.0	660.0	41.0	37.0	39.0	0.08	0.10	0.09
Beaufort	1,413.0	1,887.0	1,650.0	41.0	25.0	33.0	0.09	0.08	0.09
Swansboro	1,160.0	407.0	783.7	11.0	9.0	10.0	0.09	0.10	0.10
Oak Island	753.0	673.0	713.3	37.0	31.0	34.0	0.11	0.09	0.10
$\overline{X}$†	701.6	530.3	----	30.6	28.2	----	0.10	0.09	----
LSD‡ 0.05:									
Loc.		154.0			5.3			0.01	
Ht. zone		83.0			§			0.01	
Loc. x ht. zone		218.0			7.5			0.02	
	BMg (%)			BMn (p/m)			BS (%)		
Oregon Inlet	0.24	0.31	0.27	28.7	41.3	35.0	0.30	0.48	0.39
Hatteras Village	0.37	0.28	0.33	22.0	17.3	19.7	0.72	0.84	0.78
Ocracoke	0.36	0.37	0.37	14.7	14.0	14.3	0.60	1.44	1.02
North River	0.30	0.31	0.37	31.3	24.0	27.7	0.38	1.01	0.70
Beaufort	0.30	0.31	0.30	28.0	16.0	22.0	0.52	1.19	0.85
Swansboro	0.38	0.32	0.35	10.7	6.7	8.7	0.88	0.91	0.89
Oak Island	0.33	0.32	0.32	23.3	20.0	21.7	0.48	1.03	0.76
$\overline{X}$†	0.34	0.32	----	22.7	19.9	----	0.55	0.98	----
LSD‡ 0.05:									
Loc.		0.04			5.5			0.14	
Ht. zone		§			§			0.07	
Loc. x ht. zone		0.05			7.8			0.19	

*Height zone †$\overline{X}$ = main effects ‡Least significant difference §Not significant

Table 32. Means and Least Significant Differences for Variables which appear in Regression Equations for Yield and Height-Continued

Location	Percent/Parts Per Thousand/Parts Per Million								
	Tall*	Short	$\overline{X}$†	Tall*	Short	$\overline{X}$†	Tall*	Short	$\overline{X}$†
	CN (%)			CK (%)			CCa (%)		
Oregon Inlet	0.72	0.82	0.77	0.80	0.87	0.83	0.33	0.37	0.35
Hatteras Village	0.83	0.70	0.77	0.73	0.60	0.67	0.29	0.23	0.26
Ocracoke	0.77	0.84	0.81	0.53	1.03	0.78	0.38	0.47	0.43
North River	0.76	0.92	0.84	0.60	0.93	0.77	0.33	0.26	0.30
Beaufort	0.76	0.89	0.83	0.73	1.03	0.88	0.27	0.29	0.28
Swansboro	0.77	0.93	0.85	1.13	1.33	1.23	0.34	0.29	0.31
Oak Island	0.74	0.67	0.71	0.87	0.90	0.88	0.33	0.23	0.28
$\overline{X}$†	0.77	0.82	----	0.77	0.96	----	0.32	0.31	----
LSD‡ 0.05:									
Loc.		§			0.10			0.04	
Ht. zone		0.05			0.05			§	
Loc. x ht. zone		0.13			0.14			0.06	
	S-P (p/m)			S-Mn (p/m)					
Oregon Inlet	18.3	11.0	14.7	3.33	4.00	3.67	----	----	----
Hatteras Village	46.3	6.7	15.3	4.33	13.00	8.67	----	----	----
Ocracoke	46.3	35.7	41.0	5.00	3.00	4.00	----	----	----
North River	64.7	34.7	49.7	5.67	5.33	5.50	----	----	----
Beaufort	90.7	71.7	81.2	7.33	6.33	6.83	----	----	----
Swansboro	592.0	696.0	664.0	3.00	3.67	3.33	----	----	----
Oak Island	33.0	36.0	34.5	27.00	69.33	48.17	----	----	----
$\overline{X}$†	124.1	127.4	----	7.95	14.95	----			
LSD‡ 0.05:									
Loc.		26.2			6.48			----	
Ht. zone		§			3.47			----	
Loc. x ht. zone		37.1			9.17			----	

*Height zone †$\overline{X}$ = main effects ‡Least significant difference §Not significant

solution has often been suggested as a cause for reduced growth of *S. alterniflora* (Mooring, Cooper, and Seneca, 1971).

The reason for the appearance of calcium concentration in the plant tissue at the fall sampling date (CCa) in the regression equation cannot be readily explained. The means (Tab. 32) and the simple correlations (Tab. 27) show no obvious relationships between yield and calcium concentrations in the plant. It probably enters the regression equation because of its relationship to other variables.

Manganese concentration in the plant tissue at the first sampling date (AMn) and the second sampling date (BMn) and soil manganese (S-Mn) are all negatively related to yield. The solubility of soil manganese is increased under conditions of poor aeration. The importance of manganese in the regression equation may be an indication that the more reduced soils produce lower yields of *S. alterniflora*. The chemical environment produced by waterlogging of soils produces several toxicity problems which have been studied in relation to reduction of rice yields. Common problems are iron, manganese and sulfide toxicity and toxicity from soluble organic products (Black, 1968). However, manganese toxicity is unlikely because of the concentration in the plant tissue (Tab. 32). Concentrations of 10 times this amount were found with no apparent ill effects to plants in growth chamber studies with *S. alterniflora* in which the nutrient source was modified Hoagland's solution (Hoagland and Arnon, 1950).

Phosphorus concentrations in the plant tissue at the first sampling date (AP) and the second sampling date (BP) and soil phosphorus (S-P) are positively related to yield. The need for adequate supplies of phosphorus for plant growth is well known, and phosphorus is often a limiting factor in the growth of plants.

Sulfur at the first sampling date (AS) is negatively correlated with yield. The means in Table 32 clearly show that concentration of sulfur is much less in plants from the tall height zones. It is impossible to determine from the data if this is a dilution effect or if more sulfur is available in the short-height zone.

e. Interpretation of the Height Model. Since some variables in this model are also correlated, caution must be observed in interpreting regression coefficients.

The sulfur concentration in the plant tissue at the second sampling date (BS) accounts for the highest amount of variation in height in the regression equation. Sulfur concentration at the first sampling date (AS) also appears in the equation. The sulfur concentration at the second sampling time is the single variable with the highest R^2 in both the height and yield equations (Tab. 32). There is a clear relationship between increased sulfur concentration and decreased growth, but it is impossible to determine from the data if it is a cause and effect relationship.

Sodium concentration in the plants at the first sampling date (ANa) is positively related to height as it was to yield. The concentration is significantly higher in samples from the tall-height zone (Tab. 32).

Magnesium concentration in the plant tissue at the first (AMg) and second (BMg) sampling dates are in the regression equation. However, there is no relationship of magnesium with height apparent from the simple correlations (Tab. 27) or the means (Tab. 32). This variable may have entered the regression equation due to its relationship with other variables.

The iron concentration in the plant tissue at the first sampling date (AFe) is positively correlated with height. The difference is greater between locations than between height zones. This difference is probably because finer sediments occur at the locations where taller plants are found, and these sites would be expected to contain more iron (associated with clay) than the sandy sites.

Nitrogen concentration at the first sampling date (AN) was positively correlated with height, while nitrogen concentration at the third sampling date (CN) was negatively correlated with height. A probable explanation for this is that plant-available nitrogen is scarce in the marsh environment. At the first sampling date, high nitrogen concentrations in the plant are indicative of a high potential for growth. At maturity, the nitrogen concentration is lowest in plants which have achieved maximum growth due to dilution in the greater amount of plant tissue.

Calcium concentration at the third sampling date (CCa) probably enters the regression equation because of its relationship to other variables since no relationship with height is apparent from the means (Tab. 32) or the simple correlation with height (Tab. 27).

Phosphorus concentration at the second sampling time (BP) was positively correlated with plant height. This indicates that where greater amounts of phosphorus are available for growth, greater heights are attained.

The concentration of manganese at the second sampling time (BMn) appears to be negatively related to height according to the regression coefficient (Tab. 30). However, the simple correlation shows a positive relationship of BMn to height. This is an example of sign reversal of b-values when there is correlation between variables in the model. This positive relationship of manganese concentration to height is opposite of the relationship with yield.

f. Predicting Standing Crop of Mineral Nutrients from Dry Weight. It is of interest to know the quantities of nutrients conveyed to estuarine food chains by *S. alterniflora* (Williams and Murdoch, 1969). From the data in this study, standing crop of nutrients contained in the aboveground part of mature *S. alterniflora* stands can be calculated (Tab. 33). The data used were three 0.25-square meter samples clipped

Table 33. Simple Statistics and Regression Equations for Standing Crop of Mineral Nutrients in the Aboveground Shoots of *S. alterniflora*

Nutrient	Standing Crop of Nutrients in Aboveground Shoots (kg/ha)			S.D. of the Mean	Regression Equation*	R^2
	Minimum	Maximum	Mean†			
N	11.1	134.5	43.3	29.0	$\hat{Y} = -0.356 + 0.0079(X)$	0.97
P	1.1	14.9	5.3	3.4	$\hat{Y} = 0.408 + 0.0009(X)$	0.88
K	11.5	130.7	45.0	29.0	$\hat{Y} = 6.014 + 0.0071(X)$	0.77
S	8.4	154.4	45.2	31.6	$\hat{Y} = 3.295 + 0.0076(X)$	0.75
Ca	3.1	49.9	17.5	12.7	$\hat{Y} = 0.928 + 0.0033(X)$	0.90
Mg	5.4	91.3	24.7	18.7	$\hat{Y} = -1.392 + 0.0047(X)$	0.83
Na	24.0	431.6	117.0	80.4	$\hat{Y} = 8.068 + 0.0198(X)$	0.78
Fe	0.19	9.90	2.60	2.51	$\hat{Y} = 0.757 + 0.0003(X)$	0.23
Zn	0.01	0.34	0.06	0.06	$\hat{Y} = -0.0002 + 0.00001(X)$	0.46
Mn	0.02	0.42	0.12	0.10	$\hat{Y} = -0.0056 + 0.00002(X)$	0.64
Cu	0.003	0.07	0.07	0.01	$\hat{Y} = 0.0028 + 0.000003(X)$	0.49

*$\hat{Y}$ = Standing crop of nutrients in aboveground shoots at maturity (kg/ha);
X = dry weight of aboveground shoots at maturity (kg/ha).

