# UNIVERSITY OF NORTH CAROLINA

# SEA GRANT PROGRAM



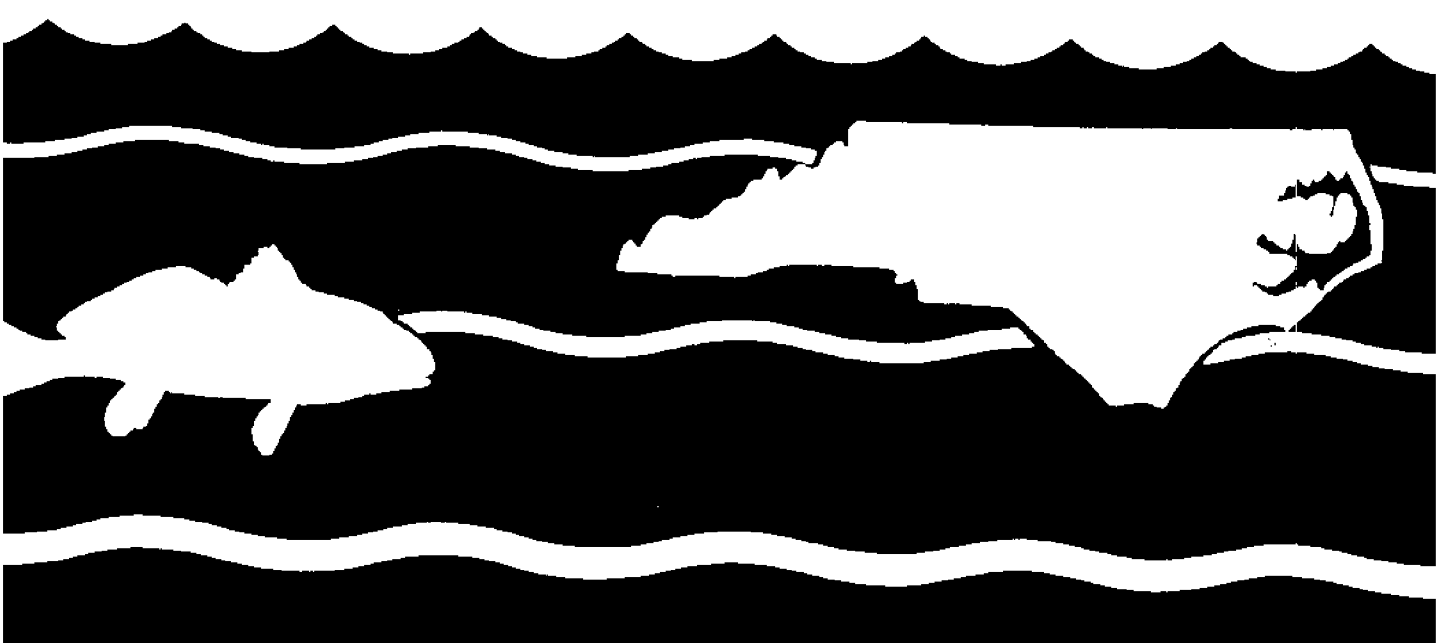
## AN INVESTIGATION OF PROPAGATION AND THE MINERAL NUTRITION OF *Spartina alterniflora*

Stephen W. Broome
William W. Woodhouse
Ernest D. Seneca

SEA GRANT PUBLICATION

UNC – SG – 73 – 14

JULY, 1973



# AN INVESTIGATION OF PROPAGATION AND THE MINERAL NUTRITION OF *SPARTINA ALTERNIFLORA*

by

S. W. Broome[1], W. W. Woodhouse Jr.[1], and E. D. Seneca[1,2]

[1]Department of Soil Science

[2]Department of Botany
N. C. State University
Raleigh, North Carolina

This work was partially sponsored by Office of Sea Grant, NOAA, U. S. Department of Commerce under Grant numbers 2-35178 and 04-3-158-40, the Coastal Engineering Research Center, U. S. Army Corps of Engineers, and the North Carolina Coastal Research Program. The U. S. Government is authorized to produce and distribute reprints for governmental purposes notwithstanding any copyright that may appear hereon.

SEA GRANT PUBLICATION UNC-SG-73-14 JUNE 1973

Sea Grant Program, 1235 Burlington Laboratories, N. C. State University, Raleigh, North Carolina 27607

# TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

## PROPAGATION OF SPARTINA ALTERNIFLORA FROM SEED

### Introduction

Spartina alterniflora Loisel. is the dominant plant of the intertidal zone of bays and estuaries along most of the east coast of North America. This salt marsh grass produces a considerable amount of food energy which is utilized by certain fauna of the estuaries (Odum, 1961; Teal, 1962; de la Cruz and Odum, 1967) and is also important in transferring mineral nutrients from the sediments to surrounding waters (Pomeroy et al., 1967; Williams and Murdoch, 1969). An additional value of S. alterniflora is retarding erosion of shorelines and in some cases trapping sediments and increasing the elevation.

Although S. alterniflora salt marshes are a valuable natural resource, protection and preservation of these wetlands has begun only recently. In the past, many acres of Spartina have been destroyed by man's activities. Consequently, creating new salt marshes by propagating S. alterniflora seems to be a desirable objective (Woodhouse, Seneca and Broome, 1972).

There are few records of attempts to establish new salt marshes in this country (Larimer, 1968). However, S. townsendii H. & J. Groves., an ecological equivalent of S. alterniflora, has been planted in Europe for many years (Ranwell, 1967). Spartina townsendii has been used to reduce the source area for channel silting, to reduce erosion of shorelines and to help reclaim mudflats on behalf of agricultural interests. It is reasonable to assume that it would be feasible to propagate S. alterniflora in this country if economical techniques are worked out.

Oliver (1925) recognized the economic and labor-saving advantages of seed over transplants as a mode of establishment of *S. townsendii*. However, reports in the literature (Chapman, 1960; Larimer, 1968) indicate that *S. alterniflora* produces very few viable seed and that seed are not as important as rhizomes in spreading this grass. Contrary to these reports, we have observed, along the North Carolina coast, that seedlings are the primary means of natural colonization of *S. alterniflora* on freshly deposited sediments within the intertidal zone. Seeds germinate in late March and seedlings are numerous in the debris of drift lines near the high tide mark. Seedlings can also be found at lower elevations in protected intertidal areas. These seedlings grow rapidly during the summer and produce flowers and seed by the end of the growing season. Laboratory studies by Mooring, Cooper and Seneca (1971) showed that 52% of *S. alterniflora* seed germinated when subjected to a 65-95 F (35-18 C) alternating diurnal thermoperiod after storage in sea water at 43 F (6 C) for 8 months. None of the seed stored dry at 43 F germinated after 8 months, suggesting that seed must be kept moist to remain viable over winter.

This paper reports a study of the effect of source of seed and storage treatments on viability of seed of *S. alterniflora* and the performance of seed planted in suitable habitats in North Carolina estuaries.

## Materials and Methods

### Effect of Storage Treatment on Germination

In October 1969, seed of *S. alterniflora* were collected from five locations along the North Carolina coast. These locations were Oregon

Inlet (lat. 35° 46' N, long. 75° 32' W), Ocracoke Island (lat. 35° 12' N, long. 75° 44' W), Beaufort (lat. 34° 43' N, long. 76° 40' W), Surf City (lat. 34° 22' N, long. 77° 38' W), and Oak Island (lat. 33° 54' N, long. 78° 01' W). Samples of seed from each location were subjected to the following storage treatments: (1) submerged in estuarine water at 2-3 C, (2) submerged in distilled water at 2-3 C, (3) suspended over water on screen wire at 2-3 C, (4) frozen dry, (5) frozen in estuarine water, and (6) freeze-dried. The salinity of the estuarine water was in the range of 2.0 to 2.5%.

Germination was tested in February 1970 by placing 50 seed, which were disinfected by soaking in a 25% 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 seed. Careful selection was made to be reasonably sure a seed was present within each glume. The petri dishes containing the seeds were placed in canisters (which excluded light) and were subjected to an alternating thermoperiod of 7 hr at 35 C and 17 hr at 18 C (Mooring et al., 1971) in a growth chamber. The numbers of seed germinated (indicated by the emergence of the epicotyl) were counted after 5, 7, 9, 21 and 30 days. Since none of the seed 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 et al. (1971) and showed S. alterniflora seed must remain moist to retain viability.

Seed were also collected in 1970 and 1971 to study the effects of date of harvest, length of after-ripening period, and storage on germination.

Field Experiments

Harvesting and Storage of Seed. In the beginning of the studies, seed were harvested by hand and stored in small containers in estuarine water at refrigerator temperatures. However, for field-scale plantings of significant size, it is necessary to obtain a large volume of seed. Since harvesting by hand is slow and laborious, a mechanical harvester was developed which consists of a sickle bar blade, a reel and a canvas bag for catching the seed heads. This apparatus was mounted on a two-wheel garden tractor. Harvested seed heads were placed in 8 x 8-ft burlap sheets for easy transportation. The sheets of seed heads were temporarily stored in a cooler (2-3 C) until they could be threshed. A threshing machine, previously used for small grain from experimental plots, was used to separate the seed from the straw. This threshing procedure considerably reduced the amount of storage space required. The threshed seed were placed in 30-gallon plastic garbage cans which were filled with estuarine water and stored at a temperature of 2-3 C.

Seeding Methods. Trial plantings of *S. alterniflora* seed were made in the field in 1970, 1971 and 1972. In 1970 and 1971 a limited amount of seed were available; consequently, planting was limited to small plots. A seeding trial at Oregon Inlet in 1970 was included in a randomized complete block experiment. Each plot of the three replicates consisted of three rows of seed planted in furrows 1.0 m apart and 15.2 m long on April 21, 1970.

In 1971, seed plots were established at Oregon Inlet, Ocracoke, and Snow's Cut (lat. 34° 07' N, long. 77° 56' W). At each location a comparison was made between applying the seed to the surface mixed in a slurry of Unisoil (attapulgite clay) with a centrifugal pump or broadcasting the seed evenly over the plots by hand and working them into the substrate with rakes.

In 1972 a large volume of seed (approximately 1200 1) was available for planting. Several areas were planted to seed at Ocracoke and Beaufort on recently deposited dredge spoil. Seed were broadcast by hand and covered by using five narrow sweeps mounted on the tool bar of a tractor followed by a spiked-tooth harrow. A rototiller was also used for incorporating seed in areas not accessible to the tractor. Seeding rates were adjusted according to germination studies on each lot of seed used such that about 100 viable seed per square meter were planted. The number of viable seed per liter varied from 500 in the poorest lot of seed to 27,000 in the best lot. An average value was 10,000 viable seed per liter (10/ml).

## Results and Discussion

### Effects of Storage Treatment on Germination

The combined analysis of variance over all locations, times at which percent germination was recorded, and storage treatments revealed a highly significant (.01 level) three-factor interaction. Consequently, it was not considered meaningful to compare the main effects of locations, times, or treatments. An analysis of variance was then performed separately for each location. Since there was still a treatment x time interaction, LSD's were calculated for comparing the differences in percent germination among treatments on any particular day. Calculations of this LSD involve both error (a) and error (b) since both whole plot and subplot differences are involved (Steel and Torrie, 1960).

Results of the effect of storage treatment on germination indicate that freezing, either dry or in estuarine water, was clearly detrimental to germination of seed from all locations (Figures 1.1-1.5). 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 (which was shown to be important in other experiments) was retarded while the seed were frozen.

The effects of storage of seed in estuarine water, distilled water or over water on germination was 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 somewhat 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 seed 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 after-ripening period. The degree of seed development at the time of harvest, as well as the environment in which the after-ripening proceeds, probably influences viability of the seed. Although there is considerable variation in seed maturity even within a particular stand, flowering

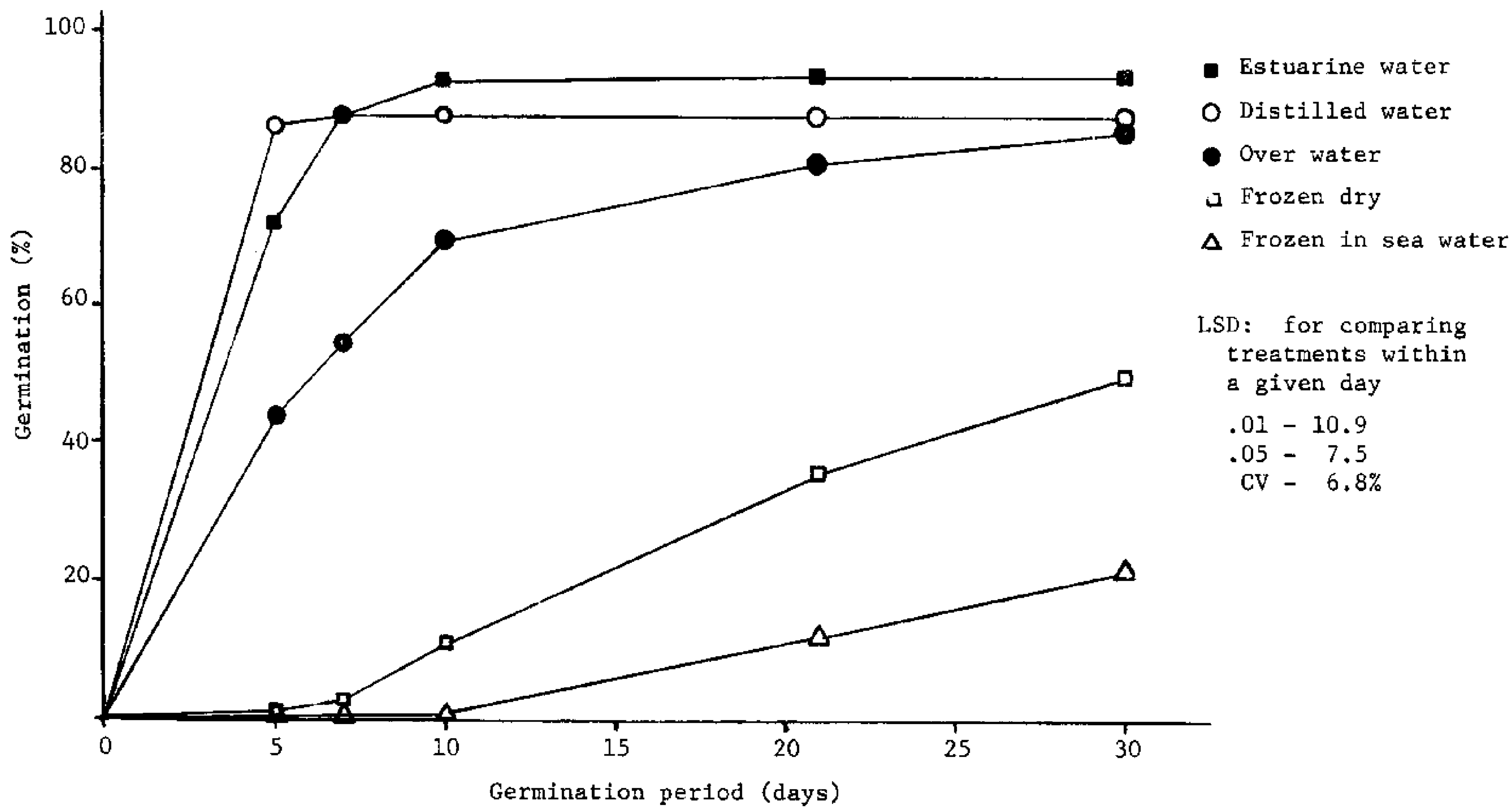



Figure 1.1. Effect of method of storage on germination of S. alterniflora seed from Oregon Inlet

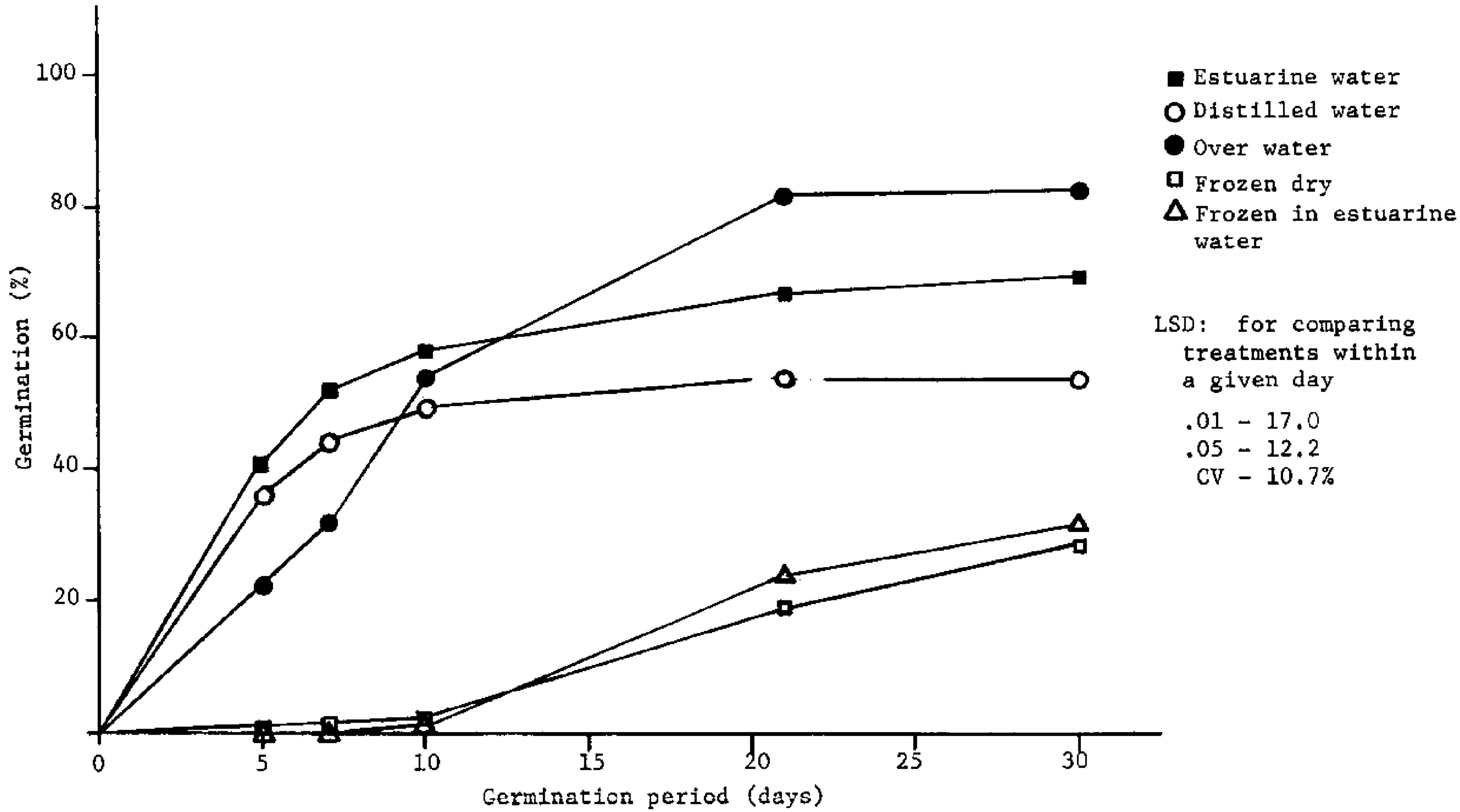



Figure 1.2. Effect of method of storage on germination of S. alterniflora seed from Ocracoke

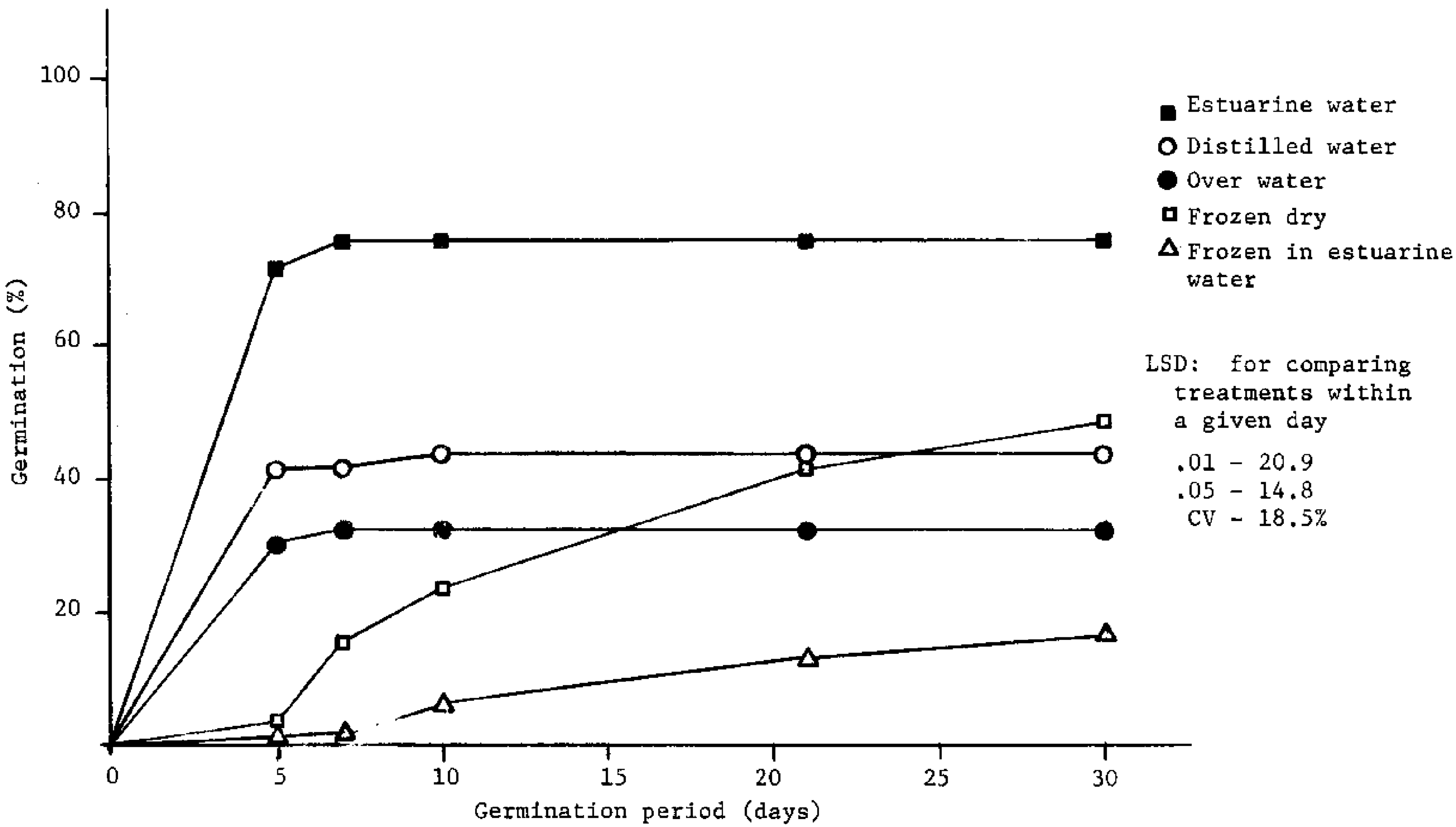



**Figure 1.3.** Effect of method of storage on germination of _S. alterniflora_ seed from Beaufort

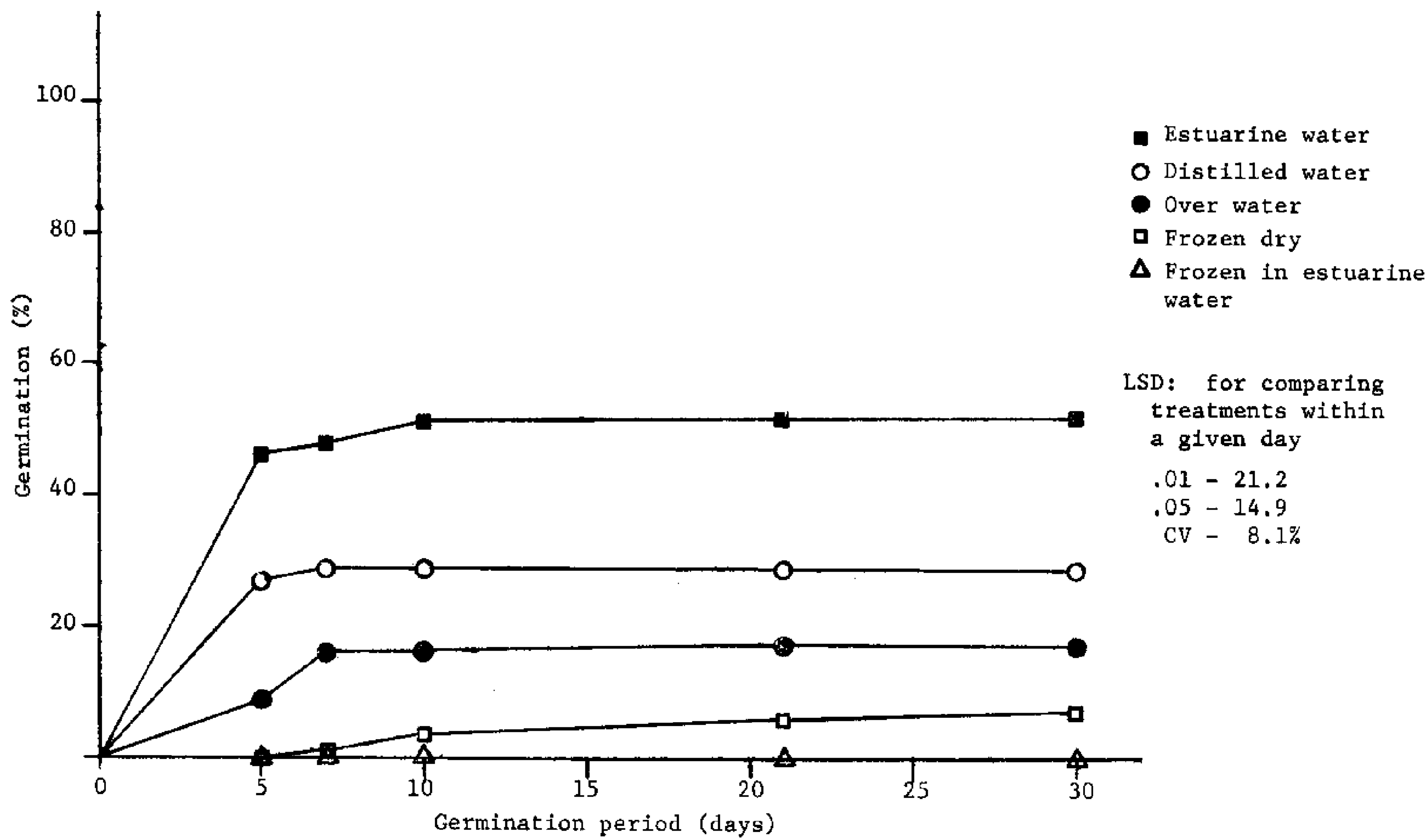



Figure 1.4. Effect of method of storage on germination of S. alterniflora seed from Surf City

