CHAPTER 43

CREATION AND STABILIZATION OF COASTAL BARRIER DUNES

By R. P. Savage[1] and W. W. Woodhouse, Jr.[2]

ABSTRACT

Experiments are underway along the coast of North Carolina using sand fences and dune grasses to create and stabilize a barrier dune line parallel to and behind the existing beaches of low lying barrier islands. Several miles of experimental sections have been established, and their effectiveness in trapping wind-blown sand has been analyzed. Results to date (1968) show that sand fences and dune grasses will trap wind-blown sand and create a barrier dune. A vigorous, rapidly-growing strip of American beachgrass, 90 feet wide, will trap and retain all of the sand being transported by the wind in the area. Thus, a stabilized dune can be "grown" in the area using American beachgrass.

Sand fences have been shown to be effective sand traps and can be used where satisfactory plants are not available or where it may not be feasible to await the establishment of vegetation. Two methods of using sand fences to create large dunes have been investigated; both are workable.

The use of fabrics as sand fences has been investigated; their effectiveness varies with the porosity of the fabric.

INTRODUCTION

Barrier dunes (the line of dunes sometimes found just landward of the beach) can be effective protective structures if they are high enough and wide enough to withstand the onslaught of storm waves. Dunes can provide the land elevation necessary to prevent the wave overtopping and storm tide overwash which often devastates low-lying land forms (barrier islands) during coastal storms. Even in their destruction, dunes provide material (sand) that enables the beach to better adjust to storm conditions and continue to perform its function as a wave energy absorber.

Many examples of protective barrier dunes could be cited, but none are so striking as those of the Netherland Coast where a significant portion of the system that holds back the sea is a massive dune system. These dunes have, understandably, been preserved and strengthened. In other countries, however, the barrier dune system has been neglected and removed or destroyed by man. As a result, many low-lying areas have little or no protection from coastal storms. Property is vulnerable and islands are often breached by inlets that must be closed at considerable expense or allowed to close over long time periods, often at considerable inconvenience.

---

[1]Assistant Chief, Research Division, U. S. Army Coastal Engineering Research Center

[2]Professor of Soil Science, North Carolina State University at Raleigh

This paper presents the results of field experiments to create and stabilize barrier dunes along the North Carolina Coast during the past decade. All of the experimental work has been carried out on low-lying barrier islands, a geographical environment typical of most of the Atlantic and Gulf Coasts of the United States. The experimentation has been directed toward the use of sand fences and dune grasses to catch and hold wind-blown sand and thus create and maintain a barrier dune.

LOCALE OF THE EXPERIMENTS

The barrier islands on which most of the work was done are that part of the barrier-island system of the east coast of the United States that extends from Cape Hatteras to Cape Lookout, North Carolina. (See Figure 1.) One study area is on the southern end of Ocracoke Island just northeast of Ocracoke Inlet; the other is on Portsmouth Island just northeast of Drum Inlet. These areas are characterized by low island profiles, generally rising from the ocean to an ordinary storm berm 4 to 6 feet above mean sea level, and then gently sloping to the sound behind the islands. The islands vary from 1/4 to 1 mile in width and are composed of medium-to-fine sands (approximately 0.2 mm in median diameter) mixed with shell. The tide is diurnal and has a mean range of about 4 feet. The relative transporting capacity of sand-moving winds (those with speeds greater than 12 miles per hour) at Cape Hatteras for a 5-year period is shown in Figure 2.

During late summer and fall the area is often subjected to waves from offshore hurricanes; occasionally, hurricanes move onshore over the area. In winter and spring, the area is affected by northeasters - extra-tropical storms that either move offshore in the area or form along this part of the coast. The low elevation and narrow width of these islands, plus the high waves along this coast, tend to produce a harsh environment for plant growth, as compared with other regions where stabilization work has been done. The salt problem here can be particularly acute. The experimental sites, covered in this paper, receive salt spray from both sea and sound, and have been flooded by both sea and sound. Under these conditions, variability of experimental data tends to be high since storm damage is extremely erratic and unpredictable.