†Mean of 42 samples

from the tall- and the short-height zones of seven locations when the grass was mature. Since the total amount of nutrients incorporated in the plant tissue is highly dependent on yields, the dry weight is a good predictor for standing crops of the mineral nutrients. The R^2 values for standing crop of nitrogen, phosphorus, potassium, sulfur, calcium, magnesium, and sodium are quite high (Tab. 33), and these equations should be reliable and useful for estimating the amount of nutrients contained in the mature shoots of *S. alterniflora* salt marshes. However, the fate of the nutrients as the plants decompose is more difficult to determine. Because of greater variation, the predictions for iron, zinc, manganese and copper standing crops would be less accurate.

g. Summary. The results indicate that tissue concentrations of several nutrients and several soil properties were significantly associated with variations in yield and height of *S. alterniflora*. It is important to keep in mind the purpose of multiple regression analyses. Predictive models are not necessarily functional, but can lead to insight into a problem. According to Draper and Smith (1966), construction of this type of model from problems where much intercorrelation of data exists is where regression techniques can make their greatest contribution. It provides guidelines for further investigation, pinpoints important variables, and is useful in screening variables.

Several variables selected by the multiple regression procedure in this study seem to warrant further investigation to determine their relationship to productivity of *S. alterniflora*. Such variables negatively associated with yield include salinity of the soil solution, manganese concentration in the plants and soil, and sulfur concentrations in the plants. Important variables positively associated with yield include phosphorus concentration in the plant tissue and in the soil.

The reduction of yield of *S. alterniflora* with increasing soil salinity has long been recognized. This study reconfirms this, but there was not a striking difference in salinity between height zones. This is indicated by the fact that the simple correlation of height with soil salinity is near 0 (Tab. 27).

The importance of manganese and sulfur in both the yield and height equations and iron in the height equation suggests investigation into the influence of the chemical effects of waterlogging of the marsh soil on *S. alterniflora* growth. Undoubtedly there are different degrees of aeration both within and between *Spartina* marshes which affect soil chemical properties. There is an extensive literature on waterlogged soils in connection with rice culture (Redman and Patrick, 1965; Black, 1968). Useful reviews on the chemistry of phosphorus and nitrogen in sediment-water systems are presented by Syers, Harris, and Armstrong (1973) and Keeney (1973).

The positive influence of phosphorus concentration in the plant tissue would be expected, since in most natural plant-soil systems phosphorus is second only to nitrogen as a limiting factor in plant growth. Nitrogen concentration in the plant tissue was a part of the regression equation for height but not for yield. Perhaps nitrogen does not show up in the equation because it is the limiting factor in growth. If the availability of nitrogen was limiting growth, then growth would proceed whenever nitrogen became available. Consequently, the concentration of nitrogen in the plant tissue would remain relatively constant due to the increase in biomass. It is possible that if samples had been taken earlier in the growing season, the nitrogen concentration in the plant tissue would have been a better indicator of yield potential.

It is interesting to note that there was no significant correlation of yield with the soil properties measured (Tab. 27). There are two factors which contribute to this: (1), the waterlogged conditions of these soils tend to equalize chemical differences, and (2), the methods by which these determinations were made. Standard soil testing procedures were used which probably are not suitable for these soils. An important limitation is that North Carolina soil test procedures and extracting solutions are designed for acid soils. The pH (hydrogen-ion concentration) of the soils in this study were between 7 and 8. Developing suitable techniques for studying properties of marsh soils would be an extensive project.

In conclusion, it is not within the scope of this study to explain each observed effect, but several relationships were shown to exist between variables which were measured and yield and height of *S. alterniflora*. Several of these effects may warrant further investigation.

2. Effects of Fertilizer.

In the natural marshes, fertilizer was used as an experimental tool to determine if nutrients were limiting factors in growth. Marshes at Ocracoke and Oak Island were selected because of differences in substrate, tide range, and age. On seedlings and transplants, the objective of the fertilizer studies was to determine if adding nutrients would enhance growth to produce cover more rapidly.

a. Fertilizer Experiments in Natural Stands.

(1) Ocracoke Island. Fertilizer plots were located on the north end of the island near Hatteras Inlet. This is a relatively young *S. alterniflora* marsh on a sandy substrate with little development of tidal creeks. There is some difference in growth between the different areas within the marsh, which is apparently due to environmental factors. However, zonation of height forms is not as obvious as in many older marshes. The regular lunar tide range at this location is about 30 centimeters, but the added wind effect may extend the range to 1 meter.

A fertilizer experiment of factorial design with two rates of phosphorus and four rates of nitrogen was started in 1971. It consisted of three randomized complete blocks with 1.22- by 7.62-meter plots and 1.22-meter borders between plots. Phosphorus was supplied by concentrated superphosphate at rates of 0 and 74 kilograms per hectare of phosphorus. Nitrogen rates were 0, 168, 336, and 672 kilograms per hectare of nitrogen supplied by ammonium sulfate. An ammonium form of nitrogen was thought to be more suitable to the marsh environment since it is the form of inorganic nitrogen found in greatest quantities in reduced soils. Application of nitrate-nitrogen to poorly drained soils is undesirable since it is subject to denitrification and loss to the atmosphere in gaseous forms (Keeney, 1973). The ammonium form has the advantage of being adsorbed by the exchange complex of the soil. It is also possible (considering the flooded condition in which it grows) that *S. alterniflora* is adapted to utilization of the ammonium form of nitrogen as has been reported for some other plants (Townsend, 1966; Van Den Driessche, 1971).

The fertilizer materials were applied in split applications with equal amounts on 12 May, 22 June, and 27 July 1971 by broadcasting evenly over the substrate surface. Samples were harvested 1 September 1971 by cutting a 0.61- by 1.52-meter swath from each plot with a Jari sicklebar mower. *Salicornia* spp., dead stems of *S. alterniflora* from the previous year's growth and other foreign matter, were separated from *S. alterniflora* plants. The plants were dried at 70° Centigrade and weighed, subsamples were ground in a Wiley mill, and analyzed for nutrient content by the Department of Soil Science, Analytical Service Laboratory of North Carolina State University.

The experiment was continued in 1972 with the same rates of nitrogen and phosphorus fertilizers applied in split applications on 13 April, 20 June, and 19 July 1972. The plots were clipped and raked in early spring in 1972 to facilitate harvesting and ensure that all plant material harvested in the fall was produced in that growing season. Samples were harvested 11 September by clipping a 0.61- by 3.96-meter swath from each plot. The plant samples were dried and processed in the manner previously described. Roots and rhizomes were also sampled in 1972 by taking five cores 8.5 centimeters in diameter and 30 centimeters deep from each plot. In the laboratory the cores were divided into 0 to 10- and 10 to 30-centimeter layers and washed with tap water to remove the soil material. Ten core samples were selected at random and roots were separated from rhizomes to determine the relative proportions of each. The root and rhizome samples were dried at 70° Centigrade. Combined root and rhizome samples were processed and analyzed in the same manner as the shoots.

The experiment was continued in 1973 in the same manner as in 1972, except roots and rhizomes were not separated.

The results of the nitrogen-phosphorus factorial experiment at Ocracoke indicate that, although additions of nitrogen alone can increase yields significantly, the availability of phosphorus quickly becomes limiting when nitrogen rates are increased (Fig. 56). Yields at the end of the first growing season were increased only slightly by the addition of nitrogen without phosphorus. The only statistically significant (0.05 level) difference was between the yield of the check plots and those receiving 672 kilograms per hectare of nitrogen. However, when phosphorus was applied at the rate of 74 kilograms per hectare, yield was markedly increased by additions of nitrogen up to 336 kilograms per hectare. The yield produced by 672 kilograms per hectare of nitrogen was not significantly greater than that where 336 kilograms per hectare were applied during the first growing season.