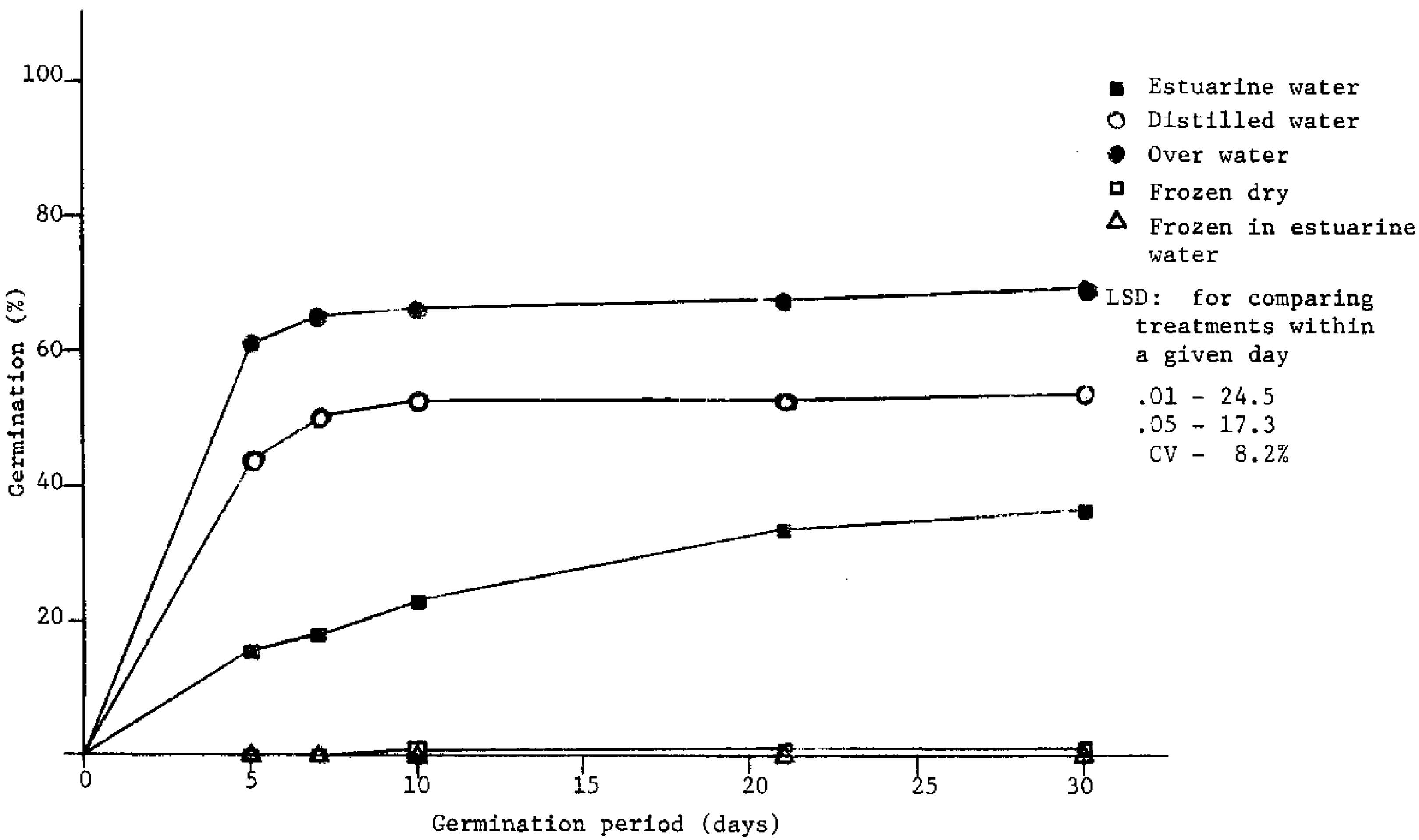



Figure 1.5. Effect of method of storage on germination of _S. alterniflora_ seed from Oak Island

and seed maturity occurs 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 after-ripening process.

This study of germination indicates that seed should be harvested as near maturity as possible and that storage in estuarine water or possibly fresh water at 2-3 C 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 optimum harvest date has been from about September 20 to October 10. The best harvest date is later farther south.

Selecting the proper location is also important in harvesting a good seed supply. It has been observed that the quality and quantity of seed produced varies greatly from one stand of *S. alterniflora* to another. As would be expected, the most vigorous plants set the most seed and these are generally found in areas recently colonized by *S. alterniflora*. There is little flowering and seed production in the short height zone areas of older marshes with most seed being produced by the tall form along creek banks. A similar observation was made by Taylor (1938) on Long Island, New York where he reported that thick stands of S. alterniflora did not flower.

Another factor which may reduce seed production in local areas is infestation by flower beetles (family Mordellidae) which destroy the flowers preventing seed from being produced.[1]

The effects of date of harvest, length of after-ripening period, and storage in distilled or estuarine water were evaluated with seed collected in 1971.

Seed harvested on September 28, 1971 at Oregon Inlet had a significantly higher germination percentage than those harvested 1 week earlier (Figure 1.6). However, it must be pointed out that there was one other difference in the way the seed from each harvest date were treated. The seed harvested on September 21 were threshed and stored in estuarine water within a few days of harvesting, while those harvested on September 28 were stored dry in a cooler for 3 weeks before threshing and storing in estuarine water.

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% germination (Figure 1.7). By February, 50% of the seed sample germinated in only 4 days. The results indicate that an after-ripening process occurs which speeds up the germination process and increases the germination percentage as the

---

[1] Campbell, W. V., Professor of Entomology, N. C. State University at Raleigh; personal communication.

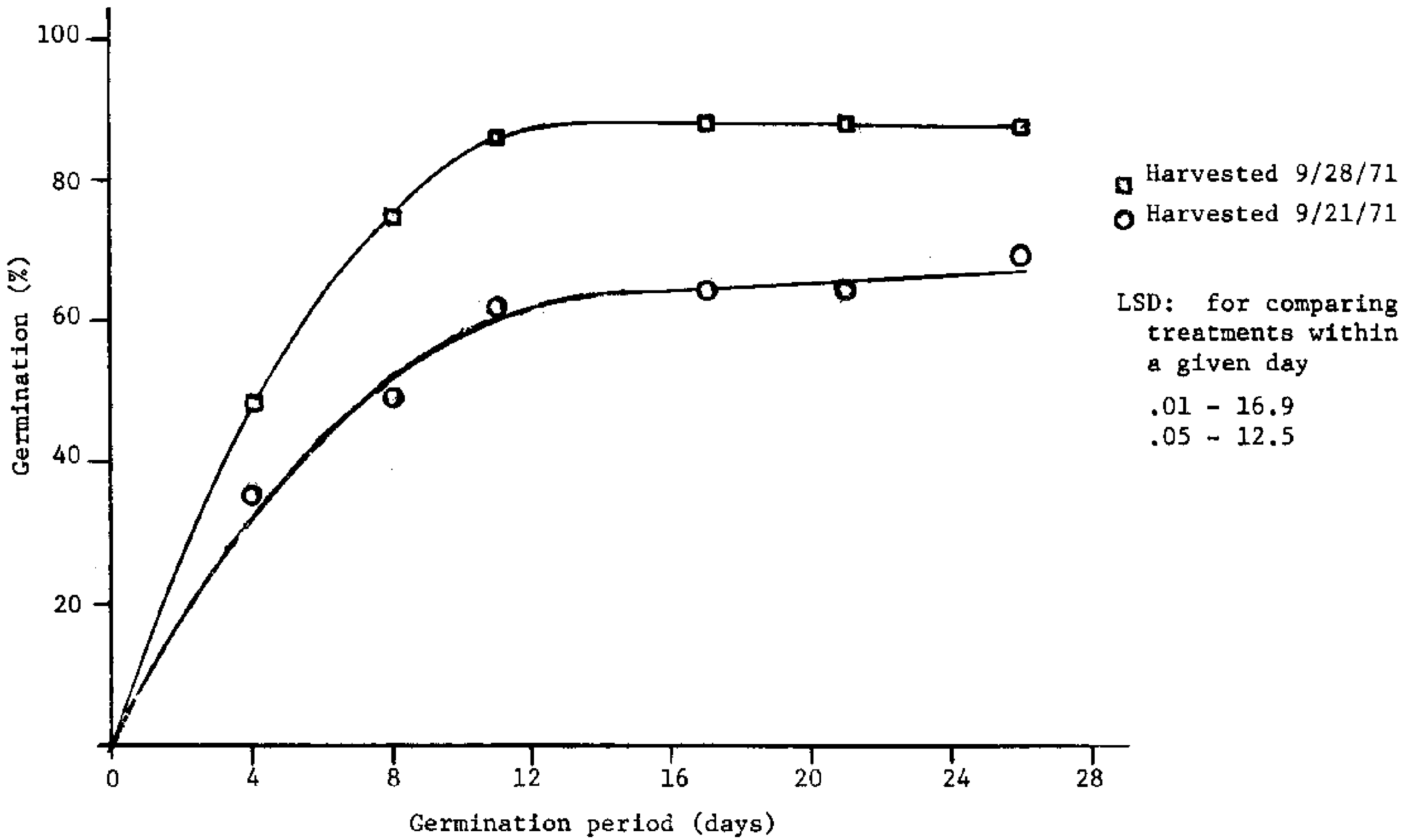



Figure 1.6. Effect of date of harvest on germination of S. alterniflora seed stored in estuarine water (seed were harvested at Oregon Inlet; the germination period began February 17, 1972)

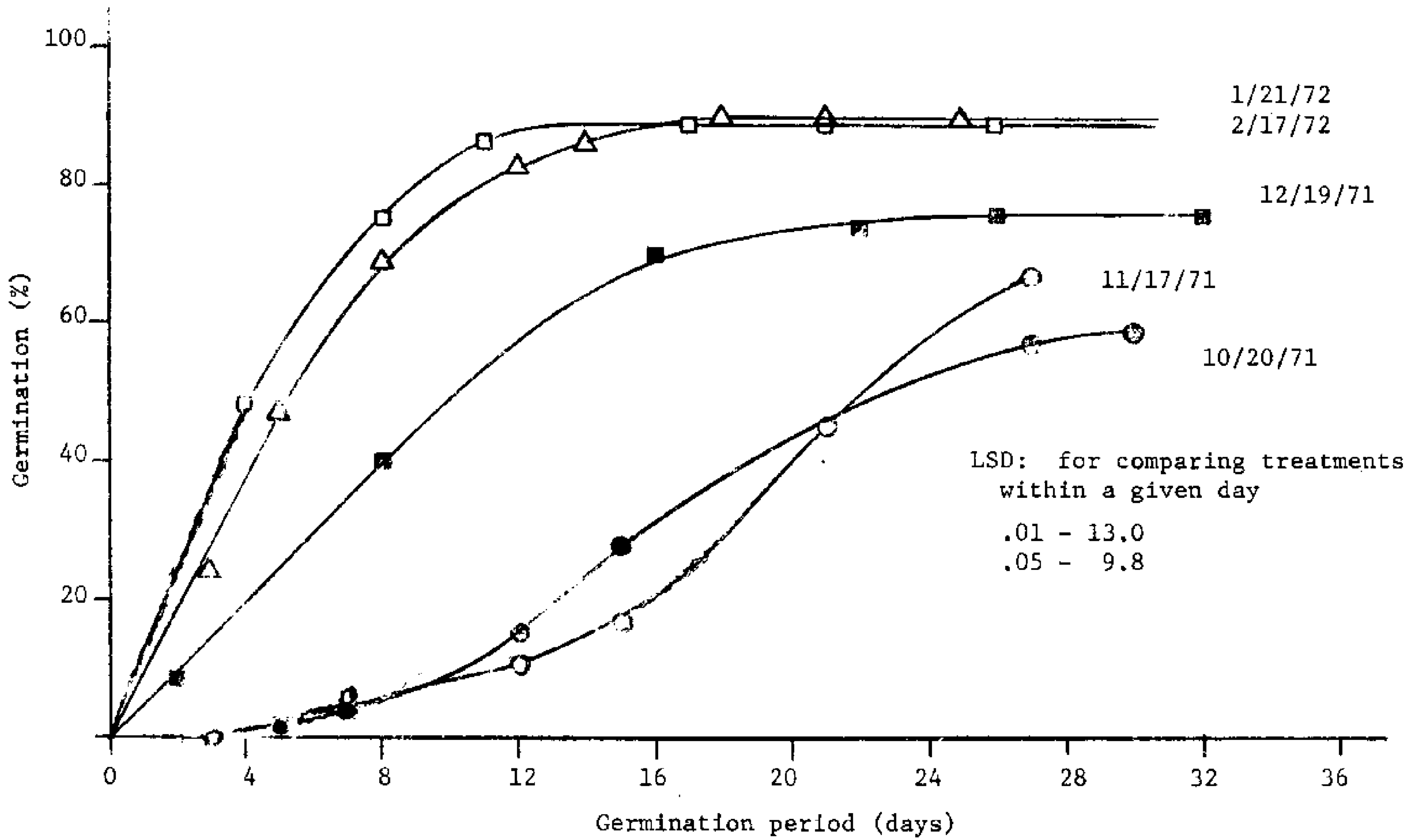



Figure 1.7. Effect of after-ripening of S. alterniflora seed stored for various lengths of time (seed harvested 9/28/71 at Oregon Inlet and stored cold in estuarine water until germination was begun on the dates indicated)

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 2-3 C.

Samples of seed harvested September 21, 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 two storage treatments (Figure 1.8). However, after 5 months, when the after-ripening process was apparently complete, seed stored in estuarine water had a significantly (.05 level) higher germination percentage than those stored in distilled water (Figure 1.8). At least in some cases storage in salt water enhances seed germination.

## Field Experiments

The success of seeding has been variable with some very good results, but also some failures due to excessive deposition of sediment or loss of seed or seedlings by erosion.

Seed planted in rows in 1970 at Oregon Inlet produced very little growth on a per-unit-area basis during the first growing season (Table 1.1). The seedlings were confined to narrow rows the first year but produced a complete cover by the end of the second growing season. From this initial experiment it was concluded that seed could be successfully used to establish *S. alterniflora*. The results also indicated that seed should be distributed evenly over an area to give a better cover during the first growing season.

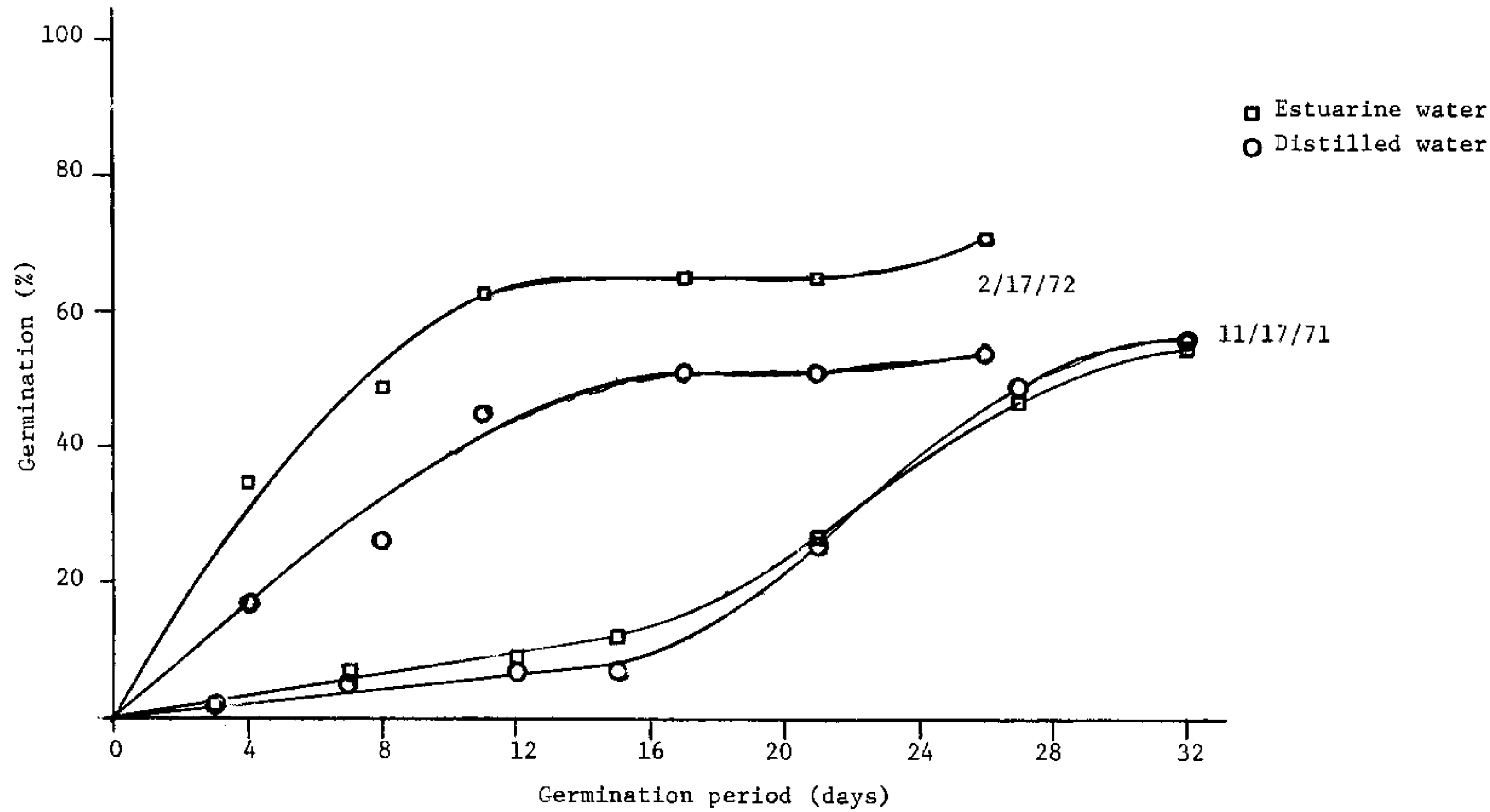



Figure 1.8. Comparison of germination of S. alterniflora stored in estuarine water and distilled water (germination tests were made November 17, 1971 and February 17, 1972)

Table 1.1. Standing crop produced from seed planted in rows 1 m apart at Oregon Inlet April 21, 1970

| Rep | Dry weight (g/m²) | | | |
|---|---|---|---|---|
| | 9/22/70 | | | 9/8/71 |
| | Roots | Rhizomes | Shoots | Shoots |
| 1 | 14.2 | 8.8 | 25.9 | 245 |
| 2 | 6.7 | 4.8 | 10.9 | 262 |
| 3 | 10.7 | 7.3 | 15.8 | 313 |
| Mean | 10.5 | 7.0 | 17.5 | 273.3 |

In 1971, split-plot experiments at Oregon Inlet and Snow's Cut were used to compare application of seed to the surface in a clay slurry versus incorporating the seed to 1 to 4 cm in the substrate with rakes. At Oregon Inlet, applying the seed to the surface in the clay slurry produced a greater amount of top growth than covering the seed (Table 1.2). The seed in the clay slurry germinated sooner and got off to a

Table 1.2. A comparison of growth measurements of seedlings produced from seed applied to the surface in a clay slurry and seed covered by raking at two locations

| | Dry wt of shoots (g/m²) | No. of stems/m² | No. of flowers/m² | Height (cm) |
|---|---|---|---|---|
| Oregon Inlet[a] (harvested 9/1/71) | | | | |
| Clay slurry | 101.2 | 208.0 | 72.0 | 41.3 |
| Raked | 60.0 | 173.2 | 25.2 | 30.3 |
| Snow's Cut (harvested 9/15/71) | | | | |
| Raked: Plot 1 | 1236.8 | 480 | 260 | 116 |
| Plot 2 | 685.6 | 388 | 120 | 116 |

[a]Means of three replications.

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 essentially 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 cm, there was a good stand of seedlings which produced very good growth (Table 1.2). It appears that broadcasting the seed and covering to a depth of 1 to 4 cm is the best method to assure a good stand of S. alterniflora seedlings over a wide range of conditions. Experiments have also shown that seeding is more successful in the upper portion of the tide range. The chance for survival of seedlings is much less at lower elevations.

In 1972 plantings of about 0.5 ha each were made at Beaufort (April 11) and Ocracoke (April 13) on freshly deposited sandy dredge spoil. A second seeding was made at Beaufort on June 21. Seed germinated well at both locations. However, a storm covered the seedlings at Ocracoke with wind-blown sand. The seed at Beaufort were protected by a sand fence and produced a good stand which grew very rapidly during the first growing season (Table 1.3). Dry matter production by plants from the April 11 seeding was equal to that from the medium height zone of a nearby long-established natural marsh. Clipped plots from the old marsh on September 7, 1971 had an average dry weight of 1019 $g/m^2$ for tall, 355 $g/m^2$ for medium and 241 $g/m^2$ for short S. alterniflora. A study by Williams and Murdock (1969) showed the average annual aerial standing crop of S. alterniflora marshes in the Beaufort area to be 545 $g/m^2$.

Table 1.3. A comparison of the above-ground standing crop of *S. alterniflora* produced from seed planted on adjacent plots on two planting dates at Beaufort (plots were harvested October 5, 1972)

| Sample no. | Dry wt ($g/m^2$) Planting date | |
|---|---|---|
| | 4/11/72 | 6/21/72 |
| 1 | 384 | 52 |
| 2 | 297 | 59 |
| 3 | 382 | 56 |
| $\bar{X}$ | 354 | 56 |

Thus the aerial standing crop produced from seed in one growing season was 65% of the average standing crop reported for long-established marshes.

The difference in standing crop produced from seed planted April 11 and June 21 is striking (Table 1.3). The difference in dry weight is due to the shorter growing season for the June seeding. However, the stand was as good or better from the June seeding and growth will probably equal the earlier planting during subsequent growing seasons. Earlier seedings produce more growth but the chances of storm damage are greater.

The seeding experiment at Beaufort also gives evidence of the limited elevation range over which seedlings are able to survive. An average of several points along the lower edge of the adjacent natural marsh showed a lower limit of 1.42 ft above local mean low water (LMLW) or 0.12 ft below mean sea level. The upper edge of the *S. alterniflora* was 3.78 ft above LMLW. However, seedlings from the April 11, 1972 seeding survived only as low as 3.33 ft above LMLW. Although seedlings survived above the upper elevation cut off of the natural marsh, the portion of the elevation range normally occupied by *S. alterniflora* at this location that was effectively colonized by seeding was rather narrow. This area was between 3.33 ft and 3.78 ft above LMLW, or a range of 0.45 ft, which amounts to about 19% of the 2.36-ft elevation range of the natural stand of *S. alterniflora*. Tide tables list the average tide range at Beaufort as 2.5 ft. Due to fewer storms and less intense wave action, seed planted June 21 produced seedlings with an average lower limit of survival of 3.05 ft above LMLW. This represents about 31% of the elevation range of *S. alterniflora* being colonized by seedlings.

Seed planted April 10, 1972 on a dredge spoil island in the Cape Fear River near Snow's Cut, produced seedlings over a larger portion of the elevation range of *S. alterniflora*. Transplants survived from 0.83 ft to 4.63 ft above LMLW or a range of 3.80 ft. Seedlings survived down to 2.58 ft above LMLW which is a range of 2.05 ft or about 54% of the elevation range at this location. The tide tables list the mean tide range as 3.8 ft at nearby Campbell Island.

## Summary and Conclusions

Under favorable environmental conditions, *S. alterniflora* produces large quantities of viable seed. Seed should be collected from vigorous stands and stored over winter submerged in estuarine or sea water at temperatures in the range of 2-3 C. Areas recently colonized by *S. alterniflora* produce the best seed crops. The performance of seed is affected by maturity and should be collected as near the shattering stage as possible. Seed are slow to germinate immediately after harvest and require a storage period of 3 or 4 months. Seed may be kept in cold storage for up to a month after harvest before submerging in water. The seed heads shatter more easily after such a storage period and a more complete threshing job is possible. It appears that this short period of dry cold storage also increases germination percentage.

Field experiments have shown that direct seeding can be an effective method of establishing new stands of S. alterniflora on dredge spoil material. The elevation range over which seedlings can be expected to survive is limited to about the upper 20-50% of the elevational range of naturally occurring stands in a given area. This is affected by the exposure of a site to normal wave action and the occurrence of storms. Other studies (Woodhouse et al., 1972) have shown that transplants are more effective in establishing S. alterniflora in the lower elevations of its habitat. The above-ground standing crop of plants produced from seed in one growing season may approach that of long-established marshes. The protective cover established by seedling growth during the first growing season exceeds that produced by transplants in the same length of time.

## List of References

Chapman, V. J. 1960. Salt Marshes and Salt Deserts of the World. Interscience Publishers, Inc., New York.

de la Cruz, A. A., and E. P. Odum. 1967. Particulate organic detritus in a Georgia salt marsh--estuarine ecosystem, pp. 383-388. In G. H. Lauff (ed.), Estuaries. Am. Assoc. Advanc. Sci., Washington, D. C.

Larimer, E. J. 1968. An investigation of possibilities for creating saltmarsh in the estuaries of the Atlantic and Gulf coasts, pp. 82-88. In J. W. Webb (ed.), Proc. of the 22nd Conf. of Southeastern Game and Fish Commissioners, Columbia, S. C.

Mooring, M. T., A. W. Cooper, and E. D. Seneca. 1971. Seed germination response and evidence for height ecophenes in Spartina alterniflora from North Carolina. Amer. J. Bot. 58:48-55.

Odum, E. P. 1961. The role of tidal marshes in estuarine production. Conservationist 15(6):12-15.

Oliver, F. W. 1925. Spartina townsendii its mode of establishment, economic uses and taxonomic status. J. Ecol. 13:74-91.

Pomeroy, L. R., R. E. Johannes, E. P. Odum, and B. Roffman. 1969. The phosphorus and zinc cycles and the productivity of a salt marsh, pp. 412-449. In D. J. Nelson and F. C. Evans (ed.), Proc. of the Second National Symposium on Radioecology, USAEC Doc. CONF-670503,

Ranwell, D. S. 1967. World resources of Spartina townsendii (Sensu Lato) and economic use of Spartina marshland. J. of Applied Ecol. 4:239-256.