EXPERIMENTAL PROCEDURE

General

The experimental procedure has consisted of establishing experimental sections of either dune grasses or sand fences parallel to the beach and from 200 to 700 feet from the shoreline. These sections vary in length from 200 to 1000 feet, but are generally 500 feet long. Profiles are taken by surveying along at least two ranges across (perpendicular to the beach) the experimental section before the fence or grass is put in place; periodic surveys of the same ranges are made to follow the sand accumulation of the section. The performance of the section is measured by the volume of sand trapped per foot of section length.

Description of Experiments

Vegetation - Three general categories of trials are reported herein:

1) Small exploratory plantings at several locations designed to obtain information on the ability of American beachgrass (*Ammophila breviligulata* Fern.) to become established under critical conditions and to get estimates of the ability of such plantings to trap and hold sand. These were made at 15 locations distributed along about 200 miles of the North Carolina Coast in March 1964. Plants were spaced 18" x 18" in plantings roughly 100' x 100'. Sand accumulation was measured on three of these in 1964-65.

2) Two series of plots long enough (400-500 feet) to grow frontal dunes and to provide estimates on rate of sand accumulation, dune shape, and grass survival. These were planted during the winter of 1964-65, one on Ocracoke Island and the other on Portsmouth Island (see Figure 3) Variables included presence or absence of sand fence, width of planting, and plant density. In addition, sand fence sections were included so that their sand-trapping effect could be compared with that of the grasses. Comparisons available at Ocracoke are shown in Table 1. The Portsmouth experiment was similar, but not identical.

3) Intermediate size plots (200 feet long) utilizing a non-uniform spacing pattern and comparing four selections of American beachgrass with each other, with nursery-run beachgrass, with sea oats (*Uniola paniculata* L), and with sea oats interplanted with American beachgrass in growing stabilized dunes.

These treatments were in duplicate making a total of 16 sections and were established on Ocracoke Island in November 1966 beginning a few hundred feet southwest of the 1965 experiment.

The same spacing plan was used on all planted sections, starting with a thick spacing in the center, thinning step-wise to a very wide spacing on the outer edges with 4 rows each as follows:

4 rows 48" x 48"
4 rows 36" x 36"
4 rows 24" x 24"
4 rows 15" x 21"
4 rows 24" x 24"
4 rows 36" x 36"
4 rows 48" x 48"

Total width, front to back, was 78 feet. The fence-alone sections were 500 feet in length, but in order to conserve planting stock, the planted sections were shortened to 200 feet, except those adjacent to fence sections and the end section which were 300 feet long.

All plants used in these studies were nursery-produced. The first exploratory trials were hand-planted, but all planting thereafter was by machine, placing 3-5 culms per hill. Fertilization consisted of three to four applications of 125 pounds per acre of 30-10-0 the first growing season, followed by two such applications the second year, and one application annually thereafter. (For details on planting and fertilization see Reference 3.)

Sand Fences - Two general sets of sand fence experiments were conducted.

The first set was designed to determine if either of two methods proposed earlier (Reference 1) for use in constructing coastal barrier dunes with sand fences was feasible. If both methods proved feasible, this set would determine which method is more economical. Since previous experiments (Reference 1) had shown that straight slat-type fences 4 feet high (see Figure 4) were satisfactory sand traps, straight slat-type fences were used in these tests. The second set of experiments was designed to test the effectiveness of fabric fences 4 feet high. The primary variable tested was the percent porosity (100 times the ratio of the open area of the fence to the total area of the fence). Slat-type fencing (50% porosity) was used in these tests as the standard to which the various fabric fences could be compared.