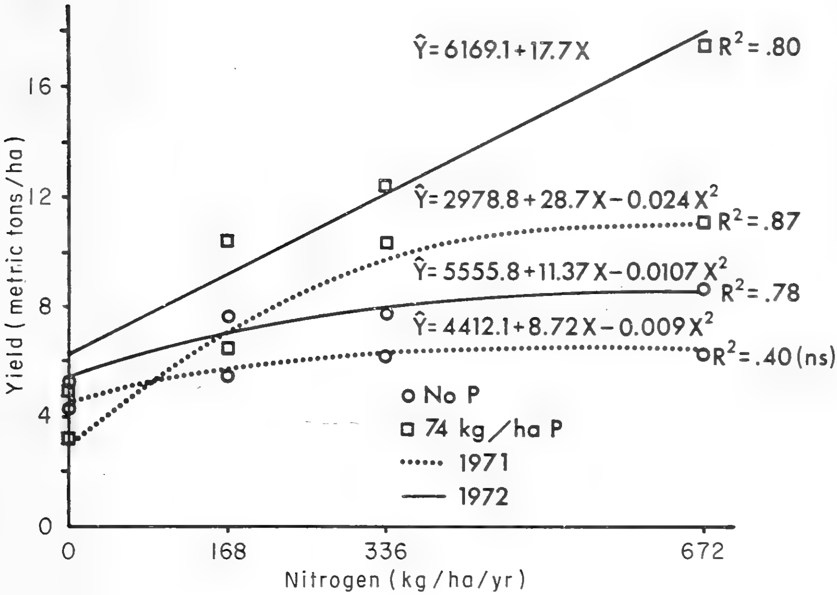

Figure 56. Effect of nitrogen and phosphorus fertilizers on yields during two successive growing seasons.

During the second growing season, higher yields and a greater response to fertilization was attained (Figs. 56 and 57). When phosphorus was supplied, the rate of yield increase did not level off beyond 336 kilograms per hectare of nitrogen as in the first year, but was linear over the range of nitrogen rates applied. There was also an increase in the difference between yields of no phosphorus and phosphorus treatments, indicating phosphorus became severely limiting during the second year as yields increased.

Figure 57. A comparison of unfertilized and fertilized plots in a natural marsh at Ocracoke Island, 11 September 1972. The fertilized plot (right) received 672 kilograms per hectare per year of nitrogen and 74 kilograms per hectare per year of phosphorus for 2 years.

Nitrogen content of the plant tissue was closely related to the rate of nitrogen applied as fertilizer (Fig. 58). During both growing seasons the R^2 (multiple correlation coefficient, a measure of the percentage variation in the dependent variable which is explained by independent variables in the equation), values were higher where no phosphorus was applied, indicating that a greater proportion of the variation in nitrogen content is accounted for by nitrogen rate when nitrogen alone is applied. Where phosphorus was applied, both the R^2 and the actual concentration of nitrogen in the tissue decreased. This decrease was probably due to dilution of nitrogen in a greater amount of dry matter as yield increased when the phosphorus became adequate.

The apparent recovery of fertilizer-nitrogen by the aboveground part of the grass and the roots and rhizomes may be calculated by subtracting the uptake of the check plots from that of the treated plots. The calculations reveal a surprisingly high recovery of nitrogen considering the flooding which occurs (Tab. 34).

Table 34. Apparent Recovery of Fertilizer Nitrogen in the Shoots at Harvest

N Rate	Apparent Recovery (Percent of Total N Applied)							
	1971		1972					
kg/ha	0*	74	0*			74		
	Shoots		Shoots	Roots and Rhizomes	Total	Shoots	Roots and Rhizomes	Total
0	----	----	----	----	----	----	----	----
168	15.2	24.3	20.2	33.3	53.5	30.3	31.5	61.8
336	12.2	33.0	11.9	22.9	34.8	28.0	16.7	44.7
672	9.6	19.9	9.7	14.7	24.4	26.3	16.7	43.0

*Rate of P (kg/ha)

Concentration of phosphorus in the plant tissue was not significantly affected by nitrogen rate; however, the increase in phosphorus concentration due to phosphorus fertilization was highly significant (0.01 level). In 1971 the mean concentration of phosphorus in the shoots was increased from 0.084 to 0.150 percent, where 74 kilograms per hectare of phosphorus were applied. In 1972 there was a similar increase due to phosphorus fertilization from 0.087 to 0.147 percent in the shoots, and concentration in the roots increased from 0.052 to 0.091 percent. The amount of fertilizer-phosphorus recovered by the shoots for treatments receiving the maximum rate of nitrogen was 15.0 and 26.1 percent of that applied during 1971 and 1972, respectively. Apparent recovery of phosphorus by the roots in 1972 was 12.4 percent. The calculations of recovery of both nitrogen and phosphorus in 1972 may include some carryover from 1971 through storage in the roots and rhizomes or residual in the soil. It is more likely that phosphorus would be retained by the soil than nitrogen.

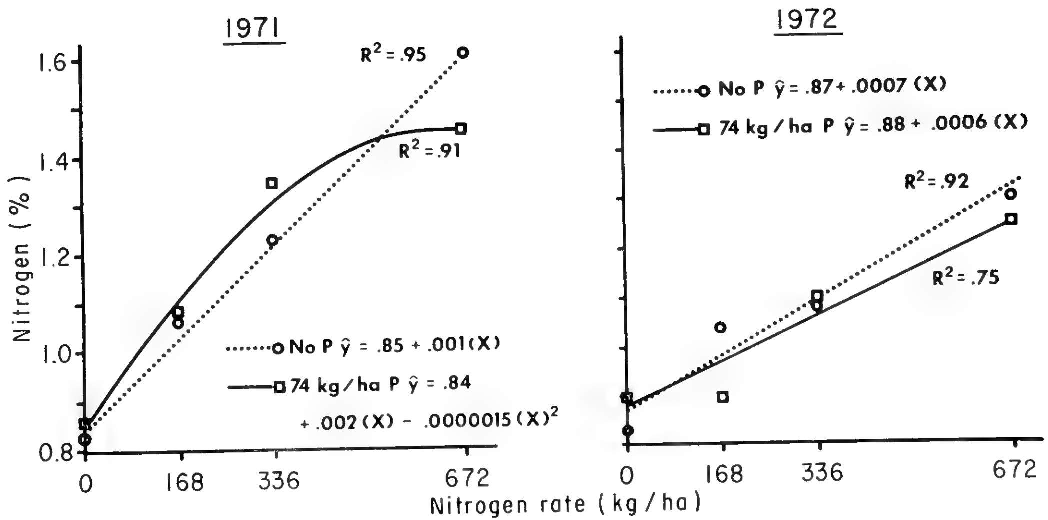

Figure 58. The relationship between nitrogen fertilizer applied and nitrogen content of plant tissue at harvest.

Analyses for other mineral nutrients included potassium, calcium, magnesium, sulfur, iron, and sodium in both 1971 and 1972. An analysis for manganese was included in 1972. Regression analysis was used to determine if there were significant linear or quadratic relationships between the nutrient concentrations in plant tissue and the nitrogen rate. Of the nutrients checked in 1971, only potassium was found to be significantly related to nitrogen rate (Tab. 35) and this was true only when phosphorus was applied. In 1972, when no phosphorus was applied, phosphorus, calcium, and manganese concentrations were significantly affected by nitrogen rate. Calcium and manganese concentrations increased as nitrogen rate increased, while phosphorus concentration decreased as nitrogen rate increased. The decrease in phosphorus concentration indicates that there is a limited amount of phosphorus available and the amount in the plant tissue is diluted as growth is increased due to nitrogen fertilization. Where phosphorus was applied, only iron and manganese concentration was significantly affect by nitrogen rate. Manganese increased and iron decreased as nitrogen rate was increased.

Table 35. The Relationship of Nutrient Concentration in the Plant Tissue to Nitrogen Rate*

Nutrient	Year	P Rate (kg/ha)	R^2	Regression Equation
K	1971	74	0.59†	$\hat{Y} = 0.987 + 0.0033(X)$
P	1972	0	0.68‡	$\hat{Y} = 0.09 - 0.00007(X) + 0.00000007(X)^2$
Ca	1972	0	0.61‡	$\hat{Y} = 0.33 + 0.00036(X) - 0.00000039(X)^2$
Mn	1972	0	0.62†	$\hat{Y} = 15.75 + 0.0092(X)$
Fe	1972	74	0.59†	$\hat{Y} = 320.0 - 0.219(X)$
Mn	1972	74	0.57†	$\hat{Y} = 18.8 + 0.117(X)$

*X = Rate of nitrogen fertilizer (kg/ha)
†Significant at the 0.05 level
‡Significant at the 0.01 level

Total uptake of mineral nutrients increased as nitrogen rate was increased (Figs. 59 and 60). This was due mainly to an increase in yield in response to nitrogen and phosphorus fertilization, producing more plant material in which nutrients in adequate supply are incorporated. The standing crop of these nutrients is controlled by yield which is in turn limited by availability of nitrogen and phosphorus to the marsh plants. The amount of nitrogen and phosphorus available is the limiting factor in the total amount of nutrients exported from the marsh in the dead plant material which contribute to the nutrient cycle of the adjacent estuary.