Steel, R. G. D., and J. H. Torrie. 1960. Principles and Procedures of Statistics. McGraw-Hill Book Co., Inc., New York. pp. 234-236.

Taylor, N. 1938. A preliminary report on the salt marsh vegetation of Long Island, New York. Bull. New York State Museum 316:21-84.

Teal, J. M. 1962. Energy flow in the salt marsh ecosystem of Georgia. Ecology 43:614-624.

Van Schreven, A. C. 1958. Kiem-en kweekproeven met Spartina townsendii Groves. Acta Bot. Neerlandica 7:205-216.

Williams, R. B., and M. B. Murdoch. 1969. The potential importance of Spartina alterniflora in conveying zinc, manganese and iron into estuarine food chains, pp. 431-439. In D. J. Nelson and F. E. Evans (ed.), Proc. of the Second National Symposium on Radioecology, USAEC, CONF-670503, Ann Arbor, Mich.

Woodhouse, W. W., E. D. Seneca, and S. W. Broome. 1972. Marsh building with dredge spoil in North Carolina. Bull. N. C. Agr. Exp. Sta. 445, 28 p.

# THE RELATIONSHIP OF MINERAL NUTRIENTS TO GROWTH OF SPARTINA ALTERNIFLORA IN NORTH CAROLINA. I. NUTRIENT STATUS OF PLANTS AND SOILS IN NATURAL STANDS

## Introduction

*Spartina alterniflora* Loisel. salt marshes are an important component of many of the productive estuarine ecosystems along the Atlantic coast of North America. A high proportion of the annual production of *S. alterniflora* is exported to adjacent estuaries in the form of particulate organic detritus (Teal, 1962; de la Cruz and Odum, 1967; Williams and Murdoch, 1969). The detritus is utilized by fish and invertebrate animals which may be permanent or temporary inhabitants of the estuary.

The annual net primary production of *S. alterniflora* has been found to be quite high, often exceeding that of many cultivated crops (Odum, 1959). Reports of the amounts of annual production of *S. alterniflora* from several locations were summarized by Cooper (1969). A general trend of decreased productivity from south to north was noted which was probably due to the decrease in length of growing season. Productivity of *S. alterniflora* also varies a great deal within a given location. Three distinct height forms described as tall, medium and short are generally recognized (Teal, 1962; Adams, 1963; Cooper, 1969). The difference in the yield of dry matter between these height forms is quite pronounced as evidenced by a study in Brunswick County, N. C. by Stroud and Cooper (1969). They reported the annual net primary production of tall, medium and short *S. alterniflora* as 1563, 471 and 280 $g/m^2/yr$, respectively. When relative areas of the height forms were considered, the average production over the entire marsh was 646 $g/m^2/yr$.

There is some disagreement as to whether the difference in growth habit and productivity between the height forms of S. alterniflora is due to genetic differences between the short and tall forms or if the size difference is a result of environmental factors. Chapman (1960) states that in his opinion the stunted S. alterniflora community is actually a special form (variety pilosa) which is smaller than variety glabra. Data reported by Stalter and Batson (1969) from a transplant experiment suggest that there are two forms of Spartina alterniflora, one of which is inherently dwarf and one which is inherently tall. However, the period of time over which the transplants were observed was too short to be conclusive.

Although some evidence has been put forth to indicate possible genetic differences between the tall and short form, there is also evidence which indicates the difference in growth and appearance is the result of certain envinonmental factors. The most obvious 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 reach their best development half way between the low and high tide levels and decline in height and luxuriance both seaward and shoreward. Reed did not measure differences in soil factors within the S. alterniflora zone, but differences in salinity and drainage were shown to exist between various plant communities in the marsh. Tide-elevation relationships obviously affect many soil physical and chemical properties which in turn influence plant growth, but salinity is the factor most often studied and related to zonation of marshes. Bourdeau and Adams (1956) found that salinity increased markedly from the tall to the short *S. alterniflora* zone. Results of a greenhouse study by Mooring, Seneca, and Cooper (1969) indicated that the height forms are ecophenes. From these results they postulated that exposure to environments differing in salinity may be the cause. Shea, Warren, and Niering (1972) also report evidence to support the ecophene status of the height forms.

Several reports of concentrations of various nutrients in the plant tissue of *Spartina* can be found in the literature (Williams, 1955; Williams and Murdoch, 1969). However, nutrient concentrations have not been related to productivity of the grass. The objective of this study is to determine if there are relationships between nutrient concentrations of the plant tissue and/or nutrient status of the soil and differences in productivity of *S. alterniflora*, either between locations or between height zones.

## Materials and Methods

Seven stands of *S. alterniflora* along the North Carolina coast were selected for sampling during the summer of 1970 (Figure 2.1). These stands are representative of variations in latitude, tide range, and type of substrate which occur along the North Carolina coast. The Oregon Inlet, Hatteras Village and Ocracoke sites are similar in that they are located on the sound side of barrier islands where the lunar tide range is 30 cm or less. There are two important damper effects which cause the narrow lunar tide range in estuaries north of Cape Lookout: (1) there are very few inlets through the barrier islands, and (2) there is a large expanse of water behind the islands. However,

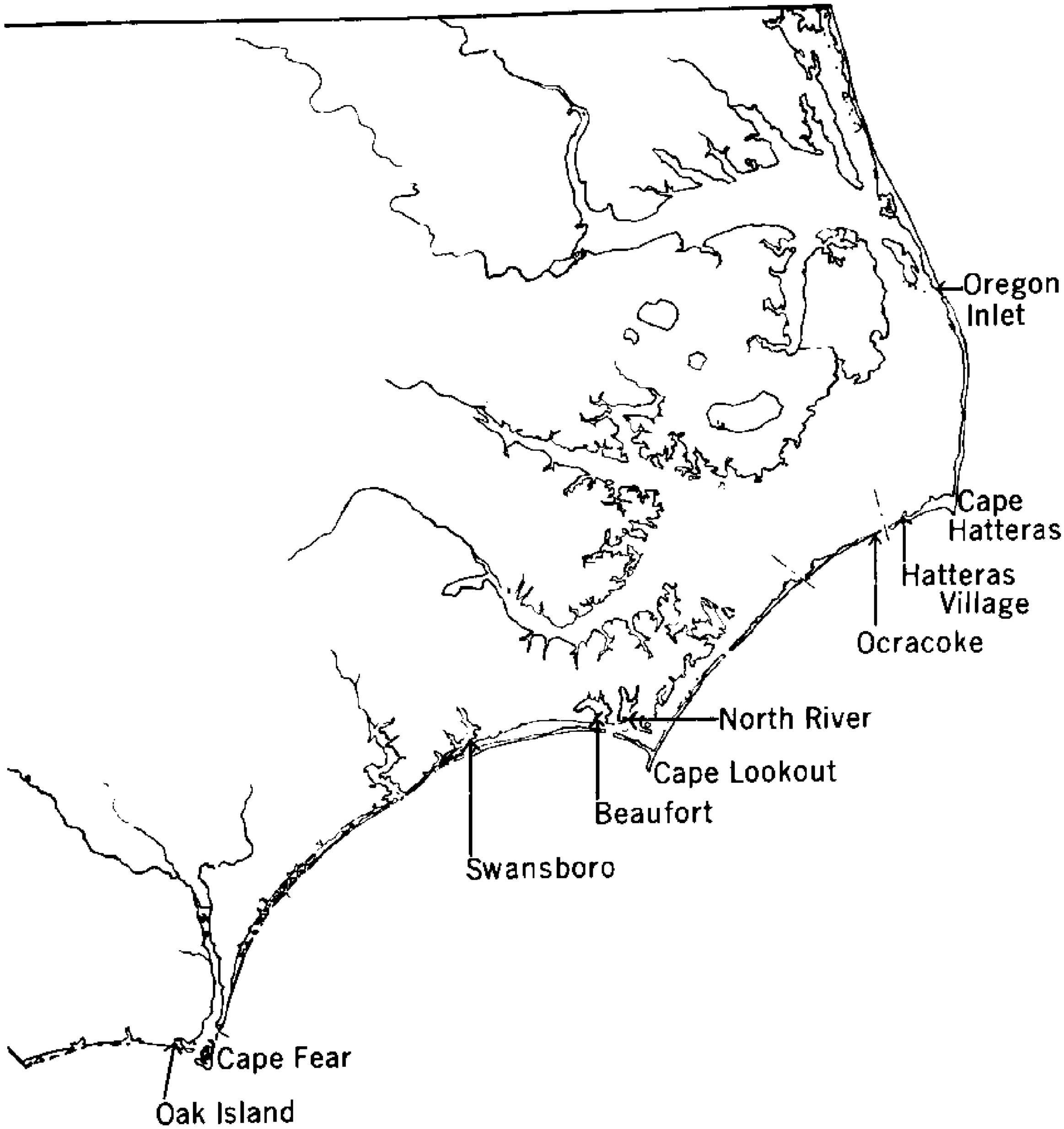



Figure 2.1. Locations of sampling sites (indicated by arrows)

winds greatly influence the tide levels causing a greater but irregular fluctuation of tide. The Oregon Inlet and Ocracoke marshes are young stands on sandy substrate. The Hatteras Village marsh is growing on a substrate which consists of 10% organic matter. The North River marsh is also in a location of low tidal amplitude. This marsh consists of a narrow fringe (about 20 m 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 as described by Cooper (1969). South of Cape Lookout inlets are more numerous and the estuaries are narrower allowing a greater tide range. Texture of the substrate is quite variable between the locations (Table 2.1).

Table 2.1. Soil texture and percent organic matter

| Location | % sand | | % silt | | % clay | | % 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[a]: | | | | | | | | |
| Loc x ht zone | | | | | | | | |
| .01 | ns | | ns | | ns | | 2.3 | |
| .05 | 10.0 | | 7.9 | | 3.1 | | 1.7 | |

[a]Main effects are not presented because of significant loc x ht zone interaction.

Plant samples were taken from each location and each height zone June 17-23, August 5-17, and September 30-October 2. 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 $m^2$ 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 3 points for sampling were randomly selected within each height zone. Sampling was done at low tide when possible.

Salinity of the soil solution was determined in the field with a hand-held refractometer (American Optical Co.). Measurements on the grass included dry weight (dried at 70°C in a forced-air oven), number of stems and height (the average of five randomly selected stems in each 0.25 $m^2$ 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 N, P, K, Na, Ca, Mg, S, Fe, Zn, Mn and Cu were made by the Department of Soil Science Analytical Service Laboratory at N. C. State University. Soil samples of the upper 15 cm were taken in each height zone at the time of the first plant sampling. These samples were air dried, screened and the following determinations were made by the Soil Testing Division of the N. C. Department of Agriculture using their routine methods: organic matter, Ca, Mg, P, K, Mn, Na, CEC and soluble salts. Soil texture was determined by the Bouyoucos hydrometer method (Day, 1965).

Regression analysis was the statistical technique used to detect relationships among nutrient levels in the soil, plant tissue and productivity. The logarithm (base 10) of yield and height at maturity were the dependent variables. The log-transformation was used to provide a better fit for the curves, decrease random variation and normalize the mean square error. There were 48 independent variables in the original data which consisted of the concentration of 11 different mineral nutrients in the plant tissue at each of three 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 $R^2$ improvement procedure (Service, 1972), the stepwise regression procedure (Draper and Smith, 1966) and critical examination of the independent variables from an agronomic viewpoint. 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 as 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 re-examined for significance. A variable which was entered at an early stage may become insignificant because of its relationship to other variables which enter the regression. The maximum $R^2$ improvement technique developed by J. H. Goodnight selects the "best" one variable model, the "best" two-variable model, etc. according to $R^2$.

## Results and Discussion

### 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 (Table 2.2). Multiple regression procedures were used as variable screening devices in an attempt 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 (Figure 2.2). Although the relationship between yield and height is highly significant, the $R^2$ (multiple correlation coefficient) is only 0.26. The $R^2$ was not greatly improved by transformation to logarithms. This lack of fit is due to the variation in growth habit between locations. Stands are thinnest where the tallest grass occurs; consequently, shorter grass may produce higher yields where stands are thicker. An example of this may be seen by comparing the data for yield and height from the tall height zones at Oregon Inlet and Beaufort (Table 2.3). The average height at Beaufort is much greater than at Oregon Inlet, but the yield at Oregon Inlet is greater. This can be attributed to the fact that there are 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. Shorter grass and thick stands occur at Oregon Inlet, Hatteras Village and Ocracoke where the regular lunar tide range is less than 30 cm. At Beaufort, Swansboro, and Oak Island where the tide range is about 1 m, the grass is taller but the stands are more sparse.

There is also a significant difference between the number of stems per unit area between the tall and short height zones. The stands are thicker in the short height zones but the yields are much less than in the tall height zones. Height and yield are more closely related within

Table 2.2. Variables used in model building and their simple correlations with dependent variables height and yield

| | Abbreviation | Simple correlation coefficient (r) | |
|---|---|---|---|
| | | Yield | Height |
| Soil properties (sampled June 17-23, 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 (ppm) | S-Mg | -0.04 | 0.22 |
| Manganese (ppm) | S-Mn | -0.19 | -0.08 |
| Sodium (ppm) | 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 (%) | | | |
| June 17-23 | AS-SAL | -0.49** | -0.05 |
| August 5-17 | BS-SAL | -0.23 | 0.01 |
| September 30-October 2 | CS-SAL | -0.39** | 0.00 |
| Nutrient content of the plant tissue | | | |
| June 17-23 | | | |
| 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 |
| August 5-17 | | | |
| 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 |

Table 2.2 (Continued)

| | Abbreviation | Simple correlation coefficient (r) | |
|---|---|---|---|
| | | Yield | Height |
| Magnesium (%) | BMg | 0.05 | 0.02 |
| Sulfur (%) | BS | -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 |
| September 30-October 2 | | | |
| 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 |

*.05 $r \geq |0.30|$
**.05 $r \geq |0.39|$

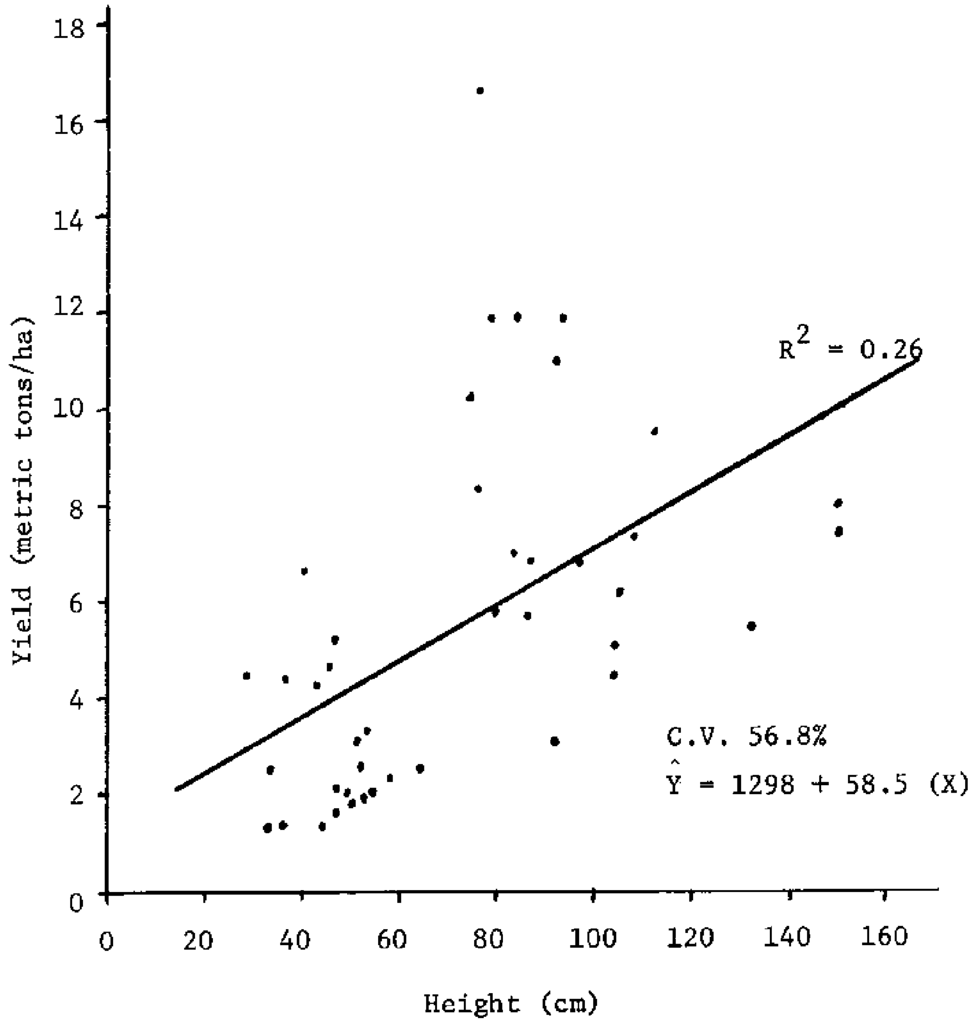



Figure 2.2. Relationship between height and yield of *S. alterniflora*

Table 2.3. Means and LSD's 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[a] | Short | $\bar{X}$ | Tall | Short | $\bar{X}$ | Tall | Short | $\bar{X}$ |
| Oregon Inlet | 8253 | 2213 | 5233 | 87 | 49 | 68 | 68 | 90 | 79 |
| Hatteras Vil. | 12867 | 5213 | 9040 | 76 | 38 | 57 | 144 | 171 | 158 |
| Ocracoke | 8800 | 2013 | 5407 | 91 | 47 | 69 | 102 | 148 | 125 |
| North River | 4200 | 1707 | 2953 | 100 | 34 | 67 | 30 | 59 | 44 |
| Beaufort | 6973 | 2253 | 4613 | 144 | 58 | 101 | 35 | 46 | 40 |
| Swansboro | 7800 | 4613 | 6207 | 83 | 42 | 62 | 62 | 131 | 96 |
| Oak Island | 7893 | 2360 | 5127 | 105 | 37 | 79 | 37 | 61 | 49 |
| $\bar{X}$ | 8112 | 2910 | | 98 | 45 | | 68 | 100.8 | |

| LSD: | Yield (kg/ha) | Height (cm) | No. stems/0.25 $m^2$ |
|---|---|---|---|
| Loc .01 | 2899 | 11 | 30 |
| .05 | 2149 | 8 | 22 |
| Ht zone .01 | 1549 | 6 | 16 |
| .05 | 1149 | 4 | 12 |
| Loc * ht zone .01 | ns | 15 | ns |
| .05 | ns | 11 | ns |

[a]Height zone.

a given marsh or type of marsh (Williams and Murdoch, 1969). That is, at a particular location the taller grass produces higher yields. For whatever reason, the correlation between height and yield was low enough that it was necessary to create separate models for height and yield.

## 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%. 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 aid of the stepwise regression procedure and the maximum $R^2$ improvement procedure. By using regression techniques two sets of variables most likely to be related to yield (Table 2.4) and height (Table 2.5) were selected. Each model contains 11 variables with an $R^2$ of 0.90. Thus, about 90% 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 necessarily 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 (Table 2.6). 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 error mean square and C.V., and it appeared that overfitting was a factor.

## Interpretation of the Model for Yield

As would be expected in a natural ecological system, there is some intercorrelation of variables (Table 2.7). When there is a correlation between independent variables in a model, the regression coefficients (b's) may not be reliable. However, by considering the regression model in combination with the simple correlations of each independent variable with yield (Table 2.2) and the means and LSD's obtained by analysis of variance, some insight as to the effect of each variable on variation in

Table 2.4. 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[a] | 0.3197 | 0.309 | 23.9** |
| CCa[a] | 1.3632 | 0.238 | 18.4** |
| AS-SAL | -0.0161 | 0.233 | 18.1** |
| BMn[a] | -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[a] | 3.2208 | 0.091 | 7.1** |
| S-P | 0.0005 | 0.085 | 6.6** |
| AS[a] | -0.3368 | 0.033 | 2.6* |

[a]Variables which also appear in the height equation.

*0.10 level of significance
**0.01 level of significance

Table 2.5. 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[a] | 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[a] | 0.6428 | 0.040 | 8.4** |
| BP[a] | 1.8244 | 0.031 | 6.5* |
| BMn[a] | -0.0028 | 0.019 | 4.0* |
| AS[a] | -0.2340 | 0.018 | 3.7† |

[a]Variables which also appear in the yield equation.

*0.05 level of significance
**0.01 level of significance
†0.10 level of significance

Table 2.6. 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, SMn, 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 |

yield 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 (Table 2.4).

The K content of the plant tissue at the fall sampling date (CK) is the variable which accounts for the highest amount of yield variation in the regression equation. At five of the seven locations K concentrations were greater in plants taken from the short height zone (Table 2.8). The trend of lower K concentrations in higher yielding plants is probably an indication of a greater dilution of K in the plant tissue where higher yields occur.

Table 2.7. Correlation matrix for the 11-variable model selected for dependent variable log (base 10) yield

| | AS-SAL | AP | ANa | AS | AMn | BP | BMn | CK | CCa | S-P | S-Mn | Yield |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AS-SAL | | -0.03 | 0.30 | 0.08 | 0.09 | -0.29 | -0.23 | 0.46 | 0.23 | 0.37 | -0.18 | -0.49 |
| AP | | | 0.32 | -0.68 | 0.25 | 0.21 | 0.20 | 0.05 | -0.25 | -0.14 | 0.40 | 0.09 |
| ANa | | | | -0.23 | 0.18 | -0.24 | -0.06 | -0.03 | -0.24 | 0.09 | 0.19 | 0.16 |
| AS | | | | | -0.17 | -0.30 | -0.28 | 0.03 | 0.30 | 0.01 | -0.32 | -0.14 |
| AMn | | | | | | 0.10 | 0.48 | -0.49 | 0.19 | -0.72 | 0.10 | -0.24 |
| BP | | | | | | | 0.39 | 0.10 | 0.16 | -0.06 | -0.10 | 0.23 |
| BMn | | | | | | | | -0.42 | 0.03 | -0.54 | -0.01 | -0.06 |
| CK | | | | | | | | | 0.07 | 0.68 | -0.00 | -0.32 |
| CCa | | | | | | | | | | -0.02 | -0.38 | 0.06 |
| S-P | | | | | | | | | | | -0.19 | 0.06 |
| S-Mn | | | | | | | | | | | | -0.19 |

$R^2 = 0.90$; CV = 3.1%

$r \geq |0.39|$ significant .01
$r \geq |0.30|$ significant .05
$r \geq |0.25|$ significant .10

Table 2.8. Means and LSD's for variables which appear in regression equations for yield and/or height

| Location | Tall[a] | Short | $\bar{X}$ | Tall | Short | $\bar{X}$ | Tall | Short | $\bar{X}$ |
|---|---|---|---|---|---|---|---|---|---|
| | | % | | | % | | | % | |
| | | AS-SAL | | | AN | | | AP | |
| Oregon Inlet | 15.7 | 27.7 | 21.7 | 1.06 | 1.04 | 1.05 | 0.13 | 0.11 | 0.12 |
| Hatteras Vil. | 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 | 0.98 | 0.09 | 0.12 | 0.11 |
| Oak Island | 30.0 | 25.0 | 27.5 | 0.92 | 0.89 | 0.91 | 0.19 | 0.13 | 0.16 |
| $\bar{X}$ | 27.6 | 31.6 | | 0.98 | 0.98 | | 0.12 | 0.11 | |
| LSD: | | | | | | | | | |
| Loc .01 | | 3.4 | | | 0.11 | | | 0.02 | |
| .05 | | 2.6 | | | 0.08 | | | 0.01 | |
| Ht zone .01 | | 1.8 | | | ns | | | 0.01 | |
| .05 | | 1.4 | | | ns | | | 0.01 | |
| Loc x ht zone .01 | | 4.9 | | | ns | | | 0.02 | |
| .05 | | 3.6 | | | ns | | | 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 Vil. | 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 |
| $\bar{X}$ | 2.50 | 2.29 | | 0.40 | 0.51 | | 0.29 | 0.29 | |
| LSD: | | | | | | | | | |
| Loc .01 | | 0.38 | | | 0.13 | | | 0.04 | |
| .05 | | 0.25 | | | 0.09 | | | 0.03 | |
| Ht zone .01 | | 0.18 | | | 0.07 | | | ns | |
| .05 | | 0.13 | | | 0.05 | | | ns | |
| Loc x ht zone .01 | | ns | | | ns | | | 0.05 | |
| .05 | | ns | | | ns | | | 0.04 | |

Table 2.8 (Continued)

| Location | Tall[a] | Short | X̄ | Tall | Short | X̄ | Tall | Short | X̄ |
|---|---|---|---|---|---|---|---|---|---|
| | | % | | | % | | | % | |
| | | AFe | | | AMn | | | BP | |
| Oregon Inlet | 89 | 121 | 105.0 | 32 | 31 | 31.7 | 0.14 | 0.13 | 0.13 |
| Hatteras Vil. | 96 | 113 | 104.3 | 22 | 25 | 23.3 | 0.11 | 0.07 | 0.09 |
| Ocracoke | 460 | 131 | 295.3 | 29 | 40 | 34.7 | 0.08 | 0.09 | 0.09 |
| North River | 940 | 380 | 660.0 | 41 | 37 | 39.0 | 0.08 | 0.10 | 0.09 |
| Beaufort | 1413 | 1887 | 1650.0 | 41 | 25 | 33.0 | 0.09 | 0.08 | 0.09 |
| Swansboro | 1160 | 407 | 783.7 | 11 | 9 | 10.0 | 0.09 | 0.10 | 0.10 |
| Oak Island | 753 | 673 | 713.3 | 37 | 31 | 34.0 | 0.11 | 0.09 | 0.10 |
| X̄ | 701.6 | 530.3 | | 30.6 | 28.2 | | 0.10 | 0.09 | |
| LSD: | | | | | | | | | |
| Loc .01 | | 208 | | | 7.2 | | | 0.02 | |
| .05 | | 154 | | | 5.3 | | | 0.01 | |
| Ht zone .01 | | 111 | | | ns | | | 0.01 | |
| .05 | | 83 | | | ns | | | 0.01 | |
| Loc x ht zone .01 | | 295 | | | 10.1 | | | 0.03 | |
| .05 | | 218 | | | 7.5 | | | 0.02 | |
| | | BMg | | | Bmn | | | BS | |
| Oregon Inlet | 0.24 | 0.31 | 0.27 | 28.7 | 41.3 | 35.0 | 0.30 | 0.48 | 0.39 |
| Hatteras Vil. | 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 |
| X̄ | 0.34 | 0.32 | | 22.7 | 19.9 | | 0.55 | 0.98 | |
| LSD: | | | | | | | | | |
| Loc .01 | | 0.05 | | | 7.4 | | | 0.19 | |
| .05 | | 0.04 | | | 5.5 | | | 0.14 | |
| Ht zone .01 | | ns | | | ns | | | 0.10 | |
| .05 | | ns | | | ns | | | 0.07 | |
| Loc x ht zone .01 | | 0.07 | | | 10.5 | | | 0.26 | |
| .05 | | 0.05 | | | 7.8 | | | 0.19 | |

Table 2.8 (Continued)

| Location | Tall[a] | Short | X̄ | Tall | Short | X̄ | Tall | Short | X̄ |
|---|---|---|---|---|---|---|---|---|---|
| | | % | | | % | | | % | |
| | | CN | | | CK | | | CCa | |
| Oregon Inlet | 0.72 | 0.82 | 0.77 | 0.80 | 0.87 | 0.83 | 0.33 | 0.37 | 0.35 |
| Hatteras Vil. | 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 |
| X̄ | 0.77 | 0.82 | | 0.77 | 0.96 | | 0.32 | 0.31 | |
| LSD: | | | | | | | | | |
| Loc .01 | | ns | | | 0.14 | | | 0.06 | |
| .05 | | ns | | | 0.10 | | | 0.04 | |
| Ht zone .01 | | ns | | | 0.07 | | | ns | |
| .05 | | 0.05 | | | 0.05 | | | ns | |
| Loc x ht zone .01 | | ns | | | 0.19 | | | 0.08 | |
| .05 | | 0.13 | | | 0.14 | | | 0.06 | |
| | | S-P (ppm) | | | SMn (ppm) | | | | |
| Oregon Inlet | 18.3 | 11.0 | 14.7 | 3.33 | 4.00 | 3.67 | | | |
| Hatteras Vil. | 24.0 | 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 | 644.0 | 3.00 | 3.67 | 3.33 | | | |
| Oak Island | 33.0 | 36.0 | 34.5 | 27.00 | 69.33 | 48.17 | | | |
| X̄ | 124.1 | 127.4 | | 7.95 | 14.95 | | | | |
| LSD: | | | | | | | | | |
| Loc .01 | | 35.4 | | | 8.75 | | | | |
| .05 | | 26.2 | | | 6.48 | | | | |
| Ht zone .01 | | ns | | | 4.67 | | | | |
| .05 | | ns | | | 3.47 | | | | |
| Loc x ht zone .01 | | 50.0 | | | 12.37 | | | | |
| .05 | | 37.1 | | | 9.17 | | | | |

[a]Height zone.