The two methods of barrier dune construction tested in the first set of experiments are illustrated in Figure 5. Using method (A) of this Figure, fences 1 and 2 would be installed, and allowed to fill by installing either fence first and installing the other after the first had filled, or by installing them both at the same time and allowing them to fill together. Fence 3 would then be installed atop the accumulation of fences 1 and 2. Fence 4 would be installed concurrently with fence 3 or after fence 3 had filled. Fence 5 would be installed after fence 4 had filled and then fences 6 and 7 would be added. This process would be followed, using the fences in numerical order, to achieve the desired dune profile.

Using method (B), fence 1 would be installed and allowed to fill. Fence 2 would be constructed two-thirds of the distance up the front slope of the accumulation of fence 1 and allowed to fill. Fence 3 would then be constructed two-thirds of the distance up the front of the accumulation of fences 1 and 2 and allowed to fill. This process would be continued until the desired dune profile had been created.

The two test sections used to test methods A & B were sections 2 and A of the study sections. Section 2 was 500 feet in length and the first two fences of this section were installed in March of 1964. Section A was 1000 feet in length and the first fence was installed in December of 1962. Surveys of the sand accumulation of both sections were made periodically, and later fences were added as the existing fences filled. In all cases a survey was obtained just before each new fence was added.

In the fabric-fence tests, 16 test sections (sections 32-47), each 500 feet in length, were installed end-to-end parallel to and about 500 feet from the ocean mean-waterline. The sections at each end of the test area (sections 32 and 47) were slat-type fencing as was each fourth section within the test area. The remainder of the test sections were fences of the 6 fabrics to be tested. Two test sections of each fabric were used and these were randomly distributed within the test area. All test sections were installed in December 1965 and periodic surveys were made to follow the sand accumulation of the sections (two profiles across each section). By July 1968 the slat-type fencing was essentially filled, and the experiment was considered complete.

The fabrics used as sand fences are made from plastics or artificial fibers (see Figures 6-a through 6-f). Their porosity (see Figure 6) was determined by covering a field of 200 randomly placed points (dots on an 8 1/2 by 11-inch sheet of paper) with a sample of each fabric and counting the visible points. The number of visible points divided by the total number of points (200) determined the porosity. Five counts were made for each fabric and the average was used in computing the porosity.

Fabric fences were mounted on 2 by 4-inch posts 6 feet apart and 4 feet high. A 4-foot strip of the fabric was stretched between the posts and fastened by nailing a 4-foot lath to each post in such a way that the width of the fabric was clamped between the lath and the post. In addition, a galvanized steel wire of about 1/8-inch diameter was stretched along the top of the posts. The fabric was fastened to this wire with nylon electrical fasteners (cable ties) at 1-foot intervals to prevent sagging of the fabric between posts.

RESULTS

Vegetation

Capacity of vegetation to trap sand - Portsmouth.

This estimate was obtained from cross section surveys taken on the 100 x 100 foot plantings north of Drum Inlet in July 1965, 15 months after planting. At that time, sand accumulation of some profiles was as great as 16 cubic yards per foot of beach (an average accumulation depth of 4.3 feet over the area of the planting). Since these small plantings were exposed on all four sides, they trapped wind-blown sand from all directions. Therefore, the volume of sand trapped greatly exaggerates the amount of sand available in this area for barrier dune construction over large lengths of beach. However, there is no reason to question this figure as an estimate of the capacity of grass plantings to trap sand.

Dune Sections, 1964-65, Ocracoke and Portsmouth Islands.

The most meaningful observations on these plantings came from the Ocracoke trial. The Portsmouth site became rather heavily armored with shell by early 1966, resulting in greatly reduced sand movement at that location. Fortunately, sand movement on the Ocracoke site has continued at a moderate, though somewhat variable, rate through the experimental period. Sand accumulation for these experiments is shown in Tables 1 and 2.

Planting Width - The 100-foot sections definitely trapped more sand than the narrower plots during the first few months (February 7-August 10). However, by the following June the narrower plots (25 and 50-foot) had caught up, and later differences appeared to be due to variations in sand supply.