An obvious feature of the data for uptake of mineral nutrients is the large difference in sodium uptake between 1971 and 1972. This was probably due to periods of high salt concentration in the substrate in 1972. The level of sodium in the substrate varies with rainfall and frequency of flooding. At Ocracoke, southwest winds during summer often prevent

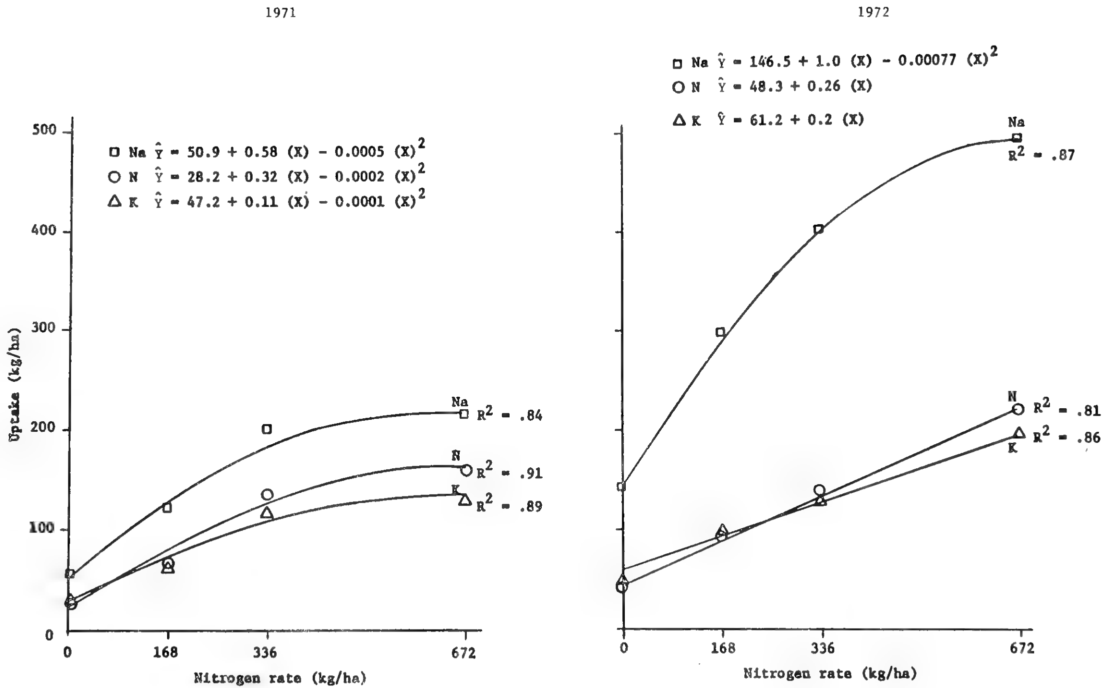

Figure 59. The relationship of nitrogen rate to total uptake of nitrogen, potassium, and sodium. Phosphorus was supplied at the rate of 74 kilograms per hectare.

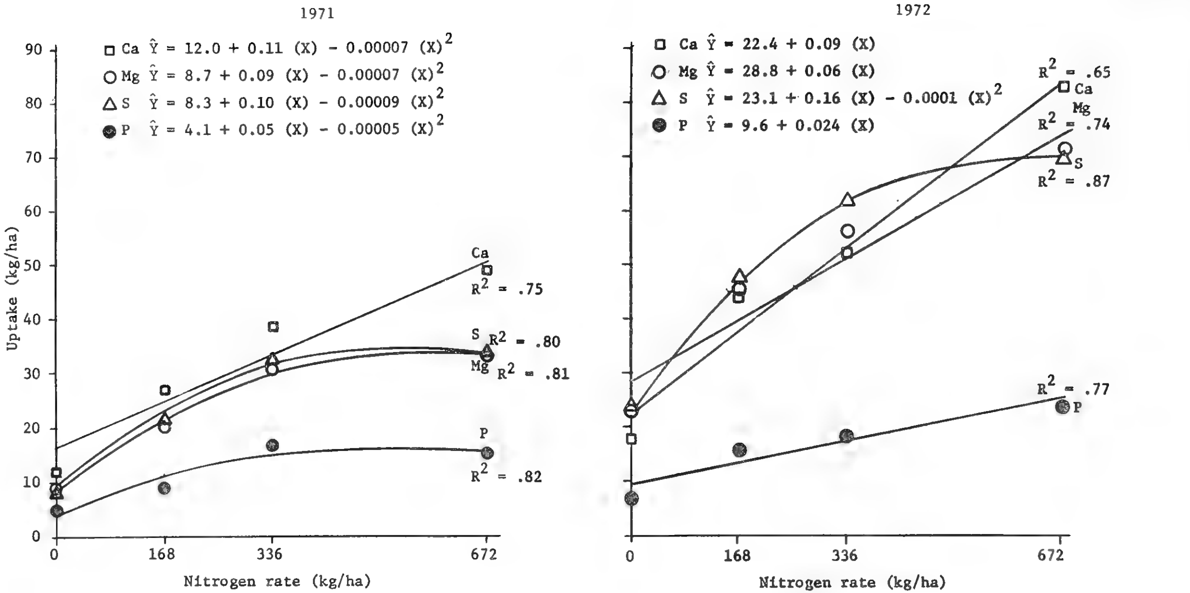

Figure 60. The relationship of nitrogen rate to total uptake of phosphorus, calcium, sulfur, and magnesium. Phosphorus was supplied at the rate of 74 kilograms per hectare.

regular flooding of the marsh for a week or more causing an increase in the salinity of the soil solution as evaporation proceeds. Measurements of salinity of the soil solution were made only at harvest time each year. The salinity was 36 parts per thousand on 2 September 1971 and 30 to 34 parts per thousand on 11 September 1972. Although no data are available, it was suspected that there were periods of salt buildup earlier in the 1972 growing season.

The standing crop of roots and rhizomes in the upper 30 centimeters was increased significantly by nitrogen fertilization in 1972 (Tab. 36). There was no response to nitrogen rates above 168 kilograms per hectare, indicating that this rate of nitrogen was adequate for maximum growth of roots and rhizomes. When root and rhizome weights are broken down from 0 to 10- and 10 to 30-centimeter layers, a variable response to fertilization is noted. In the 0 to 10-centimeter layer there was a significant response to nitrogen and no response to phosphorus similar to the case when the total weight of the upper 30 centimeters is considered. However, in the 10-to 30-centimeter layer there was a significant response to phosphorus but not to nitrogen. The overall means of 120 core samples show that 75 percent of the roots and rhizomes are in the 0-to 10-centimeter layer and only 25 percent in the 10 to 30-centimeter layer. From field observations, almost all the roots and rhizomes were contained in the upper 30 centimeters and any below this depth would be an insignificant part of the total weight. Results of separating roots and rhizomes from 10 randomly selected core samples indicated that in the 0 to 10-centimeter layer, the percentages by weight were 49.6 percent roots and 50.4 percent rhizomes. In the 10 to 30-centimeter layer, only 34.6 percent of the dry weight was roots with rhizomes accounting for 65.4 percent. Since there was a higher proportion of rhizomes in the 10 to 30-centimeter layer, it is possible that the response to phosphorus in this layer is due to an increase in rhizome growth -- that is, the response to phosphorus is relatively greater for rhizomes than for roots. The increase in dry weight of the 0 to 10-centimeter layer was probably due to an increase of root growth in response to nitrogen fertilization.

The total dry weight of roots and rhizomes in the upper 30 centimeters exceeds the dry weight of shoots (Fig. 61). Since the response of roots and rhizomes to fertilization is less than the response of shoots, the ratio of shoots to roots and rhizomes increases with nitrogen rate from 0.29 for the check to 0.75 at the highest rate of nitrogen.

The same fertilization treatments were continued on the plots during the 1973 growing season. The yield of aboveground growth (Tab. 37) was increased significantly by nitrogen applications in combination with phosphorus; however, yields were not as great as in 1972. Other factors such as rainfall and wind direction (which controls tidal flooding at this location) cause year-to-year variations in shoot yields.

Underground growth also showed a significant increase due to fertilization, particularly to phosphorus (Tab. 38).

Table 36. Effect of Nitrogen and Phosphorus on Belowground Standing Crop (1972)

N Rate (kg/ha)	Belowground Dry Weight (kg/ha) — P Rate (kg/ha)								
	0 to 10 cm Depth			10 to 30 cm Depth			0 to 30 cm Depth		
	0	74	$\bar{X}$*	0	74	$\bar{X}$*	0	74	$\bar{X}$*
0	13,714.0	11,900.0	12,807.0	4,170.0	5,525.0	4,847.0	17,884.0	17,425.0	17,654.0
168	17,308.0	16,333.0	16,820.0	4,276.0	6,136.0	5,206.0	21,584.0	22,469.0	22,026.0
336	16,162.0	16,300.0	16,231.0	5,267.0	4,972.0	5,119.0	21,429.0	21,272.0	21,350.0
672	15,702.0	16,864.0	16,283.0	4,537.0	6,613.0	5,575.0	20,239.0	23,477.0	21,858.0
$\bar{X}$*	15,721.0	15,349.0	--------	4,563.0	5,812.0	-------	20,284.0	21,161.0	--------
LSD† 0.05:									
N	2,295.0			‡			2,763.0		
P	‡			695.0			‡		
N x P	‡			‡			‡		
CV§ %	28.8			37.0			26.0		

*$\bar{X}$ = main effects
†Least significant difference
‡Not significant
§Coefficient of variation

Table 37. Effect of Nitrogen and Phosphorus Aboveground Growth at Ocracoke (1973)