Sodium concentration of the plant tissue at the first sampling date (ANa) is positively related to yield. Significant differences in Na concentrations occur between height zones and locations (Table 2.8). Plants from the tall height zones had higher concentrations than from the short height zones. The explanation for this is not apparent; particularly in light of the fact that higher salinities of the soil solution (AS-SAL) were clearly related to decreased yields (Table 2.2). High salinity of the soil solution has often been suggested as a cause for reduced growth of S. alterniflora (Mooring, Seneca, and Cooper, 1969).

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 (Table 2.8) and the simple correlations (Table 2.2) 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 Mn (S-Mn) are all negatively related to yield. The solubility of soil manganese is increased under conditions of poor aeration. The importance of Mn 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, Mn toxicity is unlikely in light of the concentration in the plant tissue (Table 2.6). We found concentrations of 10X this amount with no apparent ill effects to plants in growth chamber studies with S. alterniflora in which the nutrient source was modified Hoagland's solution.

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 P for plant growth is well known and 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 2.8 clearly show that concentration of sulfur is much less in plants from the tall height zones. It is not possible to determine from the data if this is a dilution effect or if there is more sulfur available in the short height zone.

## Interpretation of the Model for Height

Since some variables in this model are also correlated (Table 2.9), caution must again 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 (Table 2.8). There is a clear relationship between increased sulfur concentration and decreased

Table 2.9. Correlation matrix for the 11-variable model selected for dependent variable log (base 10) height

| | AN | ANa | AMg | AS | AFe | BP | BMg | BS | BMn | CN | CCa | Yield | Ht |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AN | | -0.29 | -0.32 | 0.21 | -0.09 | 0.05 | -0.32 | 0.10 | -0.15 | 0.09 | 0.38 | 0.14 | 0.04 |
| ANa | | | 0.36 | -0.23 | 0.63 | -0.24 | 0.19 | 0.01 | -0.06 | -0.02 | -0.24 | 0.16 | 0.52 |
| AMg | | | | 0.01 | 0.21 | -0.09 | 0.50 | 0.14 | -0.08 | 0.12 | 0.26 | -0.23 | 0.03 |
| AS | | | | | -0.18 | -0.30 | 0.34 | 0.57 | -0.28 | 0.29 | 0.30 | -0.14 | -0.52 |
| AFe | | | | | | -0.38 | 0.06 | 0.10 | -0.11 | 0.06 | 0.18 | -0.11 | 0.43 |
| BP | | | | | | | -0.31 | -0.37 | 0.39 | 0.11 | 0.16 | 0.23 | 0.09 |
| BMg | | | | | | | | 0.26 | -0.11 | 0.10 | 0.30 | 0.05 | 0.02 |
| BS | | | | | | | | | -0.56 | 0.25 | 0.09 | -0.42 | -0.59 |
| BMn | | | | | | | | | | -0.10 | 0.03 | -0.06 | 0.24 |
| CN | | | | | | | | | | | 0.15 | -0.14 | -0.27 |
| CCa | | | | | | | | | | | | 0.06 | 0.05 |
| Yield | | | | | | | | | | | | | 0.51 |
| Ht | | | | | | | | | | | | | |

$r \geq |0.39|$ significant at .01
$r \geq |0.30|$ significant at .05
$r \geq |0.25|$ significant at .10

growth, but it is not possible 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 (Table 2.8).

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 Mg with height apparent from the simple correlations (Table 2.2) or the means (Table 2.8). 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 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 N concentration at the third sampling date (CN) was negatively correlated with height. A probable explanation for this is that plant available N is scarce in the marsh environment. At the first sampling date high N concentrations in the plant are indicative of a high potential for growth. At maturity the N 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 (Table 2.8) or the simple correlation with height (Table 2.2).

Phosphorus concentration at the second sampling time (BP) was positively correlated with plant height. This indicates that where greater amounts of P 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 (Table 2.5). 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 Mn concentration to height is opposite of that with yield.

The sulfur concentration of the plant tissue at the first sampling date (AS) is negatively related to height as it was to yield. Concentrations of S in plants from the short height zones were quite high (Table 2.8).

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 our study it is possible to calculate the standing crop of nutrients contained in the above-ground portion of mature *S. alterniflora* stands (Table 2.10). Since the total amount of nutrients incorporated in the plant tissue is highly dependent on yields, the dry weight is a good predictor of standing crops of the mineral nutrients. The $R^2$ values for standing crop of N, P, K, S, Ca, Mg and Na are quite

Table 2.10. Simple statistics and regression equations for standing crop of mineral nutrients in the above-ground shoots of *S. alterniflora*

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

[a]Mean of 42 samples.

[b]Y = standing crop of nutrients of above-ground shoots at maturity (kg/ha); X = dry weight of above-ground shoots at maturity (kg/ha).

high (Table 2.10) 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 Fe, Zn, Mn and Cu standing crops would be less accurate.

## Summary and Conclusions

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 purposes 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 P 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 confirms 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 (Table 2.2).

The importance of Mn and S in both the yield and height equations and Fe in the height equation suggest 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 among _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 P and N in sediment-water systems are presented by Syers, Harris, and Armstrong (1973) and Keeney (1973).

The positive influence of P concentration in the plant tissue would be expected since in most natural plant-soil systems P is second only to N 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 N does not show up in the equation because it is the limiting factor in growth. If the availability of N was limiting growth, then growth would proceed whenever N became available. Consequently, the concentration of N 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 N 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 (Table 2.2). There are two factors which contribute to this. First, the waterlogged conditions of these soils tend to equalize chemical differences. A second factor is the methods by which these determinations were made. Standard soil testing procedures were used which probably are not suitable for these kinds of soils. An important difference is that North Carolina soil test procedures and extracting solutions are designed for acid soils. The pH 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 itself.

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.

## List of References


Adams, D. A. 1963. Factors influencing vascular plant zonation in North Carolina salt marshes. Ecology 44:445-456.

Black, C. A. 1968. Soil-Plant Relationships. John Wiley & Sons, Inc., New York.

Bourdeau, P. F., and D. A. Adams. 1956. Factors in vegetational zonation of salt marshes near Southport, North Carolina. Bull. Ecol. Soc. Am. 37:68. (Abstract).

Chapman, V. J. 1960. Salt Marshes and Salt Deserts of the World. Interscience Publishers, Inc., New York.

Cooper, A. W. 1969. Salt marshes, pp. 563-611. *In* H. T. Odum, B. J. Copeland, and E. A. McMahon (ed.), Coastal Ecological Systems of the U. S. Vol. 1. Report to the Water Pollution Control Administration, Washington, D. C.

Day, P. R. 1956. Report of the committee on physical analyses, 1954-1955. Proc. Soil Sci. Soc. Am. 20:167-169.

de la Cruz, A. A., and E. P. Odum. 1967. Particulate organic detritus in a Georgia salt marsh--estuarine ecosystem, pp. 383-388. In G. H. Lauff (ed.), Estuaries. Am. Assoc. Advanc. Sci., Washington, D. C.

Draper, N. R., and H. Smith. 1966. Applied Regression Analysis. John Wiley & Sons, Inc., New York.

Hinde, H. P. 1954. The vertical distribution of salt marsh phanerograms in relation to tide levels. Ecol. Monographs 24: 209-225.

Johnson, D. S., and H. H. York. 1915. The relation of plants to tide-levels. Carnegie Inst. Publ., Washington, D. C. 206:1-162.

Keeney, D. R. 1973. The nitrogen cycle in sediment-water systems. J. Environ. Quality 2:15-28.

Mooring, M., A. W. Cooper, and E. D. Seneca. 1971. Seed germination response and evidence for height ecophenes in Spartina alterniflora from North Carolina. Amer. J. Bot. 58:48-55.

Odum, E. P. 1959. Fundamentals of Ecology. W. B. Saunders Co., Philadelphia, Penn. p. 73.

Redman, F. H., and W. H. Patrick, Jr. 1965. Effect of submergence on several biological and chemical soil properties. Bull. Louisiana Agr. Exp. Sta. 592. pp. 1-28.

Reed, J. F. 1947. The relation of the Spartinetun glabrae near Beaufort, N. C. to certain edaphic factors. Amer. Midl. Nat. 38:605-614.

Service, J. 1972. A Users Guide to the Statistical Analysis System. Student Supply Stores, N. C. State Univ., Raleigh.

Shea, M. L., R. S. Warren, and W. A. Niering. 1972. The ecotype/ ecophene status of varying height forms of Spartina alterniflora. Bull. Ecol. Soc. Amer. 53(2):15-16. (Abstract).

Stalter, R., and W. T. Batson. 1969. Transplantation of salt marsh vegetation, Georgetown, South Carolina. Ecology 50:1087-1089.

Stroud, L. M., and A. W. Cooper. 1969. Color infrared aerial photographic interpretation and net primary productivity of a regularly-flooded North Carolina salt marsh. Water Resources Research Inst., Univ. of N. C., Raleigh. pp. 1-86.

Syers, J. K., R. F. Harris, and D. E. Armstrong. 1973. Phosphate chemistry in lake sediments. J. Environ. Quality 2:1-14.

Teal, J. M. 1962. Energy flow in the salt marsh ecosystem of Georgia. Ecology 43:614-624.

Williams, R. B., and M. B. Murdoch. 1969. The potential importance of Spartina alterniflora in conveying zinc, manganese, and iron into estuarine food chains, pp. 431-439. In D. J. Nelson and F. C. Evans (ed.), Proc. of the Second Nat. Symp. on Radioecology. USAEC, CONF-670503. Ann Arbor, Mich.

Williams, R. E. 1959. Development and improvement of coastal marsh ranges, pp. 444-449. Yearbook of Agriculture. U. S. Govt. Printing Office, Washington, D. C.

# THE RELATIONSHIP OF MINERAL NUTRIENTS TO GROWTH OF *SPARTINA ALTERNIFLORA*. II. THE EFFECTS OF N, P, K AND Fe FERTILIZERS

## Introduction

Although there have been many studies on the productivity of *S. alterniflora* and its importance to the estuarine ecosystem, there have been very few reports of studies related to the mineral nutrition of the plant. Neither the effects of nutrient supply on the difference in productivity of the height forms within a marsh nor the effects of differences in nutrient supply between marshes at different locations has been studied.

Adams (1963) suggested that the chlorotic appearance of short *Spartina* was due to iron being less available in the short height zone than in the tall. Pomeroy *et al*. (1969) found that the sediments dominate both the P and Zn cycles in a Georgia salt marsh. Pigott (1969) reported increased growth of some marsh species with the addition of N and P, but *Spartina* was not included in the study. Marshall (1970) found that the addition of sewage effluent to a marsh near Beaufort, N. C. increased the biomass of *Spartina*.

Since very little is known about the effect of mineral nutrition on the growth of *S. alterniflora*, a study was initiated to evaluate the influence of N, P, K, and Fe on primary productivity by applying these nutrients to plots in natural *S. alterniflora* salt marshes and on *S. alterniflora* seeded and transplanted on dredge spoil.

## Materials and Methods

### Description of Sites

Fertilizer experiments were established in natural stands of *S. alterniflora* on the North Carolina coast at Ocracoke Island and Oak

Island. Fertilizer plots at Ocracoke were located in a marsh on the north end of the island near Hatteras Inlet. This is a relatively young marsh established on a substrate of sand in which there is as yet very little development of creeks. There is some difference in growth between different areas within the marsh, which is apparently due to environmental factors, but zonation of height forms is not as obvious as in many older marshes. The regular lunar tide at this location is only about 30 cm, but the added effect of the wind produces a range of up to 1 m. Consequently, flooding and draining of the marsh is irregular depending on wind velocity and direction.

The Oak Island marsh, located near the Oak Island lighthouse, differs markedly from the Ocracoke site and is more typical of a South Atlantic coastal Plain marsh as described by Cooper (1969). It is an old marsh drained by a dendritic pattern of creeks. The substrate is bluish gray in color, has an organic matter content of 10%, and is silt loam in texture. A dense mat of roots 15-30 cm thick is characteristic of the short S. alterniflora. The typical zonation pattern of tall, medium and short forms as recognized by Teal (1962) is present. The lunar tide range is about 1.3 m and the marsh is regularly flooded and drained twice daily.

Some characteristics of the two marshes are presented in Table 3.1. Texture was determined by the hydrometer method. Salinity was determined on soil water with an American Optical refractometer. Organic matter, cation exchange capacity (CEC) and nutrients were determined by the Soil Testing Division, North Carolina Department of Agriculture.

Table 3.1. Location and description of the properties of the substrate at the experimental sites

| Site | Location | | Tide | Texture, % | | | O.M. | CEC, | Salinity | kg/ha in the upper 20 cm | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Lat. | Long. | range | Sand | Silt | Clay | % | meq/100 g | % | P | K | Ca | Mg |
| Ocracoke | 35°12'N | 75°44'W | 30 cm | 94.4 | 3.2 | 2.4 | 0.5 | 1.0 | 3.6 | 71 | 540 | 4040 | 1337 |
| Oak Island | | | | | | | | | | | | | |
| Tall | 33°54'N | 78°01'W | 1.3 m | 34.3 | 50.4 | 15.3 | 10.0 | 25.0 | 2.5 | 53 | 2158 | 5300 | 5370 |
| Short | -- | -- | -- | 35.7 | 50.5 | 13.8 | 10.0 | -- | 2.9 | 24 | 774 | 3964 | 4131 |

Fertilizer Experiments at Ocracoke

In 1970 two fertilizer experiments were established in the *S. alterniflora* marsh at Ocracoke. One experiment consisted of several combinations of N, P and K fertilizers. The field layout was a randomized complete block design with two replications at each of three sites within the marsh. The sites were selected to represent the range of *S. alterniflora* growth within the marsh varying from stunted to vigorous. Plots were 1.83 x 7.62 m with a 1.83-m border area between each plot. The sources of N, P and K were ammonium nitrate, concentrated superphosphate and muriate of potash, respectively, which were broadcast on the sediment surface. The rates were 56 kg/ha N, 24.6 kg/ha P and 46.5 kg/ha K applied on July 1, 1970. The plots to which N was applied received an additional 56 kg/ha N on August 3. The treatments consisted of the following combinations of fertilizers: (1) NPK, (2) NP, (3) NK, (4) PK, (5) Check.

A second experiment consisted of four rates of nitrogen (0, 112, 224, 448 kg/ha) applied as $NH_4NO_3$ in a randomized complete block design with three replications. Plots were 1.22 x 7.62 m with 1.22-m borders between plots. All of the N was applied on August 3, 1970.

Samples were harvested from both experiments October 1, 1970 by randomly selecting and clipping two 0.25-$m^2$ samples from each plot. The samples were dried in a forced-air oven at 70 C and weighed. Subsamples were ground in a Wiley mill and were analyzed for nutrient content by the Department of Soil Science Analytical Service Laboratory of North Carolina State University.

To more clearly document the effect of N and P fertilizers on yield, an experiment of factorial design with two levels of P and four levels of N was initiated at Ocracoke in 1971. The experiment was a randomized complete block design with 1.22 x 7.62-m plots and 1.22-m borders between plots. Phosphorus was supplied by concentrated superphosphate at rates of 0 and 74 kg/ha P. Nitrogen rates were 0, 168, 336 and 672 kg/ha N supplied by ammonium sulphate. An ammonium form of nitrogen was thought to be more suitable to the marsh environment since it is the form of N found in the greatest quantities in reduced soils. Application of the nitrate form of nitrogen to poorly drained soils is undesirable since it is subject to denitrification and loss to the atmosphere in the gaseous forms $N_2$ or $N_2O$ (Keeney, 1972). The ammonium form also has the advantage of being adsorbed by the exchange complex of the soil. It is also possible that S. alterniflora is adapted to utilization of the ammonium form of nitrogen similar to certain other plants which grow under waterlogged conditions.

The fertilizer materials were applied in split applications with equal amounts applied on May 12, June 22 and July 27, 1971 by broadcasting evenly over the sediment surface. Samples were harvested September 1, 1971 by cutting a 0.61 x 1.52-m swath from each plot with a Jari sickle-bar mower. Salicornia spp., dead stems of S. alterniflora from the previous years growth and other foreign matter were separated from the S. alterniflora plants. The plants were dried and processed in the same manner as previously described.

This experiment was continued in 1972. The plots were clipped and raked in early spring to facilitate harvesting and insure that all plant material harvested in the fall was produced in that growing season. The same rates of nitrogen and phosphorus fertilizers were again applied in split applications on April 13, June 20 and July 19, 1972. Samples were harvested September 11 by clipping a 0.61 x 3.96-m swath from each plot.

Roots and rhizomes were sampled in 1972 by taking five cores 8.5 cm in diameter and 30 cm deep from each plot. The cores were returned to the laboratory where they were divided into 0-10 and 10-30-cm layers and washed with tap water by placing them on screens and spraying with a hose until all the soil material was removed. Ten core samples were selected at random to separate the roots from rhizomes. All the samples were then dried in a forced-air oven at 70 C.

## Fertilizer Experiments at 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 N fertilization. Plots were 1.22 x 15.2 m with 1.22-m borders between plots and laid out perpendicular to a creek such that each plot contained the tall and short forms of *S. alterniflora*. Iron and nitrogen fertilizers were applied in split applications on May 18, June 30 and August 3, 1971 (Table 3.7). Ammonium sulphate was the nitrogen source. The iron sources were Geigy Sequestrine/330 iron chelate applied (1) as a spray to the plants and (2) in the dry form to the sediment surface and (3) ferrous sulphate applied as a spray. Samples were harvested October 4, 1971 by clipping a 0.25-$m^2$ area from the short *S. alterniflora* and a 0.25-$m^2$ area from the tall *S. alterniflora* in each plot. The samples were washed in tap water and then distilled water to remove mud from the leaves and stalks, dried at 70 C, weighed and ground in preparation for nutrient analyses of the plant tissue.

In 1972, an experiment was established adjacent to another creek in the same marsh to evaluate the effect of P fertilization. The experiment was a factorial design with two levels of P and four levels of N identical to the factorial experiment previously described for Ocracoke. Three randomized complete blocks were laid out perpendicular to a creek so that each plot contained the tall and short forms of grass. Plots were 1.22 x 15.2 m with 1.22-m borders between each plot. The fertilizer was applied in split applications with equal amounts applied on May 1, June 22 and July 26, 1972. Samples were harvested September 20, 1972 by clipping a 1-$m^2$ sample from the short height zone of each plot and a 0.25-$m^2$ sample from the tall height zone of each plot. The samples were dried in a forced-air oven at 70 C and weighed.

The Effect of Fertilizer on Seedlings and Transplants

Fertilizer plots were established on seedlings at Beaufort and transplants at Drum Inlet. Seed were planted in the intertidal zone of a pile of sandy dredge spoil, which had been in place for about 1 year, near Beaufort on April 4, 1972. The seed were broadcast and then covered by six sweeps mounted on the tool bar of a tractor and followed by a section harrow. After the seedlings were established, a randomized complete block fertilizer experiment with three treatments (N, NP, Check) and three replications was superimposed. Rates were 224 kg/ha N and 49 kg/ha P with half applied on June 26 and half on July 26, 1972. Plots were 1.22 m x 7.62 m with 1.22-m borders. Samples were harvested October 5, 1972 by cutting a swath .6 m wide x 6 m long from each plot at ground level with a Jari mower. The samples were dried at 70 C and weighed.

Fertilizer was applied to plots just before transplanting at Drum Inlet. The fertilizer treatments were a 2 x 4 factorial design (N = 0, 56, 112, 224 kg/ha and P = 0 and 25 kg/ha). Plots consisted of three rows .91 m apart and approximately 18 m 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 opened by sweeps on a tractor the day before transplanting which was June 28, 1972. 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 because extensive grading was necessary to prepare a suitable area for the experiment within the elevational range of S. alterniflora of only about 30 cm at this location (the elevational range of the grass is approximately equal to the tide range at a given location). Plant samples were taken October 4, 1972 by clipping one plant from each row. Data recorded included dry weight, number of flowers, number of center culms and number of rhizomes per plant.

In all the experiments the yield or standing crop of shoots which is reported is the dry weight of the living stems and leaves clipped at the sediment surface.

## Results and Discussion

### Ocracoke

NPK Experiment. The addition of N and P significantly increased the standing crop of S. alterniflora (Table 3.2). Since site x treatment interaction was not significant, the analysis was combined over the three

Table 3.2. Effect of N, P and K on yield and chemical composition of *S. alterniflora* shoots

| Fertilizer rates kg/ha | | | Standing crop | Nutrient concentration in the plant tissue | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Percent | | | | | | | Parts per million | | | |
| N | P | K | kg/ha | N | P | K | Ca | Mg | S | Na | Cu | Mn | Zn | Fe |
| 112 | 24.6 | 46.5 | 4026.7 | 0.84 | 0.10 | 0.74 | 0.40 | 0.45 | 0.42 | 2.34 | 2.8 | 30.8 | 10.3 | 325 |
| 112 | 24.6 | 0 | 3973.3 | 0.80 | 0.10 | 0.76 | 0.38 | 0.44 | 0.49 | 2.50 | 2.3 | 31.5 | 12.6 | 304 |
| 112 | 0 | 46.5 | 3226.7 | 0.83 | 0.07 | 0.78 | 0.37 | 0.45 | 0.50 | 2.29 | 2.6 | 29.7 | 12.9 | 319 |
| 0 | 24.6 | 46.5 | 2930.0 | 0.76 | 0.11 | 0.70 | 0.36 | 0.43 | 0.47 | 2.31 | 3.3 | 25.3 | 13.3 | 280 |
| 0 | 0 | 0 | 2670.0 | 0.69 | 0.08 | 0.69 | 0.40 | 0.48 | 0.52 | 2.62 | 2.9 | 26.5 | 12.4 | 327 |
| LSD .01 | | | 902.1 | 0.10 | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns |
| .05 | | | 643.5 | 0.07 | 0.02 | ns | ns | ns | 0.05 | 0.24 | ns | ns | ns | ns |
| CV % | | | 15.2 | 7.0 | 18.2 | 10.1 | 14.2 | 8.9 | 9.2 | 8.0 | 50.0 | 10.1 | 11.0 | 17.0 |

sites within the marsh. The addition of N, P, and K did not significantly increase the yield over the NP treatment alone. This might be expected since the K content of the soil is high (Table 3.1), and the concentration of K in the sea water which floods the marsh is also relatively high (Horne, 1969). The increase of N in the plant tissue was highly significant (.01 level) for treatments which received nitrogen when compared to the check. The addition of fertilizer P significantly (.05 level) increased P content of the plant tissue. However, the addition of fertilizer K did not increase K in the plant tissue indicating that the K supply in the environment is adequate.

Nitrogen Rates. Nitrogen alone applied to the marsh at Ocracoke produced a definite trend of increasing yields with increasing N rates (Table 3.3). The only statistically significant (.05 level) difference in yield was between the check and the 448 kg/ha rate. This heavy rate was necessary to increase yields significantly possibly because of inefficient uptake or because the fertilizer was applied late in the growing season. The increased yield resulting from nitrogen application indicates that lack of N availability is limiting productivity in this *S. alterniflora* marsh.

As the N rate increased, the N content of the plant tissue increased linearly with an $R^2$ of 0.91 [$\hat{Y} = 0.62 + 0.001 (X)$]. Potassium, Fe and Mn concentrations in the plant tissue also increased significantly with N rate.

N-P Factorial. Since the results of the two experiments in the summer of 1970 revealed a lack of growth response from the addition of K and a significant response to both N and P, a factorial experiment was

Table 3.3. Effect of N fertilizer on yield and chemical composition of *S. alterniflora* from Ocracoke

| Nitrogen kg/ha | Standing crop kg/ha | Nutrient concentrations in the plant tissue | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Percent | | | | | | | Parts per million | | | |
| | | N | P | K | Ca | Mg | Na | S | Cu | Mn | Zn | Fe |
| 0 | 2073.3 | 0.66 | 0.09 | 0.63 | 0.35 | 0.48 | 2.56 | 0.46 | 2.1 | 19.6 | 9.9 | 299.3 |
| 112 | 2573.3 | 0.81 | 0.09 | 0.73 | 0.43 | 0.52 | 2.90 | 0.51 | 3.8 | 30.1 | 11.6 | 486.3 |
| 224 | 2913.3 | 0.93 | 0.08 | 0.82 | 0.42 | 0.47 | 2.48 | 0.46 | 2.7 | 31.0 | 9.7 | 363.7 |
| 448 | 3720.0 | 1.08 | 0.08 | 0.85 | 0.42 | 0.51 | 2.81 | 0.51 | 2.9 | 37.5 | 10.9 | 485.0 |
| LSD .01 | ns | 0.14 | ns | 0.14 | ns | ns | ns | ns | ns | 11.94 | ns | ns |
| .05 | 1087.1 | 0.09 | ns | 0.09 | ns | 0.02 | ns | ns | ns | 7.88 | ns | 148.4 |
| CV % | 19.3 | 5.3 | 6.4 | 5.9 | 13.5 | 2.5 | 7.3 | 49 | 22.8 | 13.4 | 15.2 | 18.4 |

designed to more clearly document the effects of the N and P fertilizers on yield and chemical composition of the plant tissue.