Plant Spacing - The only spacing comparison is between sections 13 (plants on 24-inch centers) and 14 (plants 16 inches apart in 20-inch rows) both without sand fence. The 24" x 24" spacing trapped noticeably less sand during the period of early growth (February-June 1965) with little or no difference after that date.

Sand Fence in Combination with Grass - Trapping of sand appeared to be increased in the early stages by putting a sand fence in the narrower plantings (section 16 vs section 18 and section 14 vs section 15) with no consistent difference in the 100-foot sections. This effect tended to disappear after the first growing season. The fences on the 25-foot sections were essentially full by that time, and apparently the mass of vegetation on the wider plantings trapped most of the sand before it could penetrate to the fences.

Dune Shape - Cross section profiles are presented in Figures 7 and 8 to show the development of grass-grown dunes in dense, uniformly spaced plantings under two conditions. Figure 7 is from the site on Portsmouth Island where sand movement was very limited during the period of observation. Figure 8 is from Ocracoke Island where a fairly large volume of wind-blown sand was available.

Dune shape at this planting density is greatly affected by the volume of sand available. With a low volume (Figure 7), there was never enough sand to satisfy the trapping capacity of more than a few feet of the planting. This resulted in a narrow, rather steep, dune along the seaward edge which tended to move seaward in succeeding years as the grass spread into the bare sand in front of the planting. Very little sand succeeded in penetrating to the interior. A similar pattern developed on the landward side of the planting, but involved a much smaller volume of sand.

Under the condition represented in Figure 8, the same principle was operating, but the much larger volume of sand available, particularly from the seaward side, changed the pattern of development somewhat. More sand penetrated to the interior of the planting during the early part of the first growing season, and during the winter and early spring of each succeeding year. This resulted in a dune consisting of two ridges separated by a low area about 20 feet wide. During the approximately three-year period from planting until the March 1968 survey, the total width of the grassed area and the resulting dune had increased from the original 50 feet to around 100 feet, and the top of the seaward ridge was more than 5 feet above the starting level.

Table 1. Ocracoke Island - Sand accumulation by section (in yards^3 per foot of beach) on plots established February 7, 1965.

	25-foot sections			
	Section 17 Sand fence alone	Section 16 Planted 16 x 20 No fence	Section 18 Planted 16 x 20 With fence	Section 19 Planted 16 x 20 With fence
To June 21, 1965	1.12	0.72	1.68	1.35
To Aug. 10, 1965	2.09	1.66	1.94	2.09
To June 1966	4.46	4.46	4.90	5.05
To Jan. 1967	6.09	8.01	7.03	6.34
To Mar. 1968	7.87	10.13	9.87	10.86

	50-foot sections		
	Section 13 Planted 24 x 24 No fence	Section 14 Planted 16 x 20 No fence	Section 15 Planted 16 x 20 With fence
To June 21, 1965	0.62	1.05	1.32
To Aug. 10, 1965	1.78	2.30	2.18
To June 1966	3.46	4 04	5.30
To Jan. 1967	4.65	5.11	7.13
To Mar. 1968	10.07	10.98	10.73

	100-foot sections			
	Section 8 Sand fence alone	Section 12 Planted 16 x 20 No fence	Section 10 Planted 16 x 20 With Fence	Section 9 Planted 16 x 20 With fence
To June 21, 1965	1.02	1.81	2.52	1.40
To Aug. 10, 1965	1.93	2.36	2.74	2.61
To June 1966	3.05	4.61	5.04	4.67
To Jan. 1967	3.69	6.14	6.37	5.17
To Mar. 1968	4.72	9.78	11.35	9.25

- - - - - - - - - - - - - - - - - - -

Table 2. Ocracoke Island - Average sand accumulation of similar sections (in yards^3 per foot of beach) by periods.