Aerial Dry Weight (kg/ha)			
N Rate (kg/ha)	P Rate (kg/ha)		
	0	74	$\overline{X}$*
0	3,032.0	2,434.0	2,733.0
168	3,584.0	5,472.0	4,528.0
336	3,026.0	6,704.0	4,865.0
672	3,628.0	9,544.0	6,586.0
$\overline{X}$*	3,317.0	6,038.0	-------
LSD†:			
N 0.01	407.0		
0.05	293.0		
P 0.01	288.0		
0.05	207.0		
N x P 0.01	575.0		
0.05	414.0		
CV%‡	20.9		

*$\overline{X}$ = main effects
†Least significant difference
‡Coefficient of variation

Table 38. Effect of Nitrogen and Phosphorus on Belowground Standing Crop (1973)

N Rate (kg/ha)	Belowground Dry Weight (kg/ha) P Rate (kg/ha)								
	0 to 10 cm Depth			10 to 30 cm Depth			0 to 30 cm Depth		
	0	74	$\bar{X}$*	0	74	$\bar{X}$*	0	74	$\bar{X}$*
0	16,800.0	15,758.0	17,329.0	5,463.0	6,520.0	5,992.0	22,263.0	24,378.0	23,321.0
168	16,409.0	20,207.0	18,308.0	5,013.0	6,050.0	5,532.0	21,421.0	26,258.0	23,840.0
336	19,777.0	23,575.0	21,676.0	5,933.0	7,656.0	6,795.0	25,709.0	31,231.0	28,470.0
672	15,312.0	22,459.0	18,886.0	3,466.0	8,576.0	6,021.0	18,778.0	31,035.0	24,907.0
$\bar{X}$*	17,074.0	21,024.0	--------	4,969.0	7,201.0	-------	22,043.0	28,226.0	--------
LSD†:									
N 0.01	‡			‡			‡		
0.05	2,874			‡			3,700.0		
P 0.01	2,711.0			1,973.0			3,490.0		
0.05	2,032.0			1,479.0			2,616.0		
N x P 0.01	‡			‡			‡		
0.05	‡			‡			5,232.0		
CV§ %	22.5			51.3			22.0		

*$\bar{X}$ = main effects
†Least significant difference
‡Not significant
§Coefficient of variation

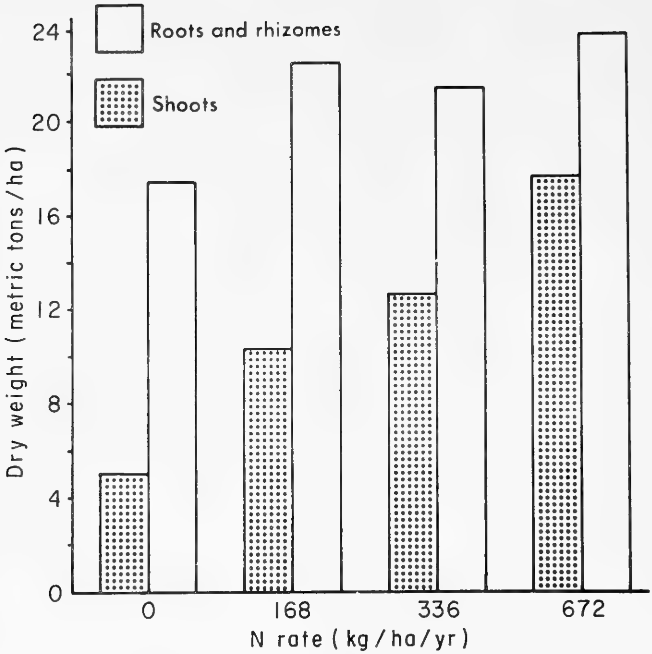

Figure 61. The effect of nitrogen fertilization on the aboveground and belowground standing crop of *S. alterniflora*.

(2) Oak Island. In 1971 at Oak Island an experiment was begun to test the theory of Adams (1963) that iron deficiency may be the cause of the chlorotic condition often observed in stands of *S. alterniflora* and to evaluate the effect of nitrogen fertilization. The experiment consisted of three randomized complete blocks with plots that were 1.22 by 15.2 meters with 1.22-meter borders between plots lying perpendicular to a tidal creek so that each plot contained the tall and short forms of *S. alterniflora*. Iron and nitrogen fertilizers were applied in split applications 18 May, 30 June and 3 August 1971 (Tab. 39). Ammonium sulphate was the nitrogen source. The iron sources were: (1) a commercial iron chelate applied as a spray to the plants, (2) iron chelate applied in the dry form to the sediment surface and (3) ferrous sulphate applied as a spray. Samples were harvested 4 October 1971 by clipping a 0.25-square meter area from the short *S. alterniflora* and a 0.25-square meter area from the tall *S. alterniflora* in each plot. The samples were washed in tap water and distilled water to remove mud from the leaves and stalks, dried at 70° Centigrade, weighed and ground in preparation for nutrient analyses of the plant tissue.

Table 39. The Effect of Nitrogen and Iron Applications on *S. alterniflora* at Oak Island

N (kg/ha)	Fe*	Aerial Dry Wt. (kg/ha)	Height (cm)	Number Stems/ m^2	Percent							Fe ppm
					N	P	K	Ca	Mg	S	Na	
Short Height Form												
0	Chelate spray	3,040.0	76.7	350.8	0.76	0.086	0.80	0.20	0.40	0.70	2.02	1,230.0
336	Chelate spray	7,587.0	103.0	478.8	0.98	0.090	0.90	0.25	0.46	0.68	2.05	969.0
672	Chelate spray	5,867.0	106.3	614.8	1.10	0.093	1.00	0.24	0.46	0.84	2.20	1,156.0
336	0	7,320.0	103.3	533.6	0.90	0.083	0.83	0.23	0.42	0.72	2.02	831.0
336	Chelate dry	6,280.0	104.3	480.0	0.90	0.076	0.83	0.30	0.45	0.78	2.00	1,018.0
336	$FeSO_4$ spray	7,227.0	92.7	616.0	0.99	0.093	0.97	0.29	0.46	0.68	2.06	1,006.0
CV† (%)		20.87	15.40	25.11	10.10	10.18	10.61	9.48	8.09	8.46	11.29	36.17
LSD‡ 0.05		2,361.3	§	§	0.17	§	§	0.04	§	§	§	§
Tall Height Form ‖												
Overall means		10,780.0	157.4	101.6	0.80	0.102	0.83	0.24	0.37	0.44	2.13	446.0

*Iron rate = 16.8 kg/ha Fe
†Coefficient of variation
‡Least significant difference
§Not significant
‖Only overall means are presented since there were no significant differences due to treatment

In 1972, an experiment was established adjacent to another tidal creek in the same marsh to evaluate the effect of phosphorus fertilization. The experiment was a factorial design with two levels of phosphorus and four levels of nitrogen identical to the factorial experiment previously described for Ocracoke. Three randomized complete blocks were established with the individual plots perpendicular to a creek so that each plot contained the tall and short forms of grass. Plots were 1.22 by 15.2 meters with a 1.22-meters border between each plot. The fertilizer was applied in split applications with equal amounts applied on 1 May, 22 June and 26 July 1972. Samples were harvested 20 September 1972 by clipping a 1-square meter sample from the short height zone of each plot and a 0.25-square meter sample from the tall height zone of each plot. The samples were dried in a forced-air oven at 70° Centigrade and weighed.

The marsh at Oak Island differs from that at Ocracoke in several ways which would cause the response to fertilizer applications to be different. The most important difference is that the sediments which form the substrate of the marshes are different. At Ocracoke the substrate is almost pure sand, while at Oak Island it is much finer-textured (silt loam with 10 percent organic matter) and would be expected to be inherently more fertile. Another difference is that the Oak Island marsh is older with well-developed tidal creeks and distinct zonation of height forms. A third difference is the greater tide range at Oak Island (1.3 meters) which floods the marsh twice a day and is seldom affected appreciably by the wind.

The experimental fertilizer plots at Oak Island contained the tall and short forms of *S. alterniflora*. Neither growth, chemical composition of the plant tissue or general appearance of the tall form, was significantly affected by additions of iron or nitrogen (Tab. 39). This is probably because the creek bank area is adequately supplied with nutrients from fresh sediments deposited by the overflowing creeks at floodtide. Levees which form are evidence of greater deposition along creek banks. The meandering of creeks may expose fresh sediments which have not been exploited by plant roots. If nutrients are taken up directly from the tidal waters, then the tall height zone area is in a favorable position for more frequent and longer inundation. However, it is also possible that fertilizer applied to the sediments in the tall zone of *S. alterniflora* is dissolved in the estuarine water on floodtide rather than being taken up by the plants. Fewer fine roots are near the sediment surface in the tall *S. alterniflora* than in the short; consequently, uptake of nutrients applied to the surface might be less. Calculation of the apparent recovery of fertilizer-nitrogen for plants from the tall height zone which received 336 kilograms per hectare of nitrogen indicates that only 3.2 percent of that applied was recovered in the grass shoots.