The results indicate that, although additions of nitrogen alone can increase yields significantly, the availability of P quickly becomes limiting when N rates are increased (Figure 3.1). Yields at the end of the first growing season were increased only slightly by the addition of N without P. The only statistically significant (.05 level) difference was between the yield of the check plots and those receiving 672 kg/ha N. However, when P was applied at the rate of 74 kg/ha, yield was markedly increased by additions of N up to 336 kg/ha. The yield produced by 672 kg/ha N was not significantly greater than that where 336 kg/ha were applied during the first growing season.

During the second growing season, higher yields and a greater response to fertilization was attained (Figure 3.1). When P was supplied, the rate of yield increase did not level off beyond 336 kg/ha N as in the first year, but was linear over the range of N rates applied. Apparently a rate of N fertilization even beyond 672 kg/ha would have produced significant yield increases. It is not surprising that response to fertilizer would be greater the second year since S. alterniflora is a perennial grass which would likely require a period of adjustment to an increase in nutrient availability before maximum yields were reached. There was also an increase in the difference between yields of no P and P treatments, indicating P became more severely limiting during the second year as yields increased.

Nitrogen content of the plant tissue was closely related to the rate of N applied as fertilizer (Figures 3.2a and 3.2b). During both

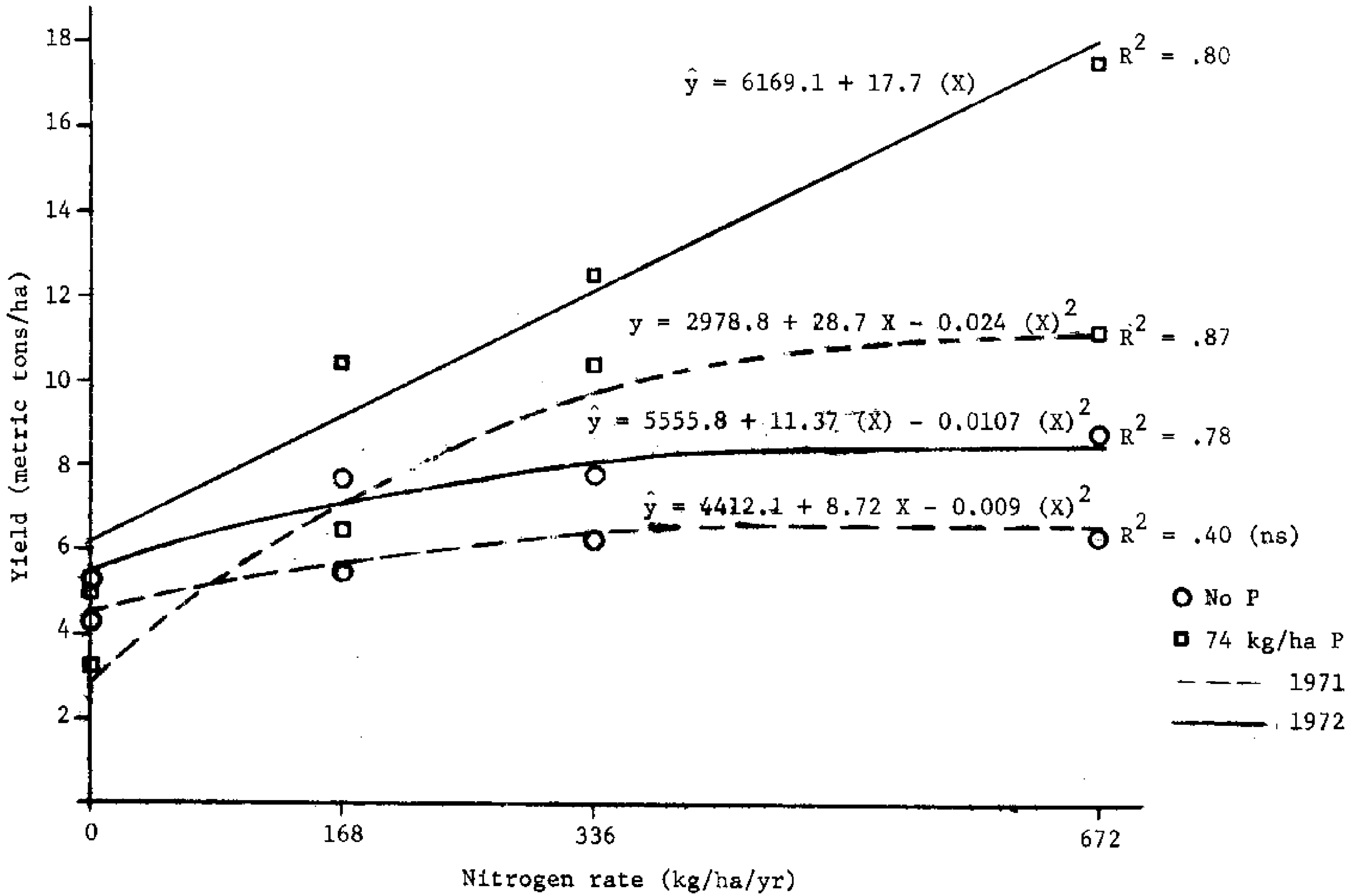



Figure 3.1. Effect of nitrogen and phosphorus fertilizers on yields during two successive growing seasons

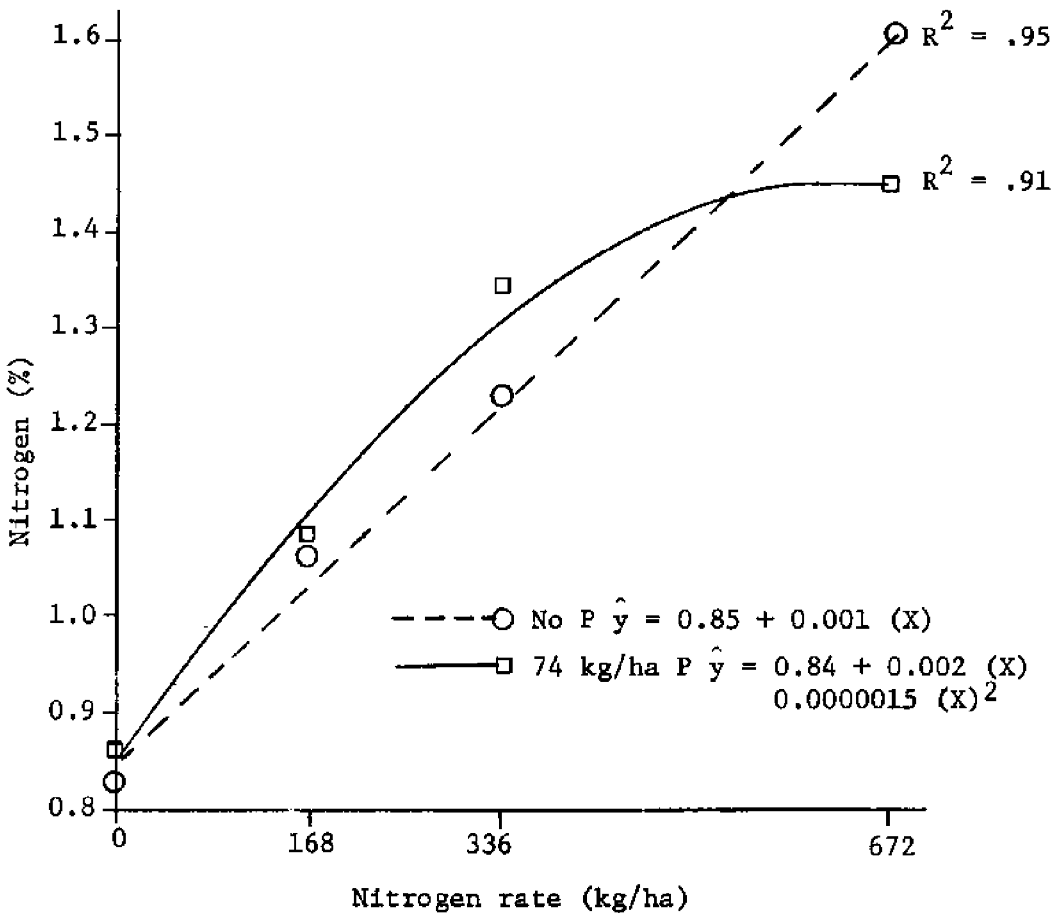



Figure 3.2a. The relationship between N fertilizer applied and N content of the plant tissue at harvest (1971)

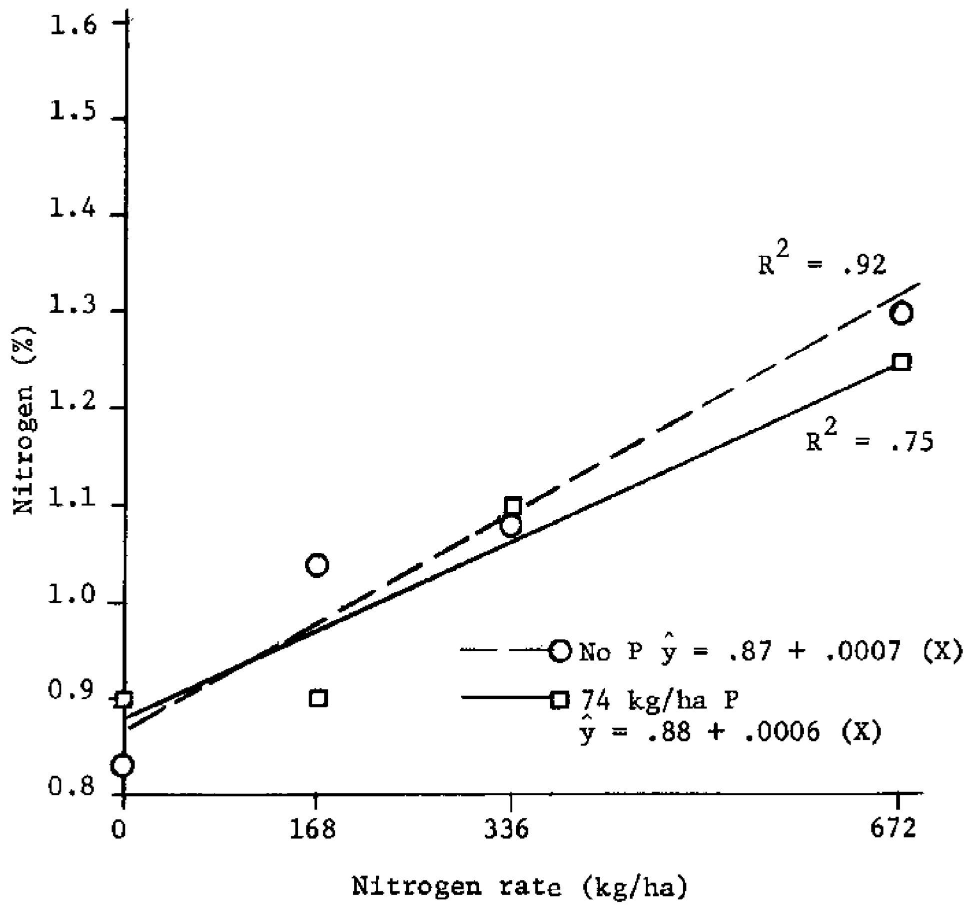



Figure 3.2b. The relationship between N fertilizer applied and N content of the plant tissue at harvest (1972)

growing seasons the $R^2$ values were higher where no P was applied, indicating a greater proportion of the variation in N content is accounted for by nitrogen rate when N alone is applied. Where P was applied, both the $R^2$ and the actual concentration of N in the tissue decreased. This decrease was probably due to dilution of N in a greater amount of dry matter as yield increased when the P supply became adequate.

The apparent recovery of fertilizer-N by the above-ground portion of the grass 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 N considering the flooding which occurs (Table 3.4).

Table 3.4. Apparent recovery of fertilizer nitrogen in the shoots at harvest

| N rate kg/ha | Apparent recovery (% of total N applied) | | | |
|---|---|---|---|---|
| | 1971 | | 1972 | |
| | 0[a] | 74 | 0 | 74 |
| 0 | -- | -- | -- | -- |
| 168 | 15.2 | 24.3 | 20.2 | 30.3 |
| 336 | 12.2 | 33.0 | 11.9 | 28.0 |
| 672 | 9.6 | 19.9 | 9.7 | 26.3 |

[a]Rate of P (kg/ha).

Concentration of P in the plant tissue was not significantly affected by N rate; however, the increase in P concentration due to P fertilization was highly significant (.01 level). In 1971 the mean concentration of P was increased from 0.084 to 0.150%, where 74 kg/ha P were applied. In 1972 there was a similar increase due to P fertilization from 0.087 to 0.147%. The amount of fertilizer P recovered for treatments receiving the maximum rate of N was 15.0 and 26.1% of that applied during 1971 and 1972, respectively. The calculations of recovery of both N and P 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 P would be retained by the soil than N. Also it should be noted that uptake of fertilizer was not determined for roots and rhizomes and this may be a significant amount.

Analyses for other mineral nutrients included K, Ca, Mg, S, Fe and Na in both 1971 and 1972. An analysis for Mn was included in 1972. Regression analysis was used to determine if there were significant linear or quadratic relationships between the nutrient concentrations in the plant tissue and N rate. Of the nutrients checked in 1971, only K was found to be significantly related to N rate (Table 3.5) and

Table 3.5. The relationship of nutrient concentration in the plant tissue to N rate[a]

| 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** | $\hat{y} = 320 - 0.219(X)$ |
| Mn | 1972 | 74 | 0.57** | $\hat{y} = 18.8 + 0.117(X)$ |

[a]X = rate of N fertilizer (kg/ha).

*Significant at the .05 level

**Significant at the .01 level

this was true only when P was applied. In 1972, when no P was applied, P, Ca and Mn concentrations were significantly affected by N rate. Ca and Mn concentrations increased as N rate increased, while P concentration decreased as N rate increased. The decrease in P concentration indicates that there is a limited amount of P available and the amount in the plant tissue is diluted as growth is increased due to N fertilization. Where P was applied, only Fe and Mn concentration was significantly affected by N rate. Manganese increased and Fe decreased as N rate was increased.

Total uptake of mineral nutrients increased as N rate was increased (Figures 3.3 and 3.4). This was due mainly to an increase in yield in response to N and P fertilization producing more plant material in which nutrients in adequate supply may be incorporated. The standing crop of these nutrients is controlled by yield which is in turn limited by availability of N and P to the marsh plants. Obviously, the amount of N and P available is the limiting factor in the total amount of nutrients in the dead plant material which is exported from the marsh to contribute to the nutrient cycle of the adjacent estuary as well as the amount of energy contributed to the estuarine food chain.

An obvious feature of the data for uptake of mineral nutrients is the large difference in Na uptake between 1971 and 1972. This was probably due to periods of high salt concentration in the substrate in 1972. The level of Na in the substrate varies with rainfall and frequency of flooding. At Ocracoke, southwest winds during summer often prevent regular flooding of the marsh for periods of a week or more causing an increase in the salinity of the soil solution as evaporation proceeds. However, measurements of salinity of the soil solution were

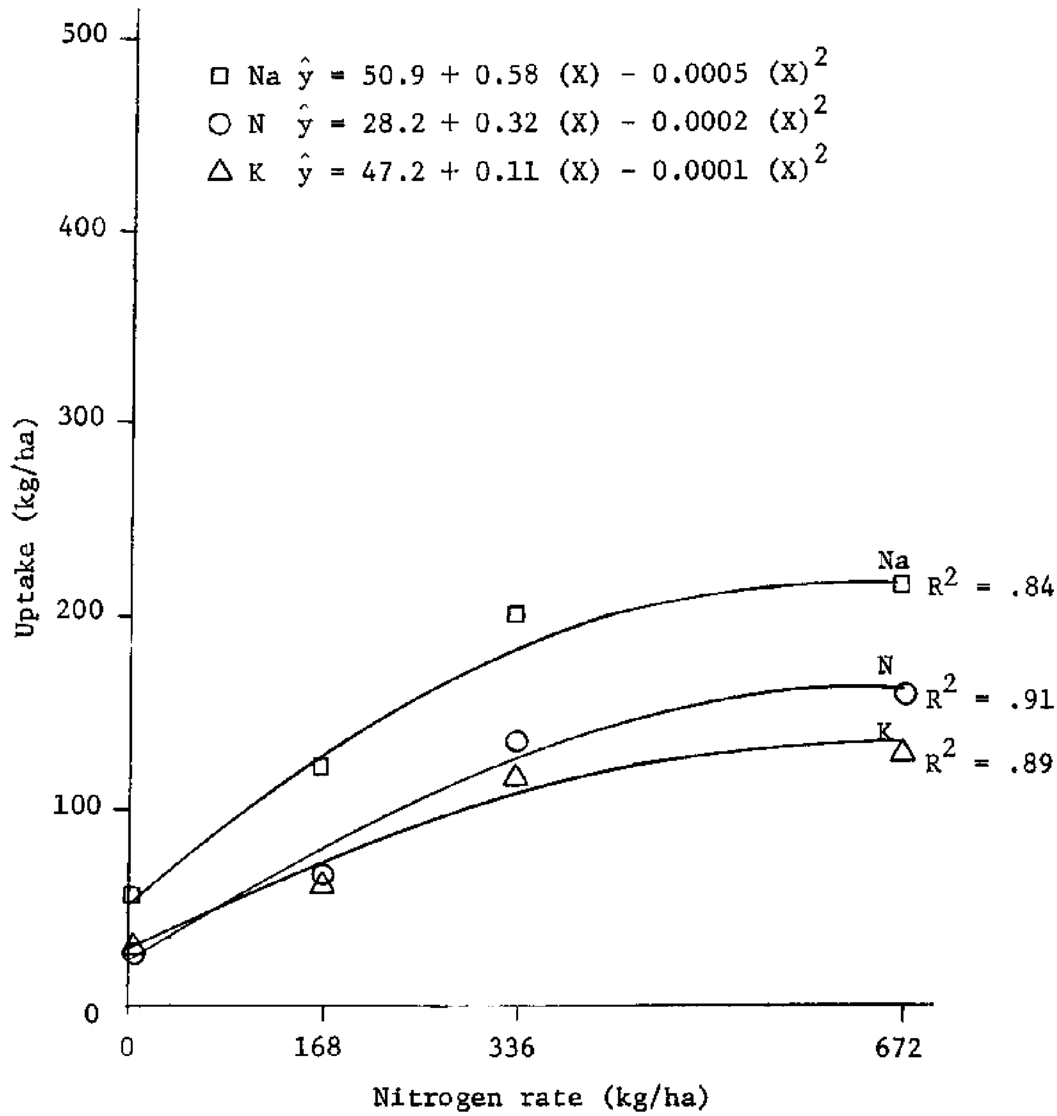



Figure 3.3a. The relationship of N rate to total uptake of N, K and Na in 1971 (P was supplied at the rate of 74 kg/ha)

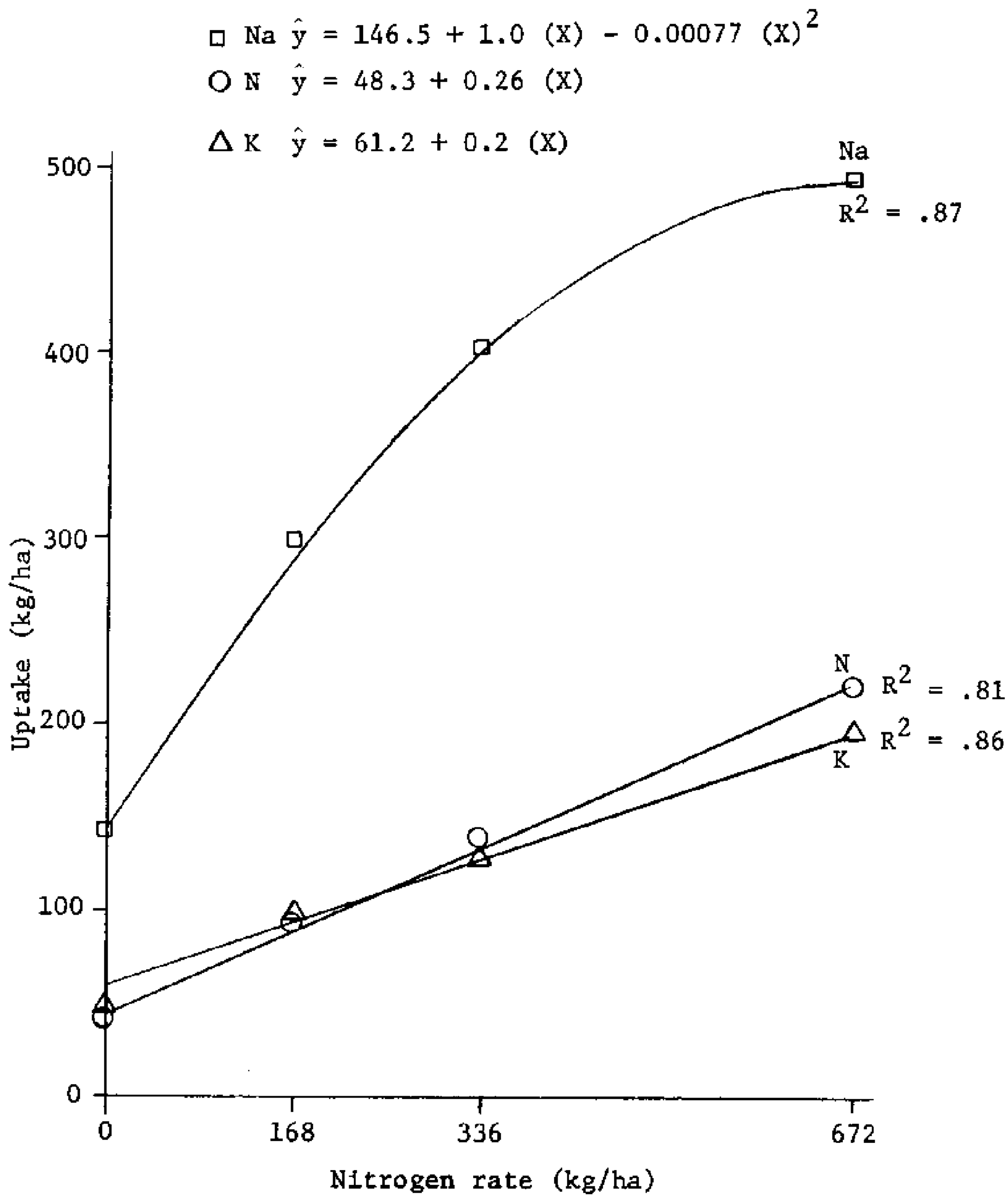



Figure 3.3b. The relationship of N rate to total uptake of N, K and Na in 1972 (P was supplied at the rate of 74 kg/ha)

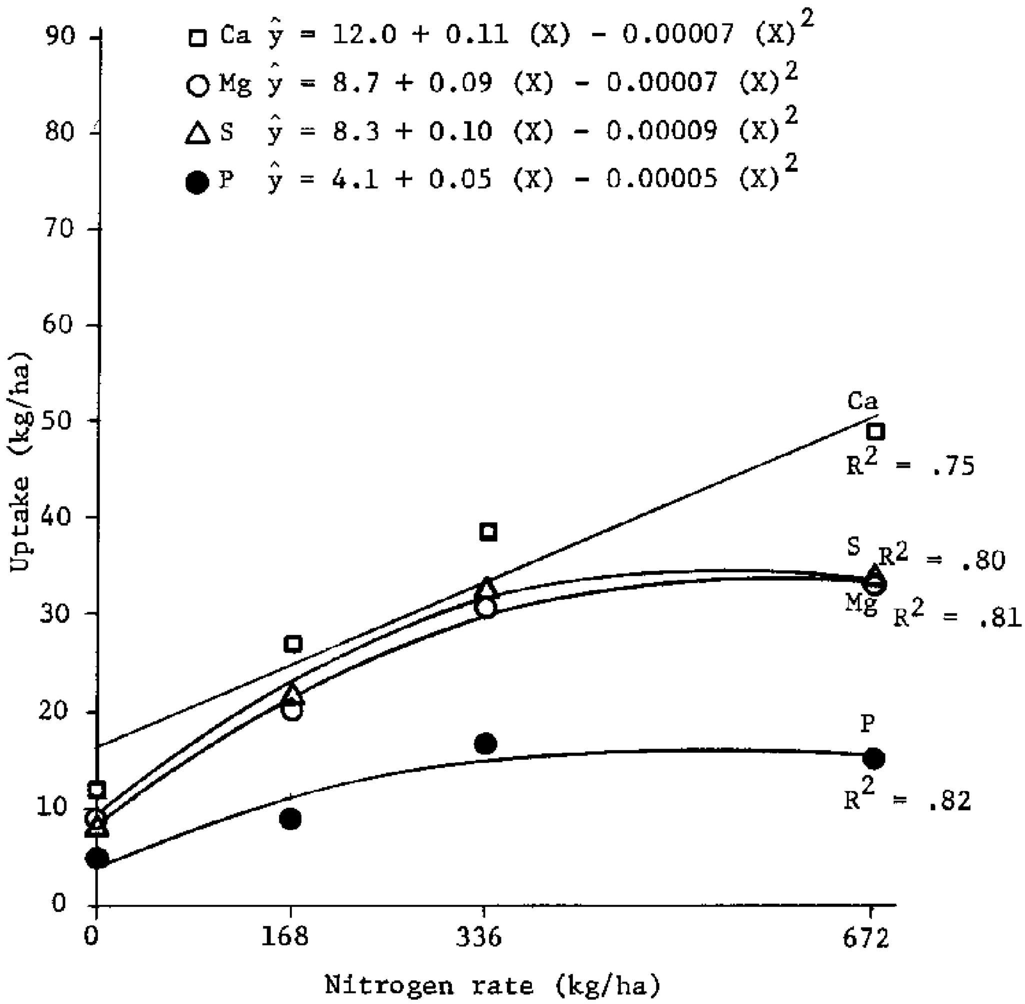



Figure 3.4a. The relationship of N rate to total uptake of P, Ca, S and Mg in 1971 (P was supplied at the rate of 74 kg/ha)