	Av. of 3-25 foot plots	Av of 3-50 foot plots	Av. of 3-100 foot plots	Av. of 2 Sand Fence sections
Feb. 7 - June 21, 1965	1.25	1.00	1.91	1.07
June 21-Aug. 10, 1965	0.65	1.09	0.66	0.94
Aug. 10,1965-June 1966	1.90	2.18	2.20	1.75
June 1966 - Jan. 1967	3.33	1.36	1.12	1.14
Jan. 1967 - Mar. 1968	3.16	4.93	3.23	1.41
Total	10.29	10.56	9.12	6.31

Effect of plant species and strains and planting pattern on dune development - Ocracoke, November 1966.

These sections were located on a very low sand flat (average elevation above MSL of 4 feet or less) which is subject to overtopping by only moderately high storm tides. However, no serious damage occurred to these plantings until April 27, 1967, when they were overtopped by a succession of tides for the next three days. Very few plants were washed out, but salt damage on all sections was severe, with the nursery-run plants being almost completely eliminated and sea oats severely decimated as shown in Table 3.

Table 3. Stand Estimates and Sand Accumulation, Ocracoke Island.

Treat-ment No.	Species	Selection	Estimated survival - %* Oct. 17, 1967	Sand Accumulation yards3* March 1968
1	Amer. beachgrass	N.C. Selection A	70	4.52
2	Amer. beachgrass	N.C. Selection B	78	5.01
3	Amer. beachgrass	N.C. Selection 1	77	5.71
4	Amer. beachgrass	N.C. Selection 3	75	5.59
5	Amer. beachgrass	Nursery-run	5	trace
6	Sea oats		30	trace
7	Sea oats**		32)	3.01
	Amer. beachgrass**	N.C. Selection A	68)	
8	(Sand fence alone)		--	7.15

* Average of 2 replications.
**Alternate rows.

The severity of salt damage at this stage is believed to be due to the fact that this was a dry storm occurring during an extended dry period.* Consequently, there was maximum opportunity for sea water to penetrate the root zone during and immediately following the storm, and little opportunity for dilution or removal of salt for some time afterward. In addition, this occurred after spring growth had begun, at a time when the metabolic rate of the plants would be expected to be high. Consequently, many plants were killed and all were obviously damaged with their regrowth drastically delayed.

Differential survival between species and strains can be explained on the basis of the work of Berenyi (Reference 2) who showed that where even a small patch of these grasses is able to survive long enough to trap a few inches of sand, a blister of less saline water begins to develop, under the resulting hummock, enabling the plants to better tolerate later additions of salt.

*Precipitation (in inches) recorded at Ocracoke Village, about two miles from the experimental site, was 0.73 in March, 1.26 in April (0.76 after April 12), with a total of 0.70 occurring as light showers in the period between May 5 and May 21. Fortunately, 4.67 inches fell in the May 22-31 period.

The survey made on this experiment in March 1968 (see Table 3) showed sand accumulations roughly in line with the stand estimates. All four beachgrass selections had collected substantial amounts of sand, the mixed sea oats-beachgrass planting about half as much, while the sea oats-alone and nursery-run beachgrass plots showed only a trace. In this instance, the sand fence sections were superior to the best vegetative plots, accumulating 7 cubic yards per foot against 5 cubic yards per foot for the beachgrass selections.

The spacing pattern followed in this experiment was successful in developing a dune having a much more desirable shape than those in previous trials as shown in Figure 9. The typical beachgrass-selection dune was highest slightly behind the center with an average seaward slope of about 5%. The dune formed by the mixed planting which, due to thinner stand and slower growth, had developed more slowly, had an average slope of about 3% on the seaward side.

The more rapidly growing dunes produced by the beachgrass selections exhibited a definite break in slope about two-thirds of the way down the seaward side (see Figure 9). This appears to have been caused by the large drop in plants/unit area between the 24" and 36" spacings.