Growth in the zone of short *S. alterniflora* was enhanced by the addition of nitrogen but was not affected by the iron treatments (Tab. 39). The characteristic chlorotic appearance of short *S. alterniflora* was unaffected by iron, but nitrogen produced a greener appearance. Plots which received applications of nitrogen fertilizer yielded about twice as much dry matter as the check plots. The nitrogen content of the plant tissue also increased as the amount of nitrogen fertilizer was increased, indicating that uptake was more efficient than in the tall height zone. The average recovery of nitrogen by the grass shoots in plots receiving 336 kilograms per hectare of nitrogen was 13 percent. This more efficient recovery of fertilizer nitrogen is probably due to the greater amount of roots at the soil surface in the short height zone and that loss due to flooding is probably less than in the tall height zone. Another possible difference is that the nitrogen supply in the tall height zone is adequate and less of the fertilizer-nitrogen is used, while nitrogen is in short supply in the short height zone. The efficiency of uptake of nitrogen is less than at Ocracoke even in the short height zone. The less frequent flooding at Ocracoke may allow the fertilizer to remain in place and available for uptake for a longer period of time.

A fertilizer experiment was begun at Oak Island in 1972 to determine if phosphorus was a limiting factor in productivity at this location as for Ocracoke. At the end of the first growing season there was no significant yield increase due to phosphorus fertilization (Tab. 40). The highest rate of nitrogen nearly doubled the yield of short *S. alterniflora* compared to the check, and plots which received nitrogen were much greener, but again the tall did not respond to fertilization. The lack of response to phosphorus was expected due to the nature of the substrate at Oak Island. The fine-textured reduced sediments have a greater potential for supplying phosphorus than the sand at Ocracoke. However, the experiment was continued during the 1973 growing season and the response to phosphorus and nitrogen was significant (Tab. 41). Apparently, as yields increase due to fertilization the supply of phosphorus in the soil becomes limiting.

b. The Effect of Fertilizer on Seedlings and Transplants. To determine if the addition of fertilizer would enhance propagation of *S. alterniflora*, fertilizer plots were established on seedlings growing on dredged material at Beaufort. Seeds were planted on 4 April 1972 in the intertidal zone of a pile of sandy dredge spoil, which had been in place for about 1 year. The seed were hand broadcast and covered by six sweeps mounted on the tool bar of a tractor, followed by a section harrow (Fig. 22). After the seedlings were established, a randomized complete block fertilizer experiment with three treatments (nitrogen, nitrogen-phosphorus, check) and three replications was superimposed. Rates were 224 kilograms per hectare of nitrogen (ammonium sulphate) and 49 kilograms per hectare of phosphorus (concentrated superphosphate) with half applied 26 June and half 26 July 1972. Plots were 1.22 meters by 7.62 meters with 1.22-meter borders. Samples were harvested 5 October 1972 by cutting a swath 0.6-meter wide by 6-meters long from each plot at ground level with a Jari mower. The samples were dried at 70° Centigrade and weighed.

The dry weight of seedlings at the end of one growing season was increased from 3,470 kilograms per hectare to 9,340 kilograms per hectare by the addition of nitrogen. Where nitrogen and phosphorus were applied, the dry weight was increased to 10,800 kilograms per hectare (Tab. 42). These results indicate that at this location fertilizer was beneficial in

Table 40. Effect of Nitrogen and Phosphorus on Short and Tall Height Forms of *S. alterniflora* at Oak Island, 1972

N Rate (kg/ha)	Aerial Dry Weight (kg/ha) — P Rate (kg/ha)					
	Short*			Tall		
	0	74	$\overline{X}$†	0	74	$\overline{X}$†
0	5,100.0	6,503.0	5,802.0	16,713.0	17,113.0	16,913.0
168	6,653.0	9,653.0	8,153.0	15,547.0	18,623.0	17.085.0
336	8,370.0	7,337.0	7,853.0	25,553.0	22,777.0	24,165.0
672	11,053.0	9,653.0	10,353.0	18,967.0	16,840.0	17,903.0
$\overline{X}$*	7,794.0	8,287.0	--------	19,195.0	18,838.0	--------
LSD:‡						
N 0.05		2,884.0			§	
P 0.05		§			§	
N x P 0.05		§			§	
CV% ‖		29.0			30.1	

*Height zone
†$\overline{X}$ = main effects
‡Least significant difference
§Not significant
‖Coefficient of variation

Table 41. Effect of Nitrogen and Phosphorus Fertilizers on Short *S. alterniflora* at Oak Island (1973)

N Rate (kg/ha)	P Rate (kg/ha)														
	Aerial Dry Weight (kg/ha)			Flowers /m^2			No. Culms/m^2			Height (cm)			Basal Area (cm^2/m^2)		
	0	74	$\overline{X}$*	0	74	$\overline{X}$*	0	74	$\overline{X}$*	0	74	$\overline{X}$*	0	74	$\overline{X}$*
0	3,253.0	4,933.0	4,093.0	2.7	8.0	5.3	418.0	464.0	441.0	55.0	58.0	57.0	142.0	145.0	144.0
168	6,226.0	8,840.0	7,533.0	2.7	18.7	10.7	490.0	526.0	508.0	51.0	81.0	66.0	197.0	328.0	262.0
336	9,413.0	16,493.0	12,953.0	6.7	17.3	12.0	605.0	644.0	624.0	83.0	98.0	90.0	446.0	496.0	471.0
672	11,813.0	17,573.0	14,693.0	4.0	14.7	9.3	560.0	544.0	452.0	88.0	104.0	96.0	338.0	435.0	386.0
$\overline{X}$*	7,677.0	11,960.0	--------	4.0	14.7	----	518.0	544.0	-----	69.0	85.0	----	281.0	351.0	-----
LSD :†															
N 0.01		6,902.0			‡			‡			30.0			182.0	
0.05		4,973.0			‡			118.0			21.0			131.0	
P 0.01		‡			‡			‡			‡			‡	
0.05		3,516.0			9.9			‡			15.0			‡	
CV% §		40.9			122.3			18.0			22.2			33.6	

*$\overline{X}$ = main effects

†Least significant difference
(There were no significant N x P interaction)

‡Not significant

§Coefficent of variation

producing increases in growth; consequently there was an increase in the cover produced by seedlings on dredged material during the first growing season.

Table 42. The Standing Crop of Seedlings at Beaufort to which Nitrogen and Phosphorus Fertilizers were Applied*

Replicate	Aerial Dry Weight (kg/ha)		
	Fertilizer Treatment†		
	Check	N	NP
1	4,450	11,100	14,180
2	2,860	9,430	10,200
3	3,100	7,480	8,010
$\bar{X}$‡	3,470	9,340	10,800

*Plots seeded 4 April 1972; harvested 5 October 1972.

†N rate = 224 kg/ha N; P rate - 49 kg/ha P; half the fertilizer was applied on 26 June 1972 and half on 26 July 1972.

‡$\bar{X}$ = main effects

A fertilizer experiment on seedlings was begun on an island near Drum Inlet in 1973. The fertilizer was applied in a randomized complete block design with three blocks and was superimposed on a part of the large-scale seeding experiment planted 18 April 1973. The fertilizer treatments were two rates of phosphorus as concentrated superphosphate (0 and 49 kilograms per hectare of phosphorus) and four rates of nitrogen as ammonium sulfate (0, 112, 224, 448 kilograms per hectare of nitrogen) in a factorial arrangement. Fertilizer was applied in split applications 11 July and 16 August. Plots were 1.22 meters by 7.62 meters with 1.22-meter borders between plots. Samples were harvested 8 November by clipping 1 square meter from each plot. Roots were also sampled by taking two cores 8.5 centimeters in diameter and 30-centimeters deep from each square meter which was clipped.

Growth measurements indicate significant responses to both nitrogen and phosphorus fertilization (Tab. 43). Unlike fertilizer experiments in the natural marsh at Ocracoke, the nitrogen-phosphorus interaction was not statistically significant. The dry weights of shoots and roots were doubled by both additions of nitrogen and additions of phosphorus.

In another experiment, fertilizer was applied before planting at Drum Inlet. The fertilizer treatments were a 2 by 4 factorial design (nitrogen = 0, 56, 112, 224 kilograms per hectare and phosphorus = 0 and 25 kilograms per hectare). Plots consisted of three rows 0.91 meters

Table 43. Effect of Nitrogen and Phosphorus Fertilizers on Growth of Seedlings on South Island near Drum Inlet*

N Rate (kg/ha)	P Rate (kg/ha)								
	0	49	$\bar{X}$†	0	49	$\bar{X}$†	0	49	$\bar{X}$†
	No. Flowers/m^2			No. Culms/m^2			Height (cm)		
0	10.7	10.3	10.5	142.0	144.0	143.0	24.0	29.0	26.0
112	4.7	10.0	7.3	144.0	137.0	141.0	23.0	30.0	27.0
224	10.3	21.3	15.8	171.0	285.0	228.0	30.0	35.0	33.0
448	5.7	17.0	11.3	109.0	219.0	164.0	23.0	31.0	27.0
$\bar{X}$†	7.8	14.8	----	141.0	196.0	-----	25.0	31.0	----
LSD:‡									
N 0.01		§			§			§	
0.05		§			67.0			§	
P 0.01		7.1			§			§	
0.05		5.1			47.0			5.0	
CV% ‖		52.1			32.0			21.2	
	Basal Area (cm^2/m^2)			Aerial Dry Wt. (kg/ha)			Belowground Dry Wt. (kg/ha)		
0	8.6	9.1	8.8	66.0	86.0	76.0	529.0	1,615.0	1,072.0
112	8.6	12.2	10.4	70.0	132.0	101.0	705.0	1,586.0	1,145.0
224	18.8	23.9	21.3	129.0	247.0	188.0	1,469.0	2,056.0	1,762.0
448	6.0	20.5	13.2	53.0	170.0	111.0	1,204.0	2,937.0	2,071.0
$\bar{X}$†	10.5	16.4	----	80.0	158.0	-----	977.0	2,049.0	-------
LSD: ‡									
N 0.01		§			§			§	
0.05		§			69.0			790.0	
P 0.01		§			68.0			757.0	
0.05		§			49.0			559.0	