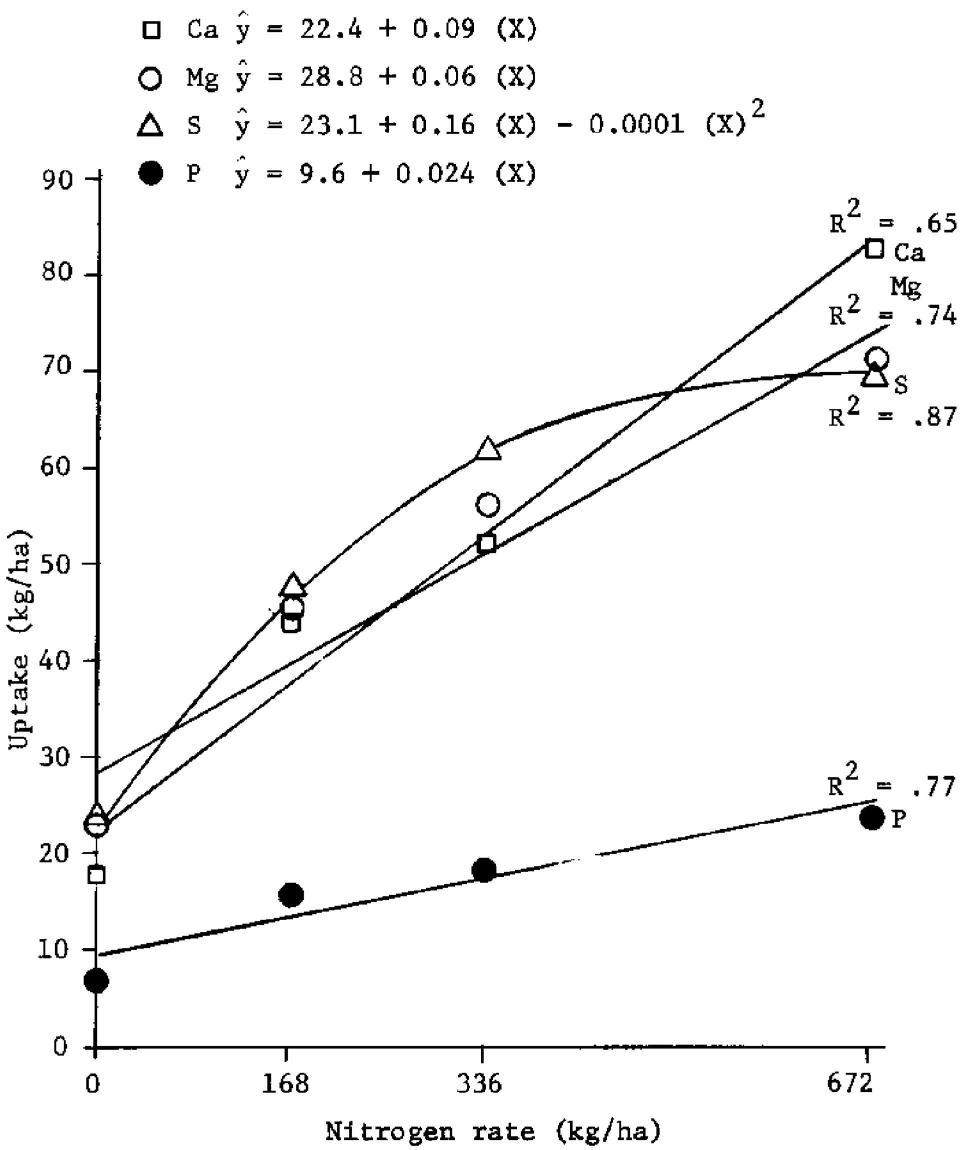



Figure 3.4b. The relationship of N rate to total uptake of P, Ca, S and Mg in 1972 (P was supplied at the rate of 74 kg/ha)

made only at harvest time each year. The salinity was 3.6% on September 2, 1971 and 3.0 to 3.4% on September 11, 1972. Even though no data are available, apparently where were periods of salt buildup earlier in the 1972 growing season.

Standing Crop of Roots and Rhizomes. The standing crop of roots and rhizomes in the upper 30 cm was increased significantly by N fertilization (Table 3.6). There was no response to N rates above 168

Table 3.6. Effect of N and P on standing crop of roots and rhizomes

| N rate kg/ha | Dry weight of roots and rhizomes (kg/ha) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 0-10 cm | | | 10-30 cm | | | 0-30 cm | | |
| | 0[a] | 74 | X̄ | 0 | 74 | X̄ | 0 | 74 | X̄ |
| 0 | 13714 | 11900 | 12807 | 4170 | 5525 | 4847 | 17884 | 17425 | 17654 |
| 168 | 17308 | 16333 | 16820 | 4276 | 6136 | 5206 | 21584 | 22469 | 22026 |
| 336 | 16162 | 16300 | 16231 | 5267 | 4972 | 5119 | 21429 | 21272 | 21350 |
| 672 | 15702 | 16864 | 16283 | 4537 | 6613 | 5575 | 20239 | 23477 | 21858 |
| X̄ | 15721 | 15349 | | 4563 | 5812 | | 20284 | 21161 | |
| LSD: | | | | | | | | | |
| N: .01 | | 3039 | | | ns | | | 3659 | |
| .05 | | 2295 | | | ns | | | 2763 | |
| P: .01 | | ns | | | 920 | | | ns | |
| .05 | | ns | | | 695 | | | ns | |
| N x P: .01 | | ns | | | ns | | | ns | |
| .02 | | ns | | | ns | | | ns | |
| CV % | | 28.8 | | | 37.0 | | | 26.0 | |

kg/ha, indicating that this rate of N was adequate for maximum growth of roots and rhizomes. When root and rhizome weights are broken down to 0.10 and 10-30-cm layers, a variable response to fertilization is noted. In the 0-10-cm layer there was a significant response to N and no response to P similar to the case when the total weight of the upper 30 cm is considered. However, in the 10-30-cm layer there was a significant response to P but not to N. The distribution of roots and rhizomes in the profile is apparently the reason for this variable response. The overall means of 120 core samples show that 75% of the roots and rhizomes are in the 0-10-cm layer with only 25% of the total in the 10-30-cm layer. From field observations it appears that essentially all the roots and rhizomes were contained in the upper 30 cm and any below this depth would be an insignificant portion of the total weight. Results of separating roots and rhizomes from 10 random core samples indicated that in the 0-10-cm layer, the percentages by weight were 49.6% roots and 50.4% rhizomes. In the 10-30-cm layer, only 34.6% of the dry weight was roots with rhizomes accounting for 65.4%. Since there was a higher proportion of rhizomes in the 10-30-cm layer, it is possible that the response to P in this layer is due to an increase in rhizome growth. That is the response to P is relatively greater for rhizomes than for roots. The increase in dry weight of the 0-10-cm layer was probably due to an increase of root growth in response to N fertilization.

The total dry weight of roots and rhizomes in the upper 30 cm exceeds the dry weight of shoots (Figure 3.5). 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 N rate from 0.29 for the check to 0.75 at the highest rate of N.

Oak Island

The marsh at Oak Island differs from that of Ocracoke in several ways which would be expected to cause the response to fertilizer applications to be somewhat different. Most important is that the sediments on

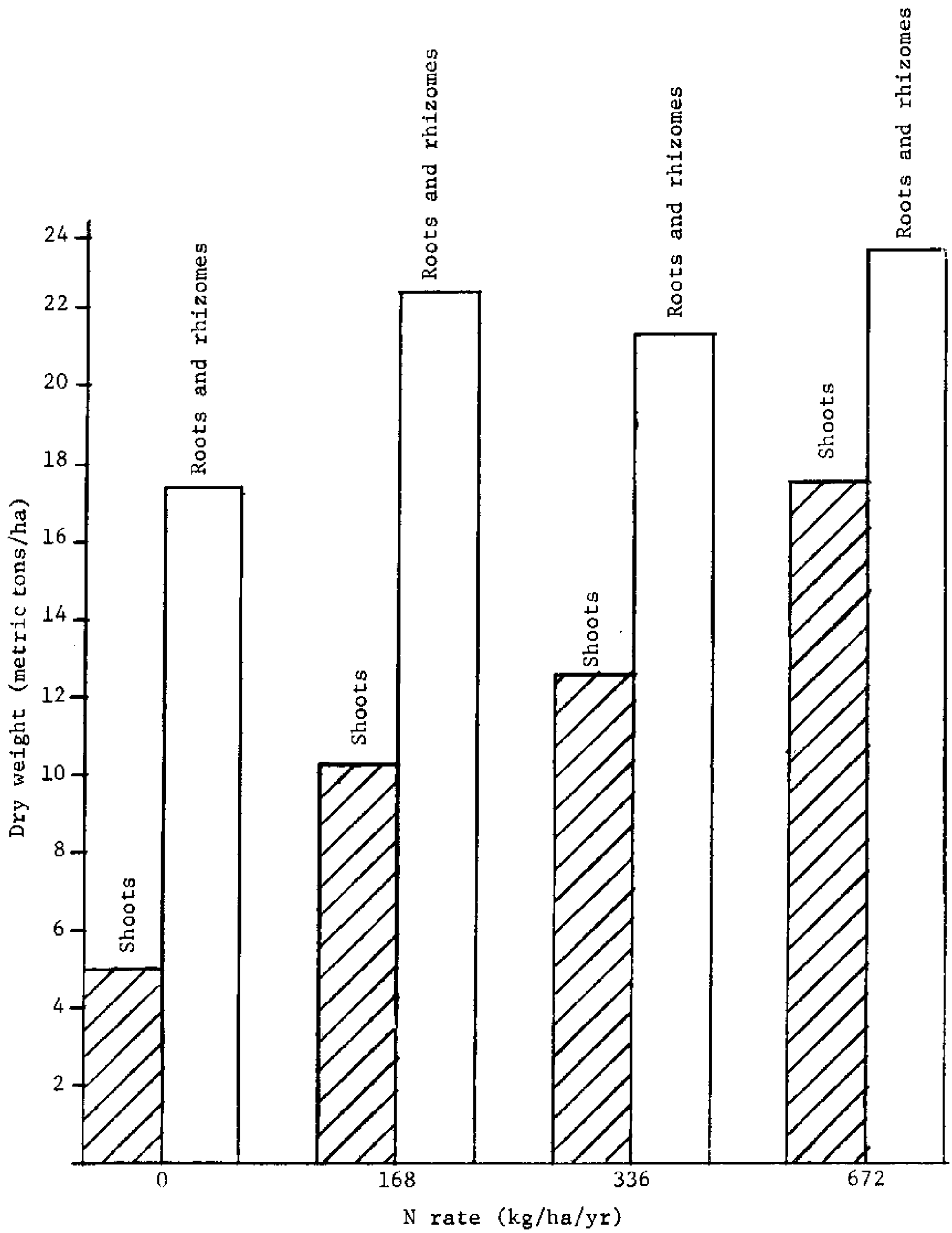



Figure 3.5. The effect of N fertilization on the above-and below-ground standing crop of S. alterniflora (all treatments received 74 kg/ha P)

which the marshes formed are quite different. At Ocracoke the substrate is almost pure sand, while at Oak Island it is much finer textured and would be expected to be inherently more fertile. Another difference is that the Oak Island marsh is older with well developed creeks and distinct zonation of the height forms. A third difference is that at Oak Island there is a greater tide range (1.3 m) which is affected very little by the wind and floods the marsh regularly twice a day.

Fe-N Experiment. The experimental fertilizer plots at Oak Island contained both the tall and short forms of *S. alterniflora*. Neither growth, chemical composition of the plant tissue, nor general appearance of the tall form was significantly affected by additions of Fe or N (Table 3.7). This is probably due to the fact that the creek bank area is adequately supplied with nutrients from fresh sediments which may be deposited by the overflowing creeks at flood tide. Levees which are formed are evidence of greater deposition along creek banks. The meandering of creeks may also 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 simply dissolved in the estuarine water on flood tide rather than being taken up by the plants. Fewer fine roots are present at the sediment surface in the tall *S. alterniflora* than in the short; consequently, uptake of nutrients applied to the surface would be less. Calculation of the apparent recovery of fertilizer N for plants which received 336 kg/ha N indicates that only 3.2% of that applied was recovered in the grass shoots.

Table 3.7. The effect of N and Fe applications on tall *S. alterniflora* at Oak Island

| N kg/ha | Fe[a] | Standing crop kg/ha | Height (cm) | No. stems $m^2$ | Ca | P | K | Ca | Mg | S | Na | Fe |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | % | | | | | | | ppm |
| 0 | Chelate spray | 9893 | 163.3 | 82.8 | 0.75 | .093 | .80 | .21 | .38 | .48 | 2.24 | 492 |
| 336 | Chelate spray | 10187 | 147.3 | 118.8 | 0.78 | .107 | .80 | .23 | .35 | .46 | 2.14 | 512 |
| 672 | Chelate spray | 12893 | 171.3 | 86.8 | 0.80 | .097 | .83 | .22 | .37 | .36 | 2.10 | 384 |
| 336 | 0 | 9813 | 165.7 | 101.2 | 0.78 | .097 | .80 | .25 | .39 | .44 | 2.06 | 401 |
| 336 | Chelate dry | 12253 | 154.3 | 118.8 | 0.78 | .100 | .77 | .26 | .38 | .44 | 2.09 | 576 |
| 336 | $FeSO_4$ spray | 9640 | 142.7 | 102.8 | 0.89 | .117 | .97 | .25 | .36 | .45 | 2.15 | 430 |
| | CV % | 22.18 | 10.67 | 25.19 | 11.05 | 16.85 | 15.54 | 15.04 | 6.88 | 23.04 | 7.46 | 45.86 |
| | LSD .05 | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns |

[a]Iron rate = 16.8 kg/ha Fe.

Growth in the zone of short S. alterniflora was enhanced by the addition of N but was not affected by the Fe treatments (Table 3.8). The characteristic chlorotic appearance of short S. alterniflora was not affected by Fe, but N produced an obviously greener appearance. Plots which received applications of N fertilizer yielded approximately twice as much dry matter as the check plots. The N content of the plant tissue also increased as the amount of N fertilizer applied was increased, indicating that uptake was more efficient than in the tall height zone. The average recovery of N by the grass shoots in plots receiving 336 kg/ha N was 13%. The recovery of fertilizer N by the grass in the short height zone is much more efficient than in the tall height zone. This is probably due to the greater amount of roots at the soil surface in the short height zone and to the fact that the loss due to flooding is probably much less than in the tall height zone. Another possible difference is that the N supply in the tall height zone is adequate and little of the fertilizer-N is utilized, while N is in short supply in the short height zone. The efficiency of uptake of N is less than at Ocracoke even in the short height zone. The less frequent flooding at Ocracoke allows the fertilizer to remain in place and subject to uptake for a longer period of time.

N-P Factorial. A fertilizer experiment was begun at Oak Island in 1972 to determine if P was a limiting factor in productivity at this location as was the case at Ocracoke. At the end of the first growing season there was no significant yield increase due to P fertilization (Table 3.9). The highest rate of nitrogen nearly doubled the yield of short S. alterniflora compared to the check, and plots which received N were much greener, but again the tall did not respond to fertilization.

Table 3.8. The effect of N and Fe applications on short *S. alterniflora* at Oak Island

| N kg/ha | Fe[a] | Standing crop kg/ha | Height (cm) | No. stems $m^2$ | N | P | K | Ca % | Mg | S | Na | Fe ppm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | Chelate spray | 3040 | 76.7 | 350.8 | 0.76 | 0.086 | 0.80 | 0.20 | 0.40 | 0.70 | 2.02 | 1230 |
| 336 | Chelate spray | 7587 | 103.3 | 478.8 | 0.98 | 0.090 | 0.90 | 0.25 | 0.46 | 0.68 | 2.05 | 969 |
| 672 | Chelate spray | 5867 | 106.3 | 614.8 | 1.10 | 0.093 | 1.00 | 0.24 | 0.46 | 0.84 | 2.20 | 1156 |
| 336 | 0 | 7320 | 103.3 | 533.6 | 0.90 | 0.083 | 0.83 | 0.23 | 0.42 | 0.72 | 2.02 | 831 |
| 336 | Chelate dry | 6280 | 104.3 | 480.0 | 0.90 | 0.076 | 0.83 | 0.30 | 0.45 | 0.78 | 2.00 | 1018 |
| 336 | $FeSO_4$ spray | 7227 | 92.7 | 616.0 | 0.99 | 0.093 | 0.97 | 0.29 | 0.46 | 0.68 | 2.06 | 1006 |
| CV % | | 20.87 | 15.40 | 25.11 | 10.10 | 10.18 | 10.61 | 9.48 | 8.09 | 8.46 | 11.29 | 36.17 |
| LSD | .01 | 3358.6 | ns | ns | ns | ns | ns | 0.06 | ns | ns | ns | ns |
| | .05 | 2361.3 | ns | ns | 0.17 | ns | ns | 0.04 | ns | ns | ns | ns |

[a]Iron rate = 16.8 kg/ha Fe.

Table 3.9. Effect of N and P on *S. alterniflora* at Oak Island

| | Standing crop (kg/ha) | | | | | |
|---|---|---|---|---|---|---|
| | Short | | | Tall | | |
| | 0[a] | 74 | $\bar{X}$ | 0 | 74 | $\bar{X}$ |
| 0 | 5100 | 6503 | 5802 | 16713 | 17113 | 16913 |
| 168 | 6653 | 9653 | 8153 | 15547 | 18623 | 17085 |
| 336 | 8370 | 7337 | 7853 | 25553 | 22777 | 24165 |
| 672 | 11053 | 9653 | 10353 | 18967 | 16840 | 17903 |
| $\bar{X}$ | 7794 | 8287 | | 19195 | 18838 | |
| LSD: N - .05 | | 2884 | | | ns | |
| P - .05 | | ns | | | ns | |
| N x P - .05 | | ns | | | ns | |
| CV % | | 29.0 | | | 30.1 | |

[a]P rate (kg/ha).

The lack of response to P was expected due to the nature of the substrate at Oak Island. The fine textured reduced sediments have a greater potential for supplying P than the sand at Ocracoke. If the experiment were continued for several years, a response to P might be obtained as increased yields produced by N fertilization depleted the supply of soil P. The second year of fertilization at Ocracoke produced a greater response to P than the first giving evidence for such a depletion of available P in the soil.

The Effect of Fertilizer on Seedlings and Transplants. Propagation of *S. alterniflora* on dredge spoil is being investigated to provide a means for creating new tidal marshes and to stabilize the spoil material (Woodhouse, Seneca, and Broome, 1972). To determine if the addition of fertilizer would speed up this process, fertilizer plots were established on seedlings at Beaufort and transplants at Drum Inlet.

The dry weight of seedlings at the end of one growing season was increased threefold by the addition of N (Table 3.10). Where N and P were applied, the dry weight was increased slightly over the N treatment. These results indicate that at this location fertilizer was beneficial in producing increases in growth and consequently increasing the cover produced by seedlings on dredge spoil during the first growing season.

Table 3.10. The standing crop of seedlings at Beaufort to which N and P fertilizers were applied (plots were harvested October 5, 1972)

| Rep | Dry weight (kg/ha) Fertilizer treatment[a] | | |
|---|---|---|---|
| | Check | N | NP |
| 1 | 4450 | 11100 | 14180 |
| 2 | 2860 | 9430 | 10200 |
| 3 | 3100 | 7480 | 8010 |
| $\overline{X}$ | 3470 | 9340 | 10800 |

[a]N rate = 224 kg/ha N; P rate = 49 kg/ha P; half the fertilizer was applied on June 26, 1972 and half on July 26, 1972.

Fertilization also enhanced first-year growth of transplants at Drum Inlet (Table 3.11). There were significant (.05 level) increases in dry weight and number of flowers and a highly significant (.01 level) increase in the number of center culms due to N fertilization. The number of rhizomes was not affected by N. There were highly significant increases in dry weight, number of flowers and number of center culms due to P fertilization. There was a significant increase in number of

Table 3.11. The effect of N and P on growth of *S. alterniflora* at Drum Inlet when applied at the time of transplanting

| N rate kg/ha | | 0[a] | 24.6 | $\overline{X}$ | 0[2] | 24.6 | $\overline{X}$ |
|---|---|---|---|---|---|---|---|
| | | Dry weight (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 |
| $\overline{X}$ | | 11.6 | 20.9 | | 3.3 | 6.2 | |
| LSD: | N - .01 | | ns | | | ns | |
| | .05 | | 4.9 | | | 1.4 | |
| | P - .01 | | 4.7 | | | 1.3 | |
| | .05 | | 3.5 | | | 1.0 | |
| | N x P - .01 | | ns | | | ns | |
| | .05 | | ns | | | ns | |
| CV % | | | 45.4 | | | 43.4 | |
| | | No. of center culms/plant | | | No. of rhizomes/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 |
| $\overline{X}$ | | 15.7 | 24.0 | | 0.9 | 1.8 | |
| LSD: | N - .01 | | 6.2 | | | ns | |
| | .05 | | 4.7 | | | ns | |
| | P - .01 | | 4.4 | | | ns | |
| | .05 | | 3.3 | | | 0.8 | |
| | N x P - .01 | | ns | | | ns | |
| | .05 | | ns | | | ns | |
| CV % | | | 35.2 | | | 131.8 | |

rhizomes due to P. Unlike results from experiments in the natural marsh, there was no N x P interaction. The Drum Inlet site was freshly deposited dredge spoil of almost pure white sand. The response of the transplants to fertilizer is evidence of the low N and P content of this material. It is likely that dredge spoil higher in silt, clay and organic matter would provide adequate N and P for maximum growth of transplants during the first growing season.

## Summary and Conclusions

Increased growth of *Spartina 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 N alone and increased about threefold when P was also supplied. In a marsh developed on finer textured sediments, N fertilizer doubled the standing crop of short *Spartina*, but there was no response to P. There was no growth response from applications of iron to support previous speculation that iron nutrition might be a partularly important factor causing the chlorotic appearance of short *Spartina* and reducing its productivity. The chlorotic condition was remedied by additions of N.

The response of short *Spartina* to N implies that at least a part of the difference in productivity between the tall and short forms is due to the amount of N available to the plants. Undoubtedly 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. It is true that high salinities will stunt *Spartina* and areas with high salinity and short *Spartina* can be found. However, I have observed short *Spartina* growing where the salinity was found to be only about 1% several different times during a growing season. If the stunted form is produced by environmental factors, 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 N or P or both might be limiting growth.

An explanation for N deficiency in short height zone may be in the thick mat of roots which develops, creating a sod-bound condition. When a new mud flat is deposited and becomes colonized by *Spartina*, most sediments contain adequate nitrogen for plant growth except in the case of almost pure sand such as the Drum Inlet site. Year after year as the fibrous mat of roots develops, all the available N 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 probably decomposed and mineralized very slowly due to the anaerobic condition of the marsh sediments. The addition of nutrients from natural sources apparently is not adequate for maximum plant growth. The addition of N to the marsh probably includes small amounts from rainfall, asymbiotic N 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 N supplied would, of course, be dependent on the nature of the sediments.

It is even more certain that the sediment is the dominant factor in the supply of P to *S. alterniflora* (Pomeroy *et al.*, 1969). This is borne out in the results of our fertilizer experiments which showed a response to P on sandy substrate but not on finer textured material. The texture of the sediments is quite important in the P-supplying capacity. In eroded soils in 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 phosphates to increase. At the high pH of marsh soils (7.0-8.0) calcium phosphates probably become an important form of P. The amount of P available to plants in a salt marsh then is related to the amount of clay in the substrate. Pomeroy *et al.* (1969) concluded that the subsurface reduced sediments are the source of P for *Spartina*; however, the response to surface-applied fertilizer P in this experiment seems to contradict this. Uptake of fertilizer P apparently occurred at or very near the sediment surface.

The fact that N and P 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 utilize more N and P 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 P fertilizers were shown to enhance growth of seedlings and transplants which were artificially established on dredge spoil. Since establishing a substantial vegetative cover rapidly may be critical in stabilizing an area, applications of fertilizer may be of some practical benefit. However, it should be remembered that 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 dredge spoil material.

## List of References


Adams, D. A. 1963. Factors influencing vascular plant zonation in North Carolina salt marshes. Ecology 44:445-456.

Cooper, A. W. 1969. Salt marshes, pp. 563-611. In H. T. Odum, B. J. Copeland and E. A. McMahon (ed.), Coastal Ecological Systems of the U. S. Report to the Water Pollution Control Administration, Washington, D. C.

Horne, R. A. 1969. Marine Chemistry; the Structure of Water and the Chemistry of the Hydrosphere. Wiley-Interscience, New York.

Keeney, D. R. 1973. The nitrogen cycle in sediment-water systems. J. Envion. Quality 2:15-29.

Marshall, D. E. 1970. Characteristics of Spartina marsh which is receiving treated municipal wastes, pp. 317-358. In H. T. Odum and A. F. Chestnut (ed.), Studies of Marine Estuarine Ecosystems Developing with Treated Sewage Wastes. U.N.C. Institute of Marine Science Annual Report for 1969-1970 to NSF, Sea Grants Project Division, Chapel Hill, N. C.

Pigott, C. D. 1969. Influence of mineral nutrition on the zonation of flowering plants in coastal salt-marshes, pp. 25-35. In I. H. Rorison (ed.), Ecological Aspects of the Mineral Nutrition of Plants. The British Ecological Society Symposium No. 9. Blackwell Scientific Publications, Oxford, England.

Pomeroy, L. R., R. E. Johannes, E. P. Odum, and B. Roffman. 1969. The phosphorus and zinc cycles and productivity of a salt marsh, pp. 412-419. In D. J. Nelson and F. C. Evans (ed.), Proceedings of the Second National Symposium on Radioecology. U. S. Atomic Energy Commission (Oak Ridge, Tenn.), Dec. CONF 670503.

Teal, J. M. 1962. Energy flow in the salt marsh ecosystem of Georgia. Ecology 43:614-624.

Woodhouse, W. W., Jr., E. D. Seneca, and S. W. Broome. 1972. Marsh building with dredge spoil in North Carolina. Bull. N. C. Agr. Exp. Sta. 445. pp. 1-28.