Sand Fences

Results of the tests to determine the feasibility of constructing a barrier dune with sand fences are shown in Table 4 and Figures 10 and 11. Table 4 shows the volume of sand accumulated by the existing fences of the test sections just before new fences were added and the volume of sand accumulated by all of the existing fences to July 1968. The sand accumulations of both measured profiles of each section are shown in this Table. However, Figures 10 and 11 show only one of the two profiles of each of the two test sections at the beginning of the tests, just before new fences were added, and in July 1968. While the profiles shown in Figures 10 and 11 are of the area of the test section which trapped more sand than the other profile area, the shape of the dune is representative of the entire test section.

In general, the results shown in Table 4 and Figures 10 and 11 indicate that either method A or B of Figure 3 can be used in constructing a barrier dune. However, method B appears to be superior because it trapped more sand per fence used (3.8 cubic yards per foot of fence) than does method A (2.4 cubic yards per foot per fence)*. In this respect, the comparison is biased because the third set of fences of section 2 were installed before the second set had completely filled. However, it is clear that the results of section 2 would not have been commensurate with those of section A if the third set of fences had been installed at the proper time.

Further improvement in the performance of section 2 might have been realized by increasing the space between fences (20 feet apart instead of 15 feet). Previously (Reference 1) fence spacings of 25 and 50 feet were

*Profile 2-C not used in this computation. See Footnote to Table 4.

Table 4. Sand Accumulation of Multiple Fence Sections - yd^3/ft

SECTION A			SECTION 2		
First fence installed December 1962			First fence installed March 1964		
Survey date	Profile number	Volume trapped	Survey date	Profile number	Volume trapped
Jan. 1963	A-1	4.9	March 1965	2-A	6.0
	A-3	2.7		2-C*	3.6
		Avg 3.8			Avg 4.8
March 1964	A-1	8.2	June 1966	2-A	8.8
	A-3	5.8		2-C*	7.5
		Avg 7.0			Avg 8.2
March 1966	A-1	13.2	July 1968	2-A	14.3
	A-3	10.0		2-C*	10.4
		Avg 11.6			Avg 12.4
July 1968	A-1	19.0			
	A-3	11.7			
		Avg 15.4			

*Sand accumulation in vicinity of this profile washed out by overtopping water in November of 1964. Fences were replaced, but later sand accumulation not comparable with that of profile 2-A.

tested in this area. In both cases, the two fences accumulated separate dunes (no sand accumulated in the center between the fences) and method A could not be pursued. Therefore, the 15-foot spacing was used in the present test and proved to be a workable spacing. A 20-foot spacing may also prove workable, but study of Figures 10 and 11 leads to the conclusion that one of the fences in such an arrangement would be partially in the area of effect of the other fence installed at the same time and, therefore, would be less efficient than each fence of the configuration of method B.

The results of the fabric fence tests are shown in Figures 12 and 13. Figure 12 shows the volume of sand trapped by each of the test sections, which are shown in the order of installation. The volumes shown were computed from the average of 2 profiles across each test section (at the 1/3 points along the length of the test section) with the exception of sections 35 and 41. A field inspection of the test sections just before the July 1968 survey revealed that one of the profiles of each of these sections was not representative of the sand accumulation of the section. Therefore, only the representative profile of each of these sections was used in the volumetric computations.

The results shown in Figure 12 are quite variable. In at least 4 cases (Fabrics 2, 4, 5, and 6) the volume of sand trapped by a fabric in one location is half that of the same fabric in another location. There is also considerable variation in the performance of the control (slat) fences - a range of from 2.6 cubic yards per foot to 3.1 cubic yards per foot. However, the results of sections made from the same fabrics vary generally with the variation of the control sections (compare slope of line between like fabrics with the slope of the lines between the control sections). Therefore, in using the data of Figure 12, the results were normalized by dividing the volume of sand trapped by the fabric section by the volume of sand indicated by the line between the control sections at that fabric section. Figure 13 shows the normalized volume data as a function of the fabric porosity.