*Seeded 18 April 1973; sampled 8 November 1973

†$\bar{X}$ = main effects

‡Least significant difference
(There were no significant N x P interactions)

§Not significant

‖Coefficient of variation

apart and approximately 18 meters long in a randomized complete block design with three replications. The rows were perpendicular to a drainage creek and extended over the elevational range of *S. alterniflora* at this location. The fertilizer was applied in furrows under each row which was opened by sweeps on a tractor the day before transplanting. The transplanter closed the furrows and covered the fertilizer. The dredge spoil, which is almost pure sand, was deposited during November 1971. However, transplanting was delayed until 28 June 1972 (later than ideal) because extensive grading was necessary to prepare a suitable area for the experiment within the elevational range of *S. alterniflora* which is only about 30 centimeters at this location (the elevational range of the grass is approximately equal to the tide range at this location). Plant samples were taken 4 October 1972 by clipping one plant from each row. Data recorded included dry weight, number of flowers, number of center culms and number of rhizome culms per plant.

Fertilization enhanced first-year growth considerably (Tab. 44). There were significant (0.05 level) increases in dry weight and number of flowers and a highly significant (0.01 level) increase in the number of center culms due to nitrogen fertilization. The number of rhizome culms was not affected by nitrogen. There were highly significant increases in dry weight, number of flowers and number of center culms due to phosphorus fertilization. There was a significant increase in number of rhizome culms due to phosphorus. Unlike results from experiments in the natural marsh, there was no nitrogen-phosphorus interaction. The Drum Inlet site was freshly deposited dredged material of almost pure sand. The response of the transplants to fertilizer is evidence of the low nitrogen and phosphorus content of this material. It is likely that dredged material higher in silt, clay and organic matter would provide adequate nitrogen and phosphorus for maximum growth of transplants during the first growing season.

c. Summary. Increased growth of *S. alterniflora* in response to applications of fertilizer indicates that the productivity of some salt marshes is limited by the supply of nutrients. The standing crop of aboveground shoots of salt marsh growing on a substrate of sand was increased significantly by additions of nitrogen alone and increased about threefold when phosphorus was also supplied. In a marsh developed on finer-textured sediments, nitrogen fertilizer doubled the standing crop of short *Spartina*, but there was no response to phosphorus. There was no growth response from applications of iron to support previous speculation that iron nutrition might be a particularly important factor causing the chlorotic appearance of short *Spartina* and reducing its productivity. The chlorotic condition was remedied by additions of nitrogen.

The response of short *Spartina* to nitrogen implies that a part of the difference in productivity between the tall and short forms is due to the amount of nitrogen available to the plants. Many other environmental or possibly genetic factors or combinations of factors may be responsible for producing the short form of *S. alterniflora*. The factor most often implicated is that of salinity. High salinities will stunt *Spartina* and

Table 44. The Effect of Nitrogen and Phosphorus on Growth of *S. alterniflora* at Drum Inlet when applied at the Time of Transplanting*

N Rate (kg/ha)	P Rate (kg/ha)			P Rate (kg/ha)		
	0	24.6	X̄†	0	24.6	X̄†
	Dry Wt. (g/plant)			No. of Flowers/Plant		
0	8.9	17.0	12.9	2.8	5.1	3.9
56	11.9	22.0	16.9	2.6	6.6	4.6
112	11.9	16.4	14.2	3.7	5.6	4.6
224	13.6	28.2	20.9	4.2	7.6	5.9
X̄†	11.6	20.9	----	3.3	6.2	---
LSD‡ 0.05:						
N	4.9			1.4		
P	3.5			1.0		
N x P	§			§		
CV‖ (%)	45.4			43.4		
	No. of Center Culms/Plant			No. of Rhizome Culms/Plant		
0	10.6	19.7	15.1	0.4	0.9	0.7
56	15.8	27.7	21.7	0.7	2.2	1.4
112	16.0	20.3	18.2	0.9	1.4	1.2
224	20.3	28.3	24.3	1.6	2.7	2.1
X̄†	15.7	24.0	----	0.9	1.8	---
LSD‡ 0.05:						
N	4.7			§		
P	3.3			0.8		
N x P	§			§		
CV‖ (%)	35.2			131.8		

*Transplanted 28 June 1972; harvested 4 October 1972
†X̄ = main effects
‡Least significant difference
§Not significant
‖Coefficient of variation

areas with high salinity and short *Spartina* can be found. However, we have found short *Spartina* growing where the salinity was found to be only about 10 parts per thousand at several different times during a growing season. If the stunted form is produced by environmental factors, then the factor or interaction of factors may vary from one location to another. That is -- at a particular location, high salinity may limit growth, while at another an unfavorable water regime or a shortage of nitrogen or phosphorus or both might be limiting growth.

An explanation for nitrogen deficiency in the short height zone may be in the development of a thick mat of roots which creates a sod-bound condition. When sediments are deposited and later colonized by *Spartina*, most substrates contain adequate nitrogen for plant growth except where it is mostly sand, such as the Drum Inlet site. As the fibrous mat of roots develops over the years, all the available nitrogen is absorbed and either exported in the shoot growth, carried over in living root tissue or bound up in dead root tissue. The dead root material is decomposed and mineralized slowly (evidenced by accumulation of organic matter) due to the anaerobic condition of the marsh sediments. Nutrients added from natural sources apparently are not adequate for maximum plant growth. The addition of nitrogen to the marsh probably includes small amounts from rainfall, asymbiotic nitrogen fixation, directly from flooding tidal waters, deposition of feces from filter feeders in the marsh and deposition of inorganic and organic sediments.

The amount of sediments deposited is probably the chief difference between the nutrients available to the tall and short forms of *Spartina*. Sediments are deposited regularly along creek banks providing a fresh medium for plant roots to exploit. Unexploited sediments are also exposed by meandering of creeks. The amount of nitrogen supplied would depend on the nature of the sediments.

It is more certain that the sediment is the dominant factor in the supply of phosphorus to *S. alterniflora* (Pomeroy, et al., 1969). This is borne out in the results of our fertilizer experiments which showed a response to phosphorus on sandy substrate but not on finer-textured material. The texture of the sediments is quite important in the phosphorus-supplying capacity. In eroded soils of humid climates, phosphates are associated with hydrated oxides of iron and aluminum which occur as films on clay particles. When sediments are deposited in a marsh, the reducing conditions cause the solubility of iron and aluminum phosphate to increase. At the high pH (hydrogen-ion concentration) of marsh soils (7.0 to 8.0) calcium phosphates probably become an important form of phosphorus. The amount of phosphorus available to plants in a salt marsh is related to the amount of clay in the substrate. Pomeroy, et al. (1969) concluded that the subsurface-reduced sediments are the source of phosphorus for *Spartina*; however, the response to surface-applied fertilizer-phosphorus in this experiment seems to contradict this. Uptake of fertilizer-phosphorus apparently occurred at or very near the sediment surface, indicating that nutrients in freshly deposited sediment would be readily used.

The fact that nitrogen and phosphorus are the limiting factors in growth of *S. alterniflora* in some salt marshes has several ecological implications. It is possible that the marsh may act as a buffer for the estuarine system providing a sink for excess nutrients which may stem from municipal wastes and land runoff. In the marsh, excess nutrients would produce increased growth of *S. alterniflora* which would provide an increased supply of food energy and nutrients to the detritus food chain of the estuary rather than altering energy pathways as often happens when the phytoplankton system receives excess nutrients. This ability of the salt marsh to use more nitrogen and phosphorus may be important in managing estuarine systems. Disposal of wastes high in nutrients (such as sewage effluent) may be less disruptive to the estuarine ecosystem if dumped in the salt marsh rather than in open water. With proper management such disposal might actually enhance estuarine productivity. Further research is needed to determine the exact nature of the nutrient cycle in the marsh-estuarine system and the capacity of the marsh to receive excess nutrients.

Nitrogen and phosphorus fertilizers were shown to enhance growth of seedlings and transplants artificially established on dredged material. Since establishing a substantial vegetative cover rapidly may be critical in stabilizing an area, application of fertilizer may be of some practical benefit. However, the dredge spoil was sandy at both locations; hence, the nutrient-supplying capacity was low. Response to fertilizer would be expected to vary with the inherent fertility of the substrate material.

VII. PLANTING SPECIFICATIONS - *S. ALTERNIFLORA*

1. Transplanting.

a. Plants. Healthy, single stems from uncrowded stands should be used, keeping as much of the root system intact as possible. Rhizomes, small shoots, and flowering stalks from the previous year may be removed or trimmed so as to not interfere with transplanting. Plants from the immediate area are preferable. If they are brought from any great distance, trial plantings should be made to test adaptation. Plants may be stored indefinitely by heeling-in in the intertidal zone.

b. Planting. Hand- or machine-plant 10 to 15 centimeters (4 to 6 inches) deep, taking care that soil is firmed around plant immediately to prevent the plant from "floating out" of hole or furrow.

c. Spacing. Under average conditions, plants set on 1-meter center will provide complete cover early in the second growing season. Closer spacings, 0.5 and 0.3 meters (19 and 12 inches), may be warranted on critical sites, keeping in mind that planting costs are in almost direct proportion to the number of plants planted.