# APPENDIX

Appendix Table 1. Combined analysis of variance of percent germination of *S. alterniflora* seed collected from five locations in October 1969 and subjected to five storage treatments until February 5, 1970

| Source | df | Mean square |
|---|---|---|
| Location | 4 | 12437.49* |
| Treatment | 4 | 45583.68** |
| Rep (treatment) | 10 | 66.65 |
| Treatment x location | 16 | 3430.41** |
| Rep (treatment x location) | 50 | 257.10 |
| Time | 4 | 3977.28 |
| Time x location | 16 | 452.21 |
| Treatment x time | 16 | 231.79 |
| Rep x time (treatment) | 40 | 8.78 |
| Treatment x time x location | 64 | 125.01** |
| Residual | 150 | 5.51 |
| Corrected total | 374 | 899.80 |

*Significant at .05 level

**Significant at .01 level

Appendix Table 2. The effect of storage treatment on germination of *S. alterniflora* seed collected from five locations along the North Carolina coast October 7-10, 1969

| Days in germination period | Storage treatment | | | | |
|---|---|---|---|---|---|
| | Estuarine water | Distilled water | Frozen dry | Frozen in estuarine water | Over water |
| | | Oregon Inlet | | | |
| 5 | 72.0 | 86.0 | 0.7 | 0.0 | 44.0 |
| 7 | 88.7 | 88.7 | 2.7 | 0.0 | 55.3 |
| 10 | 93.3 | 88.7 | 11.3 | 0.7 | 70.7 |
| 21 | 94.0 | 88.7 | 36.7 | 12.7 | 81.3 |
| 30 | 94.0 | 88.7 | 50.0 | 22.0 | 86.7 |

LSD: for comparing treatments within a given day

.01 - 10.9
.05 - 7.9
CV % - 6.8

| Days in germination period | Estuarine water | Distilled water | Frozen dry | Frozen in estuarine water | Over water |
|---|---|---|---|---|---|
| | | Ocracoke | | | |
| 5 | 40.7 | 36.0 | 0.7 | 0.0 | 22.0 |
| 7 | 52.7 | 44.7 | 0.7 | 0.0 | 32.0 |
| 10 | 58.7 | 49.3 | 2.0 | 1.3 | 54.0 |
| 21 | 67.3 | 54.7 | 19.3 | 24.7 | 82.0 |
| 30 | 70.0 | 54.7 | 28.0 | 32.0 | 83.3 |

LSD: for comparing treatments within a given day

.01 - 17.0
.05 - 12.2
CV % - 10.7

| Days in germination period | Estuarine water | Distilled water | Frozen dry | Frozen in estuarine water | Over water |
|---|---|---|---|---|---|
| | | Beaufort | | | |
| 5 | 72.0 | 42.0 | 4.0 | 1.3 | 30.7 |
| 7 | 76.0 | 42.0 | 16.0 | 2.0 | 32.7 |
| 10 | 76.0 | 44.0 | 24.0 | 6.7 | 32.7 |
| 21 | 76.0 | 44.7 | 37.3 | 13.3 | 32.7 |
| 30 | 76.0 | 44.7 | 49.3 | 16.7 | 32.7 |

LSD: for comparing treatments within a given day

.01 - 20.9
.05 - 14.8
CV % - 18.5

Appendix Table 2 (Continued)

| Days in germination period | Storage treatment | | | | |
|---|---|---|---|---|---|
| | Estuarine water | Distilled water | Frozen dry | Frozen in estuarine water | Over water |
| | | Surf City | | | |
| 5 | 46.0 | 27.3 | 0.0 | 0.0 | 9.3 |
| 7 | 48.0 | 28.7 | 1.3 | 0.0 | 16.7 |
| 10 | 51.3 | 28.7 | 4.0 | 0.0 | 16.7 |
| 21 | 52.0 | 28.7 | 6.7 | 0.0 | 17.3 |
| 30 | 52.0 | 28.7 | 7.3 | 0.0 | 17.3 |

LSD: for comparing treatments within a given day

.01 - 21.2
.05 - 14.9
CV % - 8.1

| Days in germination period | Estuarine water | Distilled water | Frozen dry | Frozen in estuarine water | Over water |
|---|---|---|---|---|---|
| | | Oak Island | | | |
| 5 | 15.3 | 44.0 | 0.0 | 0.0 | 61.3 |
| 7 | 18.0 | 50.7 | 0.0 | 0.0 | 65.3 |
| 10 | 23.3 | 52.7 | 0.7 | 0.0 | 66.7 |
| 21 | 34.0 | 53.3 | 1.3 | 0.0 | 68.0 |
| 30 | 37.3 | 54.7 | 1.3 | 0.0 | 70.0 |

LSD: for comparing treatments within a given day

.01 - 24.5
.05 - 17.3
CV % - 8.2

Appendix Table 3. Analysis of variance (by location) of percent germination of seed collected at five locations along the North Carolina coast in October 1969 and subjected to five storage treatments until February 5, 1970

| Source | df | Mean square | | | | |
|---|---|---|---|---|---|---|
| | | Oregon Inlet | Ocracoke | Beaufort | Surf City | Oak Island |
| Treatment | 4 | 22231.1** | 8366.1** | 9309.5** | 6158.5** | 13240.1** |
| Reps in trt (error a) | 10 | 49.3 | 173.8 | 300.2 | 327.4 | 434.9 |
| Time | 4 | 1866.5** | 3235.1** | 455.1** | 52.6** | 176.7** |
| Treatment x time | 16 | 277.7** | 235.0** | 161.8** | 9.3** | 47.9** |
| Residual (error b) | 40 | 13.75 | 15.1 | 9.2 | 2.5 | 5.5 |
| Corrected total | 74 | 1376.7 | 709.5 | 608.2 | 383.3 | 797.4 |
| LSD: for comparing trts within a given day | | | | | | |
| .01 | | 10.9 | 17.0 | 20.9 | 21.2 | 24.5 |
| .05 | | 7.9 | 12.2 | 14.8 | 14.9 | 17.3 |
| CV % | | 6.8 | 10.7 | 8.2 | 8.1 | 8.2 |

**Significant at .01 level

Appendix Table 4. The effect of date of harvest on germination of *S. alterniflora* seed (the seed were harvested at Oregon Inlet and stored in estuarine water at 2-3 C until February 17, 1972)

| Day | % germination<br>Harvest date<br>9/21/71 | <br><br>9/28/71 | $\bar{X}$ |
|---|---|---|---|
| 4 | 35.3 | 48.7 | 42.0 |
| 8 | 49.3 | 75.3 | 62.3 |
| 11 | 62.0 | 86.7 | 74.3 |
| 17 | 63.3 | 88.7 | 76.0 |
| 21 | 64.7 | 88.7 | 76.7 |
| 26 | 70.7 | 88.7 | 79.7 |
| $\bar{X}$ | 57.6 | 79.4 | |

| | | | |
|---|---|---|---|
| LSD: | Harvest date | .01 - | 6.9 |
| | | .05 - | 5.1 |
| | Time | .01 - | 11.9 |
| | | .05 - | 8.8 |
| | Harvest date x time | .01 - | ns |
| | | .05 - | ns |
| CV % | | | 10.8 |

Appendix Table 5. Analysis of variance comparing germination of seed harvested at two different dates

| Source | df | Mean square |
| --- | --- | --- |
| Harvest date | 1 | 4312.1** |
| Time | 5 | 1226.3** |
| Harvest date x time | 5 | 38.8 |
| Reps in harvest date x time | 24 | 54.9 |
| Corrected total | 35 | 341.6 |
| LSD: Harvest date | .01 - 6.9<br>.05 - 5.1 | |
| Time | .01 - 11.9<br>.05 - 8.8 | |
| Harvest date x time | .01 - ns<br>.05 - ns | |
| CV % | 10.8 | |

**Significant at .01 level

Appendix Table 6. The effect of after-ripening on germination of *S. alterniflora* seed harvested September 28, 1971 at Oregon Inlet, stored in estuarine water at 2-3 C and tested on five dates

| Date of beginning of germination period | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 10/20/71 | | 11/17/71 | | 12/19/71 | | 1/21/71 | | 2/17/71 | |
| Day | % germ. | Day | % germ. | Day | % germ. | Day | % germ. | Day | % germ. |
| 5 | 2.0 | 3 | 0.0 | 2 | 3.0 | 3 | 24.0 | 4 | 48.7 |
| 7 | 8.0 | 7 | 6.0 | 8 | 28.0 | 5 | 47.3 | 8 | 75.3 |
| 12 | 14.7 | 12 | 10.7 | 16 | 41.0 | 8 | 69.3 | 11 | 86.7 |
| 15 | 28.0 | 15 | 16.7 | 19 | 47.0 | 12 | 82.7 | 17 | 88.7 |
| 27 | 57.3 | 21 | 44.7 | 22 | 49.0 | 18 | 90.0 | 21 | 88.7 |
| 30 | 59.3 | 27 | 66.7 | 32 | 52.0 | 25 | 90.0 | 26 | 88.7 |

LSD: Germination date x time .01 - 13.0
.05 - 9.8

CV % 12.7

Appendix Table 7. Analysis of variance for percent germination of seed harvested September 28, 1971 and tested on five dates

| Source | df | Mean square |
|---|---|---|
| Germination date | 4 | 11116.6** |
| Time | 5 | 6598.6** |
| Germination date x time | 20 | 328.4** |
| Reps in germination date x time | 60 | 36.0 |
| Corrected total | 89 | 968.4 |

LSD: Germination date x time .01 - 13.0
.05 - 9.8

CV % 12.8

**Significant at .01 level

Appendix Table 8. A comparison of the effect of storing *S. alterniflora* seed in distilled water or estuarine water from September 21, 1971 until November 17, 1971 on percent germination

| Length of germination period (days) | Storage treatment | | $\bar{X}$ |
|---|---|---|---|
| | Distilled water | Estuarine water | |
| 3 | 1.3 | 1.3 | 1.3 |
| 7 | 4.7 | 6.7 | 5.7 |
| 12 | 6.7 | 9.3 | 8.0 |
| 15 | 7.3 | 12.0 | 9.7 |
| 21 | 24.7 | 26.7 | 25.7 |
| 27 | 48.7 | 46.7 | 47.7 |
| 34 | 56.0 | 54.7 | 55.3 |
| $\bar{X}$ | 21.3 | 22.5 | |

| | | |
|---|---|---|
| LSD: | Storage treatment | .01 - ns<br>.05 - ns |
| | Time | .01 - 8.36<br>.05 - 6.20 |
| | Storage treatment x time | .01 - ns<br>.05 - ns |
| CV % | | 23.91 |

Appendix Table 9. Analysis of variance for percent germination of seed harvested September 21, 1971 and stored in estuarine or distilled water until November 17, 1971

| Source | df | Mean square |
|---|---|---|
| Storage treatment | 1 | 13.715 |
| Time | 6 | 2825.270** |
| Storage treatment x time | 6 | 8.381 |
| Reps in storage treatment x time | 28 | 27.429 |
| Corrected total | 41 | 433.75 |
| LSD: Storage treatment | .01 - ns<br>.05 - ns | |
| Time | .01 - 8.36<br>.05 - 6.20 | |
| Storage treatment x time | .01 - ns<br>.05 - ns | |
| CV % | 23.91 | |

**Significant at .01 level

Appendix Table 10. A comparison of the effect of storing *S. alterniflora* seed in estuarine or distilled water from September 21, 1971 until February 17, 1972 on percent germination

| Length of germination period (days) | Storage treatment | | $\bar{X}$ |
|---|---|---|---|
| | Distilled water | Estuarine water | |
| 4 | 16.7 | 35.3 | 26.0 |
| 8 | 26.0 | 49.3 | 37.7 |
| 11 | 45.3 | 62.0 | 53.7 |
| 17 | 50.7 | 64.7 | 57.7 |
| 21 | 51.3 | 64.7 | 58.0 |
| 26 | 54.0 | 70.7 | 62.3 |
| $\bar{X}$ | 40.7 | 57.8 | |

| | | |
|---|---|---|
| LSD: | Storage treatment | .01 - 8.54<br>.05 - 6.31 |
| | Time | .01 - 14.85<br>.05 - 10.92 |
| | Storage treatment x time | .01 - ns<br>.05 - ns |
| CV % | | 18.6 |

Appendix Table 11. Analysis of variance for germination of seed harvested September 21, 1971 and stored in estuarine or distilled water until February 17, 1972

| Source | df | Mean square |
|---|---|---|
| Storage treatment | 1 | 2635.1** |
| Time | 5 | 1215.4** |
| Storage treatment x time | 5 | 19.6 |
| Reps in storage treatment x time | 24 | 84.0 |
| Total corrected | 35 | 309.3 |

| | | |
|---|---|---|
| LSD: | Storage treatment | .01 - 8.54<br>.05 - 6.31 |
| | Time | .01 - 14.85<br>.05 - 10.92 |
| | Storage treatment x time | .01 - ns<br>.05 - ns |
| CV % | | 18.6 |

**Significant at .01 level

Appendix Table 12. Combined analysis of variance of the effect of N, P and K fertilizer on yield and chemical composition of S. alterniflora at Ocracoke[a]

| Source | df | Mean square | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Yield ($g/m^2$) | % N | % P | % K | % Ca | % Mg | % Na | Cu (ppm) |
| Location | 2 | 421579.9 | 0.0434 | 0.00036 | 0.1076 | 0.0035 | 0.0074 | 0.4375 | 3.369 |
| Reps in location | 3 | 15168.8 | 0.0059 | 0.00022 | 0.0022 | 0.0013 | 0.0024 | 0.1311 | 4.792 |
| Treatment | 4 | 22488.9** | 0.0225** | 0.00141* | 0.0080 | 0.0018 | 0.0024 | 0.1248* | 0.841 |
| Loc x trt | 8 | 2968.2 | 0.0034 | 0.00025 | 0.0047 | 0.0034 | 0.0018 | 0.0844 | 2.829 |
| Error | 12 | 2616.5 | 0.0030 | 0.00029 | 0.0055 | 0.0029 | 0.0016 | 0.0370 | 1.919 |
| Corrected total | 29 | 35646.9 | 0.0089 | 0.00043 | 0.0123 | 0.0028 | 0.0023 | 0.0996 | 2.419 |
| LSD: Trt .01 | | 902.1 | 0.10 | ns | ns | ns | ns | ns | ns |
| .05 | | 643.5 | 0.07 | 0.022 | ns | ns | ns | 0.24 | ns |
| CV % | | 15.20 | 7.03 | 18.23 | 10.11 | 14.17 | 8.86 | 7.98 | 49.95 |

[a]S, Fe, Zn and Mn had a trt x loc interaction; therefore, a separate analysis by location was performed.

*Significant at .05 level

**Significant at .01 level

Appendix Table 13. Sulfur, Fe, Mn and Zn content of S. alterniflora from three locations within a marsh at Ocracoke

| Treatment | % S | Fe, ppm | Mn, ppm | Zn, ppm |
|---|---|---|---|---|
| | Location 1 | | | |
| NPK | 0.51 | 500.5 | 44.5 | 14.1 |
| NP | 0.58 | 460.0 | 39.5 | 20.2 |
| NK | 0.39 | 392.0 | 37.0 | 18.4 |
| PK | 0.37 | 385.5 | 32.5 | 21.6 |
| 0 | 0.36 | 313.0 | 28.0 | 17.2 |
| LSD: Trt .01 | ns | ns | 10.9 | ns |
| .05 | 0.13 | ns | 6.6 | 4.5 |
| CV % | 7.5 | 14.6 | 6.5 | 8.9 |
| | Location 2 | | | |
| NPK | 0.40 | 279.5 | 25.5 | 7.5 |
| NP | 0.50 | 223.5 | 29.5 | 8.2 |
| NK | 0.46 | 363.5 | 27.5 | 8.5 |
| PK | 0.53 | 263.0 | 20.0 | 9.2 |
| 0 | 0.51 | 366.5 | 24.0 | 10.4 |
| LSD: Trt .01 | ns | ns | ns | ns |
| .05 | 0.077 | ns | ns | ns |
| CV % | 5.8 | 19.5 | 9.5 | 14.8 |
| | Location 3 | | | |
| NPK | 0.34 | 194.0 | 22.5 | 9.3 |
| NP | 0.40 | 229.5 | 25.5 | 9.4 |
| NK | 0.34 | 201.5 | 24.5 | 11.8 |
| PK | 0.32 | 193.5 | 23.5 | 9.1 |
| 0 | 0.35 | 300.0 | 27.5 | 9.5 |
| LSD: Trt .01 | ns | ns | ns | ns |
| .05 | ns | ns | ns | ns |
| CV % | 15.4 | 16.5 | 15.4 | 10.7 |

Appendix Table 14. Analysis of variance by location of S, Fe, Mn and Zn content of S. alterniflora from Ocracoke fertilized with N, P and K in 1970

| Source | df | Mean square % S | Fe, ppm | Mn, ppm | Zn, ppm |
|---|---|---|---|---|---|
| | | **Location 1** | | | |
| Rep | 1 | 0.00001 | 8065.6 | 52.9 | 44.1 |
| Trt | 4 | 0.0135* | 10511.7 | 80.7** | 16.7* |
| Error | 4 | 0.00209 | 3599.4 | 5.7 | 2.7 |
| Corrected total | 9 | 0.0069 | 7167.7 | 44.2 | 13.7 |
| LSD: Trt .01 | | ns | ns | 10.9 | ns |
| .05 | | 0.13 | ns | 6.6 | 4.5 |
| CV % | | 7.5 | 14.6 | 6.5 | 8.9 |
| | | **Location 2** | | | |
| Rep | 1 | 0.0084 | 1742.4 | 22.5 | 1.30 |
| Trt | 4 | 0.0050* | 8046.4 | 26.2 | 2.43 |
| Error | 4 | 0.00076 | 3433.9 | 5.8 | 1.69 |
| Corrected total | 9 | 0.0035 | 5296.0 | 16.7 | 1.97 |
| LSD: Trt .01 | | ns | ns | ns | ns |
| .05 | | 0.077 | ns | ns | ns |
| CV % | | 5.8 | 19.5 | 9.5 | 14.8 |
| | | **Location 3** | | | |
| Rep | 1 | 0.0023 | 14516.1 | 16.9 | 1.76 |
| Trt | 4 | 0.0020 | 4071.2 | 7.4 | 2.49 |
| Error | 4 | 0.0029 | 1357.9 | 14.4 | 1.11 |
| Corrected total | 9 | 0.0024 | 4025.8 | 11.6 | 1.80 |
| LSD: Trt .01 | | ns | ns | ns | ns |
| .05 | | ns | ns | ns | ns |
| CV % | | 15.4 | 16.5 | 15.4 | 10.7 |

Appendix Table 15. Yield and nutrient content of plant samples from nitrogen plots at Ocracoke harvested September 2, 1971 (49 kg/ha P were applied to half of each plot on July 27, 1971)

| Nitrogen rate, kg/ha | 0[a] | 49 | $\bar{X}$ | 0 | 49 | $\bar{X}$ | 0 | 49 | $\bar{X}$ |
|---|---|---|---|---|---|---|---|---|---|
| | | Yield (kg/ha) | | | % N | | | % P | |
| 0 | 2848.9 | 2518.8 | 2683.9 | 0.77 | 0.79 | 0.78 | 0.10 | 0.16 | 0.13 |
| 168 | 4621.4 | 5048.4 | 4834.9 | 1.12 | 1.14 | 1.13 | 0.08 | 0.15 | 0.12 |
| 336 | 4241.1 | 6562.6 | 5401.8 | 1.29 | 1.33 | 1.31 | 0.07 | 0.15 | 0.11 |
| 672 | 4302.1 | 6856.8 | 5579.4 | 1.67 | 1.60 | 1.63 | 0.07 | 0.15 | 0.11 |
| $\bar{X}$ | 4003.4 | 5246.7 | | 1.21 | 1.21 | | 0.08 | 0.15 | |
| LSD: | | | | | | | | | |
| N rate .01 | | 1856.7 | | | 0.15 | | | ns | |
| .05 | | 1225.4 | | | 0.10 | | | ns | |
| P rate .01 | | 832.9 | | | ns | | | 0.011 | |
| .05 | | 572.4 | | | ns | | | 0.008 | |
| N x P .01 | | 1665.9 | | | ns | | | ns | |
| .05 | | 1144.8 | | | ns | | | ns | |
| CV % | | 13.15 | | | 5.28 | | | 7.42 | |
| | | % K | | | % Ca | | | % Mg | |
| 0 | 0.90 | 0.80 | 0.85 | 0.40 | 0.41 | 0.41 | 0.35 | 0.35 | 0.35 |
| 168 | 1.03 | 0.93 | 0.98 | 0.47 | 0.45 | 0.46 | 0.37 | 0.31 | 0.34 |
| 336 | 1.10 | 1.07 | 1.08 | 0.48 | 0.48 | 0.48 | 0.32 | 0.31 | 0.31 |
| 672 | 0.90 | 1.13 | 1.02 | 0.54 | 0.50 | 0.52 | 0.36 | 0.32 | 0.34 |
| $\bar{X}$ | 0.98 | 0.98 | | 0.47 | 0.46 | | 0.35 | 0.32 | |
| LSD: | | | | | | | | | |
| N rate .01 | | ns | | | ns | | | ns | |
| .05 | | 0.13 | | | 0.07 | | | ns | |
| P rate .01 | | ns | | | ns | | | ns | |
| .05 | | ns | | | ns | | | 0.03 | |
| N x P .01 | | ns | | | ns | | | ns | |
| .05 | | 0.16 | | | ns | | | ns | |
| CV % | | 8.56 | | | 6.23 | | | 9.25 | |

Appendix Table 15 (Continued)

| Nitrogen rate, kg/ha | 0[a] | 49 | $\overline{X}$ | 0 | 49 | $\overline{X}$ | 0 | 49 | $\overline{X}$ |
|---|---|---|---|---|---|---|---|---|---|
| | | % Na | | | % S | | | Fe (ppm) | |
| 0 | 1.60 | 1.84 | 1.72 | 0.26 | 0.25 | 0.26 | 117.1 | 128.9 | 123.0 |
| 168 | 1.90 | 1.78 | 1.84 | 0.27 | 0.24 | 0.26 | 134.8 | 104.9 | 119.8 |
| 336 | 1.43 | 1.97 | 1.70 | 0.25 | 0.27 | 0.26 | 92.3 | 116.6 | 104.4 |
| 672 | 1.91 | 2.02 | 1.97 | 0.38 | 0.33 | 0.36 | 141.7 | 100.1 | 120.9 |
| $\overline{X}$ | 1.71 | 1.90 | | 0.29 | 0.27 | | 121.5 | 112.6 | |
| LSD: | | | | | | | | | |
| N rate .01 | | ns | | | 0.05 | | | ns | |
| .05 | | ns | | | 0.03 | | | ns | |
| P rate .01 | | ns | | | ns | | | ns | |
| .05 | | 0.19 | | | ns | | | ns | |
| N x P .01 | | ns | | | ns | | | ns | |
| .05 | | ns | | | ns | | | ns | |
| CV % | | 11.36 | | | 16.63 | | | 27.67 | |

[a]P rate.