Though the volumetric data is quite variable, there is a marked relationship between fabric porosity and the volume of sand trapped; less porous fabrics trapping more sand. Unfortunately the range of fabric porosities used did not include fabrics dense enough to indicate the fabric porosity beyond which increasing density would not increase the effectiveness of the fabric. However, the results do show that the effectiveness of the fabrics increases with decreasing fabric porosity down to a fabric porosity of 40 percent.

CONCLUSIONS

Vegetation

Vigorous, rapidly-growing stands of dune grasses, such as American beachgrass, have a capacity to trap and retain wind-blown sand which is greatly in excess (up to 16 yd^3 per foot of beach) of the amounts usually available. This ability to trap wind-blown sand within fairly short distances (12-20 feet), and to renew this capacity by growth and spreading during the growing season tends to minimize the importance of width of planting. For example, from our present data and observations, it appears that where annual sand movement is from 1-3 cubic yards per foot of beach and plants (3 culms per hill) are spaced 18 to 24 inches apart, a planting width of 35' to 40' will trap essentially all of the sand moving. However, where storm damage is likely to occur early in dune development, wider strips are needed to retain sand that becomes dislodged by overtopping of the frontal ridge.

There does appear to be a certain critical mass as well as spacing of vegetation required to effectively halt sand movement. On the North Carolina Coast this can be obtained with American beachgrass, under good growing conditions, by early July of the first year with plants spaced 18" x 18", 3 to 5 culms per hill. Reducing planting density to 24" x 24" reduces cost considerably and may delay attainment of full cover by no more than a month to as much as a year, depending on growing conditions and storm sequences. Good plant survival is, of course, essential, and effectiveness appears to decline rapidly when survival at these densities drops below 75% (see Table 3).

A minimum of 3 culms per hill appears to be a practical compromise between cost and effectiveness. First-year growth has been found to be roughly proportional to the amount of vegetation planted (Reference 3), and single culm hills seldom develop sufficient growth to be effective the first year, unless spaced 12" x 12" or closer.

No evidence has been found to indicate that "staggered" planting patterns have any real merit over plantings in rows containing sufficient optimum size plants/unit area.

Uniformly-spaced plantings of American beachgrass have been the rule in the past. This appears to be an acceptable, although perhaps not ideal, practice where the primary purpose is that of stabilizing a previously constructed dune. However, in the use of this vegetation as a dune-building device, uniform spacing, dense enough to become effective the first year, results in a multi-humped dune cross section. The very characteristic which makes beachgrass useful in building and protecting dunes, the pronounced ability to trap and hold sand, works against the development of a dune which is highest near the center with a long, gentle fore-slope, resulting instead in cross sections such as those depicted in Figures 7 and 8. However, some pattern of non-uniform plant spacing, wide spacings on the outer edges of the grass strip and dense spacing in the center, would seem to offer a fairly simple and inexpensive solution to this problem.

Our preliminary trials along this line are quite encouraging. The planting pattern chosen for the 1966 Ocracoke trial appears to be very close to optimum, producing a dune at the end of two years with an average slope on the seaward side of 5% or less (Figure 9). We feel that this type of dune should be considerably more resistant to storm action than those produced in the earlier trials and that this is at least approaching the desired cross section. It appears that this pattern could be improved by widening the close-spaced core by 2 or 4 rows, adding a 30" spacing between the 24" and 36" plantings and perhaps omitting the outer 2 rows of 48" on each edge.

This pattern would be about 90 feet wide and require less than 8500 hills per acre, around 80% of that required for a strip of the same width, uniformly spaced 24", and less than half that needed for an 18" planting. Since planting costs are almost directly proportional to the number of hills planted, the variable spaced pattern would be more economical*. In the absence of storm damage, it would probably not trap more sand than the other two, but would build a dune which would have, from the beginning, a more stable cross section. Also, in the event that it was overtopped by one or more storm tides during the first year or two, it would be less vulnerable to damage than the uniform 24" planting.