Spacing		Plants per 1,000 square feet
inches	meters	
12	0.30	1,000
18	0.45	445
24	0.60	250
36	0.90	111

2. Planting Dates.

March, April and early May constitute the ideal planting season at the latitude of North Carolina, late enough to avoid the worst weather, and early enough to allow a long growing season. *S. alterniflora* can be transplanted successfully the year round, but not with equal success. Planting in winter subjects transplants to more severe weather, stronger wave action, and greater erosion or deposition hazards. Summer planting reduces the time for establishment before winter. Circumstances will often warrant consideration of planting times which are less than optimum.

Elevation. *S. alterniflora* will usually grow in any area, roughly between MHW and MLW for locations with low tide ranges and from MHW to MSL for higher tide ranges. Since there will be variations where wind setups are large, upper and lower limits of growth of natural stands in the vicinity should be checked.

3. Fertilization.

Plantings may respond to the addition of nutrients in nutrient-poor situations -- very sandy substrate, little or no clay or silt moving into the area, and low concentration of nitrogen and phosphorus in the surrounding water. Nitrogen and phosphorus are the most likely limiting nutrients. Chemical assays are useful only to identify extremes. Conventional tests for available phosphorus were developed for uplands and are not reliable for coastal conditions. There are no convenient chemical methods that will satisfactorily forecast available nitrogen supplies.

4. Seeding.

a. Seeds. Harvest seed as near maturity as possible (late September and early October in North Carolina) and store in estuarine water at 2° to 3° Centigrade over winter.

b. Method. Broadcast at low tide and cover 1 to 3 centimeters by tillage. Tillage is better before and after broadcasting.

c. Rate. Seeding rate should be based on viable seeds since quality varies widely. Optimum rate appears to be around 100 viable seeds per square meter. Adequate stands are possible under favorable conditions with half this rate.

d. Planting Date. The best time is probably immediately after natural seedlings appear (in March along the North Carolina coast). Earlier seeding is susceptible to weather risks. *S. alterniflora* can be seeded as late as the end of June in North Carolina. This produces greatly reduced first-year growth, but if the stand survives the winter, growth equals that of earlier seedings by the end of the second growing season.

e. Elevation. Seeding should usually be confined to about the upper half of the tide range.

f. Fertilization. Seedlings are usually more responsive to fertilizer than transplants and first-year growth can be increased substantially by fertilization in nutrient-poor environments. Top dressings of about 100 kilograms per hectare of nitrogen (90 pounds per acre) and 25 kilograms per hectare of phosphorus (50 pounds per acre P_2O_5), applied in late June and again in late July, are suggested where nutrient deficiencies are suspected. Nitrogen should be from ammonium sulfate and phosphorus from a soluble source such as treble superphosphate.

VIII. OTHER SPECIES

Although this study concentrated on the intertidal zone, stability of bare areas lying immediately above this zone could not be ignored. *Patens* (Ait.) Muhl. (saltmeadow cordgrass) frequently inhabits the zone immediately above the upper limit of *S. alterniflora* in undisturbed intertidal marshes. It is expected that this grass would be suitable for propagation at elevations higher than the *S. alterniflora* zone. No formal planting experiments were conducted with *S. patens* but enough plantings have been made during the last three growing seasons to provide some useful observations.

Where we have compared *S. patens* with *S. alterniflora* over an elevation gradient in transplant experiments, there is some overlap in survival at the end of the first growing season. After several years, competition between the two will probably limit them to their respective elevation zones as observed in nature. At Snow's Cut, the transplanted *S. patens* survived the first growing season down to 1.05 meters above MLW, but the lower limit of vigorous growth was about 1.25 meters. The upper limit of this species is not well-defined, but its growth is depressed on higher and drier sites. *Patens* was planted over an elevation gradient at Snow's Cut on 27 April 1971; six samples were harvested from below and six from above the mean high water spring tide line on 15 September 1971. The yield of aboveground growth of the plants at the higher elevation averaged 26.6 grams per plant while those at the lower elevation zone averaged 141.8 grams per plant. Survival of the transplants was very good (93 percent) over the entire elevation gradient. Careful plant selection is important for good survival and growth. The plants should be from a sparse stand; preferably a sandy area where growth is spreading, and divided into clumps of 6 to 12 culms per hill.

The growth of *S. patens* transplants is enhanced by the application of nitrogen fertilizer. At Drum Inlet *S. patens* was transplanted 28 June 1972 and one part of the planting received 89 kilograms per hectare of nitrogen on 1 August 1972. The averages of plants harvested 4 October 1972 were 4.6 grams per plant for the unfertilized and 10.4 grams per plant for the fertilized.

We assumed that findings from our dune research program are applicable to areas above the *S. patens* zone elevation. However, since *Panicum amarulum* can be established by direct seeding and dredged material sites may be less exposed than some foredunes, this species was seeded on dredged material to protect *S. alterniflora* plantings from blowing sand on both the Beaufort and Drum Inlet sites. It was of little value for this purpose during the first growing season because seedling growth was not sufficient to materially affect sand movement. However, by the end of the second growing season a good stand, capable of trapping sand, was established.

Growth of this grass can be enhanced substantially by fertilization. In an experiment at Drum Inlet, first-year seedling dry weight was increased by a factor of 5 when nitrogen at the rate of 89 kilograms per hectare was applied. Fertilizer response, if any, was obscured by blowing sand on the Beaufort site.

IX. SUMMARY AND CONCLUSIONS

Techniques were developed for propagating *Spartina alterniflora* by seeding and transplanting. Transplants are more vigorous than seedlings and are better able to survive on exposed sites and at lower elevations. Plants can be dug from natural marshes. The most vigorous and most easily obtained plants are found in recently colonized areas where the root mat has not fully developed. A sandy substrate also facilitates digging and separating the plants. A nursery area may be established on sandy dredge spoil by seeding or transplanting and used the following growing season. Plants produced in such a manner provide a source of easy to obtain vigorous plants. Transplanting should usually be done with single stems spaced about 0.9 meters apart. Closer spacing increases the chances of success on exposed sites. Machine transplanting is feasible where there is access to the planting site and the substrate will support equipment. The best months for transplanting in North Carolina are April and May, although it may be done at any time. Although survival is good for summer planting, growth is limited for that growing season. Risk of storm damage is great when transplanting is done in winter.

Seeding is an economical and effective method of establishing *S. alterniflora*. Seed and seedlings are less tolerant of rigorous conditions (such as storm waves and blowing sand) than transplants and are usually effective only in about the upper one-half of the elevation range of *S. alterniflora* in a given location. Seed should be collected as near maturity as possible (late September in North Carolina) and stored in saltwater at 2° to 3° Centigrade over winter. Seeding should be done in April (in North Carolina) at the rate of 100 viable seed per square meter by incorporating the seed in the upper 1 to 3 centimeters of the substrate. Seedlings grow rapidly during the first growing season and under favorable conditions usually produce a better cover than transplants during the same period.

Selecting a site within the proper elevation zone for growth of *S. alterniflora* is critical. The vertical zonation of the grass is determined by interaction of environmental factors (the most important being tide range) peculiar to each location. The upper and lower limits of growth for a potential planting site can usually be found by determining the upper and lower limits of growth of nearby natural stands. Stands will resist competition from invading plants in areas of higher salinity (>25 parts per thousand) and longer periods of inundation (>8 hours). The substrate of a planting site is important in its ability to support equipment, its nutrient supplying capacity, and its effect on salt buildup.

Development of transplanted or seeded areas is rapid. After two growing seasons there is little difference in appearance and primary productivity of the vegetation between artificially propagated marshes and long-established natural marshes. The length of time required for a new marsh to achieve a fully functional biological role is unknown.

The relationship of mineral nutrition to growth of *S. alterniflora* was determined by sampling plants and soils in natural stands and by applying fertilizers to natural stands, transplants, and seedlings. Results of the natural marsh sampling and subsequent regression analysis, indicated that tissue concentrations of several nutrients and several soil properties were related to productivity of *S. alterniflora*. Variables negatively associated with yield were salinity of the soil solution, manganese concentrations in the plants and soil and sulfur concentrations in the plants. Variables positively associated with yield include phosphorus concentrations in the plant tissue and in the soil.

Results of fertilizer experiments in natural stands indicate that the productivity of some salt marshes is limited by the supply of nutrients. The standing crop of aboveground growth of *S. alterniflora* growing on a sandy substrate was increased significantly by additions of nitrogen alone and increased about threefold when phosphorus was also applied. In a marsh developed on finer-textured sediments, nitrogen fertilizer doubled the standing crop of short *S. alterniflora*, but there was no response to phosphorus. Tall *S. alterniflora* did not respond to either nitrogen or phosphorus. Nitrogen and phosphorus fertilizers enhance growth of transplants and seedlings artificially established on dredge spoil. These findings suggest that salt marshes may be important in the recycling of nutrients that may otherwise occur as pollutants in the estuary.

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