Appendix Table 16. Analysis of variance of yield and nutrient content of *S. alterniflora* from Ocracoke which was fertilized with three rates of N (applied August 5, 1970 and harvested October 1, 1970)

| Source | df | Mean square | | | | | |
|---|---|---|---|---|---|---|---|
| | | Yield (kg/ha) | % N | % P | % K | % Ca | % Mg |
| Rep | 2 | 73300.0 | 0.0036 | 0.000008 | 0.0039 | 0.0058 | 0.00061 |
| Trt | 3 | 1437066.7 | 0.0958** | 0.000031 | 0.0281** | 0.0043 | 0.00144** |
| Error | 6 | 296100.0 | 0.0021 | 0.000031 | 0.0020 | 0.0029 | 0.00015 |
| Corrected total | 11 | | | | | | |
| LSD: Trt .01 | | ns | 0.14 | ns | 0.136 | ns | 0.037 |
| .05 | | 1087.1 | 0.09 | ns | 0.090 | ns | 0.025 |
| CV % | | 19.30 | 5.25 | 6.44 | 5.92 | 13.45 | 2.49 |
| | | % Na | % S | Cu (ppm) | Mn (ppm) | Zn (ppm) | Fe (ppm) |
| Rep | 2 | 0.137 | 0.0020 | 0.49 | 2.28 | 1.14 | 2892.6 |
| Trt | 3 | 0.122 | 0.0025 | 1.43 | 164.12** | 2.33 | 25837.6* |
| Error | 6 | 0.039 | 0.0006 | 0.44 | 15.56 | 2.57 | 5515.1 |
| Corrected total | 11 | | | 0.72 | 53.66 | 2.24 | 10580.8 |
| LSD: Trt .01 | | ns | ns | ns | 11.94 | ns | ns |
| .05 | | ns | ns | ns | 7.88 | ns | 148.4 |
| CV % | | 7.30 | 4.87 | 22.79 | 13.35 | 15.23 | 18.18 |

*Significant at .05 level

**Significant at .01 level

Appendix Table 17. Analysis of variance of yield and nutrient content of plant samples from nitrogen plots at Ocracoke harvested September 2, 1971 (49 kg/ha P were applied to half of each plot on July 27, 1971)

| Source | df | Mean square: Yield (kg/ha) | % N | % P | % K | % Ca | % Mg | % Na | % S | Fe (ppm) |
|---|---|---|---|---|---|---|---|---|---|---|
| Rep | 2 | 2109700 | 0.0003 | 0.00038 | 0.010 | 0.00018 | 0.00315 | 0.0658 | 0.0024 | 1174.6 |
| N rate | 3 | 10652943** | 0.7586** | 0.00041 | 0.058* | 0.01329* | 0.00128 | 0.0884 | 0.0145** | 433.8 |
| Error (a) | 6 | 752423** | 0.0052 | 0.00027 | 0.008 | 0.00243 | 0.00078 | 0.0716 | 0.0005 | 697.4 |
| P rate | 1 | 9274249** | 0.00002 | 0.03082** | 0.000 | 0.00094 | 0.00510* | 0.2223* | 0.0015 | 468.2 |
| N x P | 3 | 3012111 | 0.0040 | 0.00016 | 0.038* | 0.00085 | 0.00119 | 0.1127 | 0.0015 | 1563.7 |
| Error (b) | 8 | 369740 | 0.0041 | 0.00008 | 0.007 | 0.00085 | 0.00096 | 0.4213 | 0.0022 | 1049.0 |
| Corrected total | 23 | | | | | | | | | |
| LSD: | | | | | | | | | | |
| N rate .01 | | 1856.7 | 0.15 | ns | ns | ns | ns | ns | 0.05 | ns |
| .05 | | 1225.4 | 0.10 | ns | 0.13 | 0.07 | ns | ns | 0.03 | ns |
| P rate .01 | | 832.9 | ns | 0.011 | ns | ns | ns | ns | ns | ns |
| .05 | | 572.4 | ns | 0.008 | ns | ns | 0.03 | 0.19 | ns | ns |
| N x P .01 | | 166.6 | ns | ns | ns | ns | ns | ns | ns | ns |
| .05 | | 114.5 | ns | ns | 0.16 | ns | ns | ns | ns | ns |
| CV % | | 13.15 | 5.28 | 7.42 | 8.56 | 6.23 | 9.25 | 11.36 | 16.63 | 27.67 |

*Significant at .05 level

**Significant at .01 level

Appendix Table 18. The effect of N and P fertilizers on yield and chemical composition of S. alterniflora from Ocracoke after fertilizing for one growing season (harvested September 1, 1971)

| N rate (kg/ha) | | 0[a] | 74 | $\bar{X}$ | 0 | 74 | $\bar{X}$ | 0 | 74 | $\bar{X}$ |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Yield (kg/ha) | | | N, % | | | P, % | |
| 0 | | 4367 | 3240 | 3803 | 0.83 | 0.86 | 0.84 | 0.097 | 0.157 | 0.127 |
| 168 | | 5755 | 6416 | 6085 | 1.07 | 1.08 | 1.08 | 0.080 | 0.143 | 0.112 |
| 336 | | 6279 | 10398 | 8339 | 1.23 | 1.34 | 1.29 | 0.083 | 0.163 | 0.123 |
| 672 | | 6398 | 11209 | 8803 | 1.60 | 1.45 | 1.52 | 0.077 | 0.137 | 0.107 |
| $\bar{X}$ | | 5700 | 7816 | | 1.18 | 1.18 | | 0.084 | 0.150 | |
| LSD: | | | | | | | | | | |
| N rate | .01 | | 2309 | | | 0.134 | | | ns | |
| | .05 | | 1663 | | | 0.097 | | | ns | |
| P rate | .01 | | 1632 | | | ns | | | 0.0157 | |
| | .05 | | 1176 | | | ns | | | 0.0113 | |
| N x P | .01 | | 3265 | | | ns | | | ns | |
| | .05 | | 2352 | | | ns | | | ns | |
| CV % | | | 19.88 | | | 6.64 | | | 11.03 | |
| | | | K, % | | | Ca, % | | | Mg, % | |
| 0 | | 1.07 | 1.00 | 1.03 | 0.33 | 0.37 | 0.35 | 0.29 | 0.29 | 0.29 |
| 168 | | 1.10 | 1.00 | 1.05 | 0.41 | 0.43 | 0.42 | 0.31 | 0.32 | 0.31 |
| 336 | | 1.13 | 1.13 | 1.13 | 0.42 | 0.38 | 0.40 | 0.30 | 0.30 | 0.30 |
| 672 | | 1.17 | 1.20 | 1.18 | 0.39 | 0.44 | 0.41 | 0.30 | 0.30 | 0.30 |
| $\bar{X}$ | | 1.12 | 1.08 | | 0.39 | 0.40 | | 0.30 | 0.30 | |
| LSD: | | | | | | | | | | |
| N rate | .01 | | 0.12 | | | ns | | | ns | |
| | .05 | | 0.08 | | | ns | | | ns | |
| P rate | .01 | | ns | | | ns | | | ns | |
| | .05 | | ns | | | ns | | | ns | |
| N x P | .01 | | ns | | | ns | | | ns | |
| | .05 | | ns | | | ns | | | ns | |
| CV % | | | 6.15 | | | 13.66 | | | 10.21 | |

Appendix Table 18 (Continued)

| N rate (kg/ha) | 0[a] | 74 | $\overline{X}$ | 0 | 74 | $\overline{X}$ | 0 | 74 | $\overline{X}$ |
|---|---|---|---|---|---|---|---|---|---|
| | | Na, % | | | S, % | | | Fe, ppm | |
| 0 | 1.56 | 1.58 | 1.57 | 0.33 | 0.25 | 0.29 | 121.7 | 117.9 | 119.8 |
| 168 | 1.64 | 1.88 | 1.76 | 0.28 | 0.33 | 0.31 | 145.8 | 135.6 | 140.7 |
| 336 | 1.70 | 1.93 | 1.82 | 0.29 | 0.32 | 0.31 | 183.8 | 182.9 | 183.3 |
| 672 | 1.66 | 1.93 | 1.80 | 0.36 | 0.31 | 0.33 | 93.9 | 109.3 | 101.6 |
| $\overline{X}$ | 1.64 | 1.83 | | 0.32 | 0.30 | | 136.3 | 136.4 | |
| LSD: | | | | | | | | | |
| N rate .01 | | ns | | | ns | | | ns | |
| .05 | | ns | | | ns | | | ns | |
| P rate .01 | | ns | | | ns | | | ns | |
| .05 | | 0.16 | | | ns | | | ns | |
| N x P .01 | | ns | | | ns | | | ns | |
| .05 | | ns | | | ns | | | ns | |
| CV % | | 10.23 | | | 17.85 | | | 55.21 | |

[a]Phosphorus rate (kg/ha).

Appendix Table 19. Statistical analysis of data from *S. alterniflora* from Ocracoke fertilized with N and P during the summer of 1971 and harvested September 1, 1971

| Source of variation | df | Mean square | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Yield (kg/ha) | % N | % P | % K | % Ca | % Mg | % Na | % S | Fe (ppm) |
| Reps | 2 | 1103039 | 0.0127 | 0.0005 | 0.0113 | 0.0047 | 0.0038 | 0.0897 | 0.0020 | 1203.5 |
| N rate | 3 | 31728487** | 0.5049** | 0.0005 | 0.0300** | 0.0055 | 0.0007 | 0.0753 | 0.0017 | 7413.4 |
| P rate | 1 | 26866318** | 0.00002 | 0.0260** | 0.0067 | 0.0017 | 0.0000 | 0.2166* | 0.0011 | 0.1 |
| N x P | 3 | 11956398** | 0.0182 | 0.0001 | 0.0056 | 0.0027 | 0.0000 | 0.0189 | 0.0060 | 179.2 |
| Error | 14 | 1804394 | 0.0062 | 0.0002 | 0.0046 | 0.0029 | 0.0009 | 0.0315 | 0.0030 | 5668.5 |
| Total | 23 | | | | | | | | | |
| LSD: | | | | | | | | | | |
| N rate .01 | | 2308.7 | 0.1348 | ns | 0.116 | ns | ns | ns | ns | ns |
| .05 | | 1663.4 | 0.0971 | ns | 0.084 | ns | ns | ns | ns | ns |
| P rate .01 | | 1632.5 | ns | 0.0157 | ns | ns | ns | ns | ns | ns |
| .05 | | 1176.2 | ns | 0.0113 | ns | ns | ns | 0.155 | ns | ns |
| N x P .01 | | 3264.9 | ns | ns | ns | ns | ns | ns | ns | ns |
| .05 | | 2352.4 | ns | ns | ns | ns | ns | ns | ns | ns |
| CV % | | 19.88 | 6.64 | 11.03 | 6.15 | 13.66 | 10.22 | 10.23 | 17.85 | 55.21 |

*Significant at .05 level

**Significant at .01 level

Appendix Table 20. The effect of N and P fertilizers on yield and chemical composition of *S. alterniflora* from Ocracoke after fertilizing for two consecutive growing seasons

| N rate (kg/ha) | | 0[a] | 74 | $\overline{X}$ | 0 | 74 | $\overline{X}$ | 0 | 74 | $\overline{X}$ |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Yield (kg/ha) | | | N, % | | | P, % | |
| 0 | | 5390 | 4997 | 5194 | 0.83 | 0.90 | 0.86 | 0.093 | 0.143 | 0.118 |
| 168 | | 7605 | 10380 | 8993 | 1.04 | 0.92 | 0.98 | 0.083 | 0.153 | 0.118 |
| 336 | | 7833 | 12595 | 10214 | 1.08 | 1.10 | 1.09 | 0.077 | 0.150 | 0.113 |
| 672 | | 8400 | 17501 | 12951 | 1.31 | 1.25 | 1.28 | 0.077 | 0.140 | 0.108 |
| $\overline{X}$ | | 7307 | 11368 | | 1.06 | 1.04 | | 0.083 | 0.147 | |
| LSD: | | | | | | | | | | |
| N rate | .01 | | 2770 | | | 0.12 | | | ns | |
| | .05 | | 1996 | | | 0.08 | | | ns | |
| P rate | .01 | | 1959 | | | ns | | | 0.009 | |
| | .05 | | 1411 | | | ns | | | 0.007 | |
| N x P | .01 | | 3918 | | | ns | | | ns | |
| | .05 | | 2823 | | | ns | | | ns | |
| CV % | | | 17.26 | | | 6.49 | | | 6.77 | |
| | | | K, % | | | Ca, % | | | Mg, % | |
| 0 | | 1.00 | 1.00 | 1.00 | 0.34 | 0.37 | 0.35 | 0.48 | 0.45 | 0.46 |
| 168 | | 1.10 | 1.00 | 1.05 | 0.37 | 0.43 | 0.40 | 0.43 | 0.44 | 0.44 |
| 336 | | 1.03 | 1.10 | 1.07 | 0.42 | 0.41 | 0.42 | 0.48 | 0.44 | 0.46 |
| 672 | | 1.10 | 1.10 | 1.10 | 0.40 | 0.46 | 0.43 | 0.45 | 0.41 | 0.43 |
| $\overline{X}$ | | 1.06 | 1.05 | | 0.38 | 0.42 | | 0.46 | 0.44 | |
| LSD: | | | | | | | | | | |
| N rate | .01 | | ns | | | ns | | | ns | |
| | .05 | | ns | | | 0.05 | | | ns | |
| P rate | .01 | | ns | | | ns | | | ns | |
| | .05 | | ns | | | 0.04 | | | ns | |
| N x P | .01 | | ns | | | ns | | | ns | |
| | .05 | | ns | | | ns | | | ns | |
| CV % | | | 5.43 | | | 10.26 | | | 8.07 | |

Appendix Table 20 (Continued)

| N rate (kg/ha) | | 0[a] | 74 | $\bar{X}$ | 0 | 74 | $\bar{X}$ | 0 | 74 | $\bar{X}$ |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Na, % | | | S, % | | | Fe, ppm | |
| 0 | | 3.13 | 2.90 | 3.02 | 0.48 | 0.46 | 0.47 | 366.3 | 350.2 | 358.3 |
| 168 | | 2.73 | 2.93 | 2.83 | 0.49 | 0.46 | 0.48 | 249.2 | 260.8 | 255.0 |
| 336 | | 3.10 | 3.20 | 3.15 | 0.44 | 0.49 | 0.47 | 284.8 | 220.3 | 252.6 |
| 672 | | 2.97 | 2.87 | 2.92 | 0.51 | 0.41 | 0.46 | 272.2 | 191.7 | 231.9 |
| $\bar{X}$ | | 2.98 | 2.98 | | 0.48 | 0.45 | | 293.1 | 255.8 | |
| LSD: | | | | | | | | | | |
| N rate | .01 | | ns | | | ns | | | 91.6 | |
| | .05 | | ns | | | ns | | | 66.0 | |
| P rate | .01 | | ns | | | ns | | | ns | |
| | .05 | | ns | | | ns | | | ns | |
| N x P | .01 | | ns | | | ns | | | ns | |
| | .05 | | ns | | | ns | | | ns | |
| CV % | | | 9.15 | | | 7.55 | | | 19.43 | |
| | | | Mn, ppm | | | | | | | |
| 0 | | 14.97 | 17.00 | 15.98 | | | | | | |
| 168 | | 19.30 | 22.23 | 20.77 | | | | | | |
| 336 | | 17.43 | 24.13 | 20.78 | | | | | | |
| 672 | | 22.17 | 25.60 | 23.88 | | | | | | |
| $\bar{X}$ | | 18.47 | 22.24 | | | | | | | |
| LSD: | | | | | | | | | | |
| N rate | .01 | | 3.78 | | | | | | | |
| | .05 | | 2.72 | | | | | | | |
| P rate | .01 | | 2.67 | | | | | | | |
| | .05 | | 1.92 | | | | | | | |
| N x P | .01 | | ns | | | | | | | |
| | .05 | | ns | | | | | | | |
| CV % | | | 10.80 | | | | | | | |

[a]Rate of P (kg/ha).

Appendix Table 21. Statistical analysis of the effect of N and P fertilizers on yield and chemical composition of S. alterniflora from Ocracoke after fertilizing for two consecutive growing seasons

| Source of variation | df | Mean square: Yield (kg/ha) | N, % | P, % | K, % | Ca, % | Mg, % | Na, % | S, % | Fe, ppm | Mn, ppm |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Reps | | 7301046 | 0.0080 | 0.00018 | 0.0204 | 0.0036 | 0.0043 | 0.0867 | 0.0007 | 9933 | 2.07 |
| N rate | 3 | 62225838** | 0.1871** | 0.00014 | 0.0104 | 0.0067* | 0.0017 | 0.1115 | 0.0003 | 19376** | 63.83** |
| P rate | 1 | 98965252** | 0.0028 | 0.02470** | 0.0004 | 0.0077* | 0.0034 | 0.0004 | 0.0043 | 8381 | 85.50** |
| N x P | 3 | 23693938** | 0.0095 | 0.00016 | 0.0071 | 0.0014 | 0.0008 | 0.0571 | 0.0059* | 2725 | 6.21 |
| Error | 14 | 2598055 | 0.0047 | 0.00006 | 0.0037 | 0.0017 | 0.0013 | 0.0742 | 0.0012 | 2844 | 4.83 |
| Total | 23 | | | | | | | | | | |
| LSD: | | | | | | | | | | | |
| N rate .01 | | 2770 | 0.12 | ns | ns | ns | ns | ns | ns | 91.6 | 3.78 |
| .05 | | 1996 | 0.08 | ns | ns | 0.051 | ns | ns | ns | 66.0 | 2.72 |
| P rate .01 | | 1959 | ns | 0.009 | ns | ns | ns | ns | ns | ns | 2.67 |
| .05 | | 1411 | ns | 0.007 | ns | 0.036 | ns | ns | ns | ns | 1.92 |
| N x P .01 | | 3918 | ns | ns | ns | ns | ns | ns | ns | ns | ns |
| .05 | | 2823 | ns | ns | ns | ns | ns | ns | 0.06 | ns | ns |
| CV % | | | 6.49 | 6.77 | 5.43 | 10.26 | 8.07 | 9.15 | 7.55 | 19.43 | 10.80 |

*Significant at .05 level

**Significant at .01 level

Appendix Table 22. Analysis of variance of the effect of N and P on the standing crop of roots at Ocracoke

| Source of variation | df | Mean square | | |
|---|---|---|---|---|
| | | Depth of core (cm) | | |
| | | 0-30 | 0-10 | 0-30 |
| | | Dry weight, g/m$^2$ | | |
| Reps | 2 | 1030331 | 864411 | 79553 |
| N rate | 3 | 1279753** | 1013759** | 27099 |
| P rate | 1 | 230595 | 41610 | 468114** |
| N x P | 3 | 210663 | 126386 | 86297 |
| Rep x N rate | 6 | 118161 | 103206 | 93519 |
| Rep x P rate | 2 | 531366 | 370048 | 24678 |
| Rep x N x P | 6 | 261653 | 120772 | 43971 |
| Error | 96 | 290705 | 200565 | 36793 |
| Total | 119 | | | |
| LSD: N rate .01 | | 366 | 304 | ns |
| .05 | | 276 | 230 | ns |
| P rate .01 | | ns | ns | 92 |
| .05 | | ns | ns | 70 |
| N x P .01 | | ns | ns | ns |
| .05 | | ns | ns | ns |
| CV % | | 26.2 | 28.8 | 37.0 |

**Significant at the .01 level

Appendix Table 23. Analysis of variance of the effect of N and Fe applications on tall and short *S. alterniflora* at Oak Island

| Source of variation | | df | Mean square | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Yield (kg/ha) | Height (cm) | No. stem/$m^2$ | N, % | P, % | K, % | Ca, % | Mg, % | S, % | Na, % | Fe, ppm |
| | | | | | | | Tall | | | | | | |
| Reps | | 2 | 20656800 | 1479.1 | 9.6 | 0.0059 | 0.0006 | 0.017 | 0.0007 | 0.0005 | 0.0076 | 0.016 | 10645 |
| Trt | | 5 | 6005493 | 375.3 | 43.7 | 0.0068 | 0.0002 | 0.015 | 0.0010 | 0.0007 | 0.0052 | 0.011 | 16302 |
| Error | | 10 | 5714933 | 282.2 | 41.1 | 0.0077 | 0.0003 | 0.017 | 0.0013 | 0.0007 | 0.0102 | 0.025 | 45639 |
| Total | | 17 | | | | | | | | | | | |
| LSD: | .01 | | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns |
| | .05 | | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns |
| CV % | | | 22.2 | 10.7 | 25.2 | 11.0 | 16.8 | 15.5 | 15.0 | 6.9 | 23.0 | 7.5 | 45.9 |
| | | | | | | | Short | | | | | | |
| Reps | | 2 | 2881067 | 58.4 | 4267.7 | 0.008 | 0.00017 | 0.016 | 0.0001 | 0.008 | 0.098 | 0.69 | 1339211 |
| Trt | | 5 | 8599200* | 389.8 | 1874.1 | 0.390* | 0.00013 | 0.020 | 0.0044** | 0.002 | 0.012 | 0.02 | 59580 |
| Error | | 10 | 1684587 | 226.7 | 1034.3 | 0.009 | 0.00008 | 0.009 | 0.0006 | 0.001 | 0.004 | 0.05 | 142632 |
| Total | | 17 | | | | | | | | | | | |
| LSD: | .01 | | 3358.6 | ns | ns | ns | ns | ns | 0.062 | ns | ns | ns | ns |
| | .05 | | 2361.3 | ns | ns | 0.17 | ns | ns | 0.044 | ns | ns | ns | ns |
| CV % | | | 20.9 | 15.4 | 25.1 | 10.1 | 10.2 | 10.6 | 9.5 | 8.1 | 8.5 | 11.3 | 36.2 |

*Significant at .05 level

**Significant at .01 level

Appendix Table 24. Analysis of variance of the effect of N and P on *S. alterniflora* yield at Oak Island

| Source of variation | | df | Mean square Yield (kg/ha) | |
|---|---|---|---|---|
| | | | Tall | Short |
| Reps | | 2 | 167999117 | 33048517 |
| N rate | | 3 | 71800389 | 20818671* |
| P rate | | 1 | 763267 | 1455338 |
| N x P | | 3 | 10674811 | 6513449 |
| Error | | 14 | 38087602 | 5424341 |
| Total | | 23 | | |
| LSD: N rate | .01 | | ns | ns |
| | .05 | | ns | 2884 |
| P rate | .01 | | ns | ns |
| | .05 | | ns | ns |
| N x P | .01 | | ns | ns |
| | .05 | | ns | ns |
| CV % | | | 32.5 | 28.97 |

*Significant at the .05 level

Appendix Table 25. Analysis of variance of the effect of N and P on *S. alterniflora* transplants at Drum Inlet

| Source of variation | | df | Mean square | | | |
|---|---|---|---|---|---|---|
| | | | Dry wt plant (g) | No. flowers/ plant | No. culms/ plant | No. rhizomes/ plant |
| Reps | | 2 | 57.7 | 5.5 | 98.0 | 2.7 |
| N rate | | 3 | 223.6* | 12.0* | 293.4** | 6.5 |
| P rate | | 1 | 1577.3** | 150.2** | 1250.0** | 15.1* |
| N x P | | 3 | 80.1 | 4.1 | 44.0 | 1.2 |
| Rep x N rate | | 6 | 38.4 | 4.1 | 25.7 | 6.4 |
| Rep x P rate | | 2 | 23.6 | 1.1 | 38.6 | 6.2 |
| Rep x N x P | | 6 | 56.2 | 4.9 | 80.0 | 1.8 |
| Error | | 48 | 54.3 | 4.3 | 48.3 | 3.2 |
| Total | | 71 | | | | |
| LSD: N rate | .01 | | ns | ns | 6.2 | ns |
| | .05 | | 4.9 | 1.4 | 4.7 | ns |
| P rate | .01 | | 4.7 | 1.3 | 4.4 | ns |
| | .05 | | 3.5 | 1.0 | 3.3 | 0.84 |
| N x P | .01 | | ns | ns | ns | ns |
| | .05 | | ns | ns | ns | ns |
| CV % | | | 45.4 | 43.4 | 35.2 | 131.8 |

*Significant at .05 level

**Significant at .01 level

Appendix Table 26. Correlation matrix for soil properties of samples from tall and short height zones from seven locations

| | O.M. | Ca | Mg | P | K | Mn | CEC | Sol. salts | Na | Clay | Sand | Silt | A soil salinity | Yield | Ht |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| O.M. | | -0.04 | 0.87 | -0.32 | 0.67 | 0.46 | 0.95 | 0.72 | 0.65 | 0.52 | -0.62 | 0.64 | -0.26 | 0.07 | 0.04 |
| Ca | | | -0.05 | 0.71 | -0.06 | -0.11 | 0.01 | -0.02 | 0.01 | -0.16 | 0.20 | -0.20 | 0.30 | -0.03 | -0.17 |
| Mg | | | | -0.25 | 0.88 | 0.49 | 0.86 | 0.93 | 0.81 | 0.68 | -0.78 | 0.79 | 0.03 | -0.04 | 0.22 |
| P | | | | | -0.20 | -0.19 | -0.30 | -0.18 | 0.17 | -0.17 | 0.25 | -0.28 | 0.37 | 0.06 | -0.09 |
| K | | | | | | 0.21 | 0.74 | 0.88 | 0.81 | 0.79 | -0.84 | 0.83 | 0.26 | -0.02 | 0.38 |
| Mn | | | | | | | 0.39 | 0.53 | 0.37 | 0.34 | -0.40 | 0.40 | -0.18 | -0.19 | -0.08 |
| CEC | | | | | | | | 0.73 | 0.68 | 0.56 | -0.66 | 0.67 | -0.20 | 0.09 | 0.15 |
| Sol. salts | | | | | | | | | 0.83 | 0.66 | -0.74 | 0.75 | 0.14 | -0.07 | 0.22 |
| Na | | | | | | | | | | 0.50 | -0.56 | 0.57 | 0.09 | 0.09 | 0.29 |
| Clay | | | | | | | | | | | -0.75 | 0.91 | 0.27 | -0.12 | 0.31 |
| Sand | | | | | | | | | | | | -0.99 | -0.21 | 0.14 | -0.36 |
| Silt | | | | | | | | | | | | | 0.18 | -0.15 | 0.37 |
| A soil salinity | | | | | | | | | | | | | | -0.49 | -0.05 |
| Yield | | | | | | | | | | | | | | | 0.51 |

$r \geq |0.39|$ significant at .01 level

$r \geq |0.30|$ significant at .05 level

$r \geq |0.25|$ significant at .10 level

University of North Carolina Sea Grant Publications*

UNC-SG-72-01. Lyman, J. and W. Rickards. University of North Carolina Sea Grant Program, Annual Report, 1 July 1970 - 30 June 1971.

UNC-SG-72-02. Wurfel, S.W., ed. Attitudes regarding a law of the sea convention to establish an international seabed regime.

UNC-SG-72-03. Upchurch, J.B. Sedimentary phosphorus in the Pamlico estuary of North Carolina.

UNC-SG-72-04. Chleborowicz, A.G. Direct oil fired heat exchanger for a scallop shucking machine.

UNC-SG-72-05. Angel, N.B. Insulation if ice bunkers and fish holds in older fishing vessels.

UNC-SG-72-06. Edzwald, J.K. Coagulation in estuaries.

UNC-SG-72-07. University of North Carolina. Proposal for institutional Sea Grant support.

UNC-SG-72-08. Schwartz, F.J. and J. Tyler. Marine fishes common to North Carolina.

UNC-SG-72-09. Porter, H.J. and J. Tyler. Sea shells common to North Carolina.

UNC-SG-72-10. Woodhouse, W.W., E.D. Seneca, and S.W. Broome. Marsh building with dredge spoil in North Carolina.

UNC-SG-72-11. Copeland, B.J. Nutrients in Neuse River and Albemarle Sound estuaries, North Carolina: survey. (in preperation).

UNC-SG-72-12. Whitehurst, J.H. The menhaden fishing industry of North Carolina.

UNC-SG-72-13. Schoenbaum, T.J. Public rights and coastal zone management.

UNC-SG-72-14. Tung, C.C. and N.E. Huang. Some statistical properties of wave-current force on objects.

UNC-SG-72-15. Tung, C.C. and N.E. Huang. Wave-current force spectra.

UNC-SG-73-01. Wurfel, S.W. The surge of sea law.

UNC-SG-73-02. Williams, A.B., G.S. Posner, W.J. Woods, and E.E. Deubler, Jr. A hydrographic atlas of larger North Carolina sounds.

UNC-SG-73-03. Gerhardt, R.R., J.C. Dukes, J.M. Falter, and R.C. Axtell. Public opinion on insect pest management in coastal North Carolina.

UNC-SG-73-04. Rickards, W.L. A bibliography of artificial reefs and other man-made fish attractants.

UNC-SG-73-05. Tyler, J., M. McKenzie, and D. King. To catch a million fish.

UNC-SG-73-06. Graetz, K. Seacoast plants of the Carolinas for conservation and beautification.

UNC-SG-73-07. Campbell, P. Studies of brackish water phytoplankton.

UNC-SG-73-08. Samet, J.H. and R.L. Fuerst. The Latin American approach to the law of the sea.

UNC-SG-73-09. Rhyne, C.F. Field and ecological studies of the systematics and ecology of Ulva curvata and Ulva rotundata.

UNC-SG-73-10. Kuenzler, E.J., A.F. Chestnut and C.M. Weiss. The structure and functioning of brackish water ecosystems receiving treated sewage effluent III, 1971-1972.

UNC-SG-73-11. Dahle, E. The continental shelf lands of the United States: mineral resources and the laws affecting their development, exploitation and investment potential.

UNC-SG-73-12. Schwartz, F.J. and A.F. Chestnut. Hydrographic atlas of North Carolina estuarine and sound waters, 1972.

UNC-SG-73-13. Lyman, J. and W. Rickards. University of North Carolina Sea Grant Program, Annual Report, 1 July 1971 - 31 December 1972.

UNC-SG-73-14. Broome, S.W., W.W. Woodhouse and E.D. Seneca. An investigation of propagation and the mineral nutrition of Spartina alterniflora.

*Available from: Sea Grant Program, 1235 Burlington Laboratories, North Carolina State University, Raleigh, North Carolina 27607.