The addition of a sand fence to such plantings has little effect beyond the first few months since after the first flush of growth, essentially all sand is intercepted by the vegetation before it can reach the fence. A fence can, in some situations, however, play a very vital role by trapping sand during the several months between planting (in winter or early spring), and the development of sufficient new growth to begin to effectively halt sand movement (early summer). If there is sufficient sand movement during this period, the fence will trap a significant amount of sand before the grass becomes effective.

The distinct advantage of early vigor in American beachgrass was clearly demonstrated by all 4 N.C. selections in the 1966 experiment on Ocracoke. Under these critical conditions, the superior ability of these selections to grow off early in the spring enabled them to survive where ordinary nursery-run material failed completely.

These selections were also vastly superior to sea oats in survival, rapidity of establishment, and sand trapping ability during the first two years of the 1966 Ocracoke experiment. Even so, the latter is the dominant species on unplanted foredunes along the Atlantic Coast from the Virginia-North Carolina line southward, and tends with time to replace American beachgrass on planted foredunes in this region (Reference 4).

---

*Estimated cost of large scale machine planting and maintenance through the third year for strips 90 feet wide following a variable planting pattern, similar to that adopted for the Ocracoke-1966 experiment, runs less than $0.50 per foot. This estimate is based on:

American Beachgrass at $15 per thousand 3-stem plants; labor at $2.50 per hour; machine time at $5.00 per hour; 30-10-0 fertilizer at $90 per ton; fertilizer application by helicopter at $2.50 per acre per application.

This is the reason for the interest in interplanting the two to help insure an orderly succession. Our limited experience with this point suggests that this may well be the way to insure continued long-term protection of dunes. However, due to the rapidity with which the beachgrass becomes effective, the planted mixture might better consist of a 5 or 10 to 1 ratio of beachgrass to sea oats rather than the 1 to 1 mixture tried on Ocracoke Island.

Sand Fences

Where a satisfactory beachgrass is not available, sand fences can be used to construct a barrier dune. Either method A or B of Figure 5 can be used, but some experimentation would be required in the area in which the dune is to be constructed to determine the best distance between fences if method A is to be used. Method B appears to make more efficient use of each sand fence used and, for the conditions existing on the North Carolina Coast, is the preferred method.

Fabrics can be used as sand fences and fabric porosity is an important factor in the effectiveness of fabrics as sand traps. Under the conditions existing along the North Carolina Coast during these tests, the volume of sand trapped by fabrics varied essentially linearly with fabric porosity. Fabrics with more than 80% porosity trapped very little sand (an average of 0.6 cubic yards per foot) while a fabric with 40% porosity trapped an average of 2.7 cubic yards per foot. Slat-type fencing used as a control in the tests, trapped an average of 2.8 cubic yards per foot. If the fabric-fence data is normalized, using the slat fence results as the reference, fabrics trapped from 20 percent to 84 percent as much sand as did slat fencing.

Though the range of fabric fence porosities included the porosity of the slat fencing, slat fencing trapped on the average more sand than any of the fabrics. This is an anomaly which cannot be explained by the authors.

ACKNOWLEDGMENTS

This paper is number 2710 of the Journal Series of North Carolina State University Agricultural Experiment Station, Raleigh, N.C., in cooperation with the Coastal Engineering Research Center, Department of the Army, Washington, D.C. The authors appreciate the support and cooperation furnished by the Cape Hatteras National Seashore of the National Park Service, the Wilmington District of the U. S. Army Corps of Engineers, the North Carolina State Department of Water Resources, and the North Carolina Forestry Division. Much of the work described herein is a portion of the research program of the U. S. Army Corps of Engineers and the permission granted by the Chief of Engineers to publish this information is appreciated.

REFERENCES

1. Savage, R. P. (1963). Experimental Study of Dune Building with Sand Fences. Proceedings. Eighth Conference on Coastal Engineering, Mexico City. p. 380.

2. Berenyi, N. M. (1966). Soil productivity factors on the Outer Banks of North Carolina. Unpublished PhD Thesis, N. C. State University at Raleigh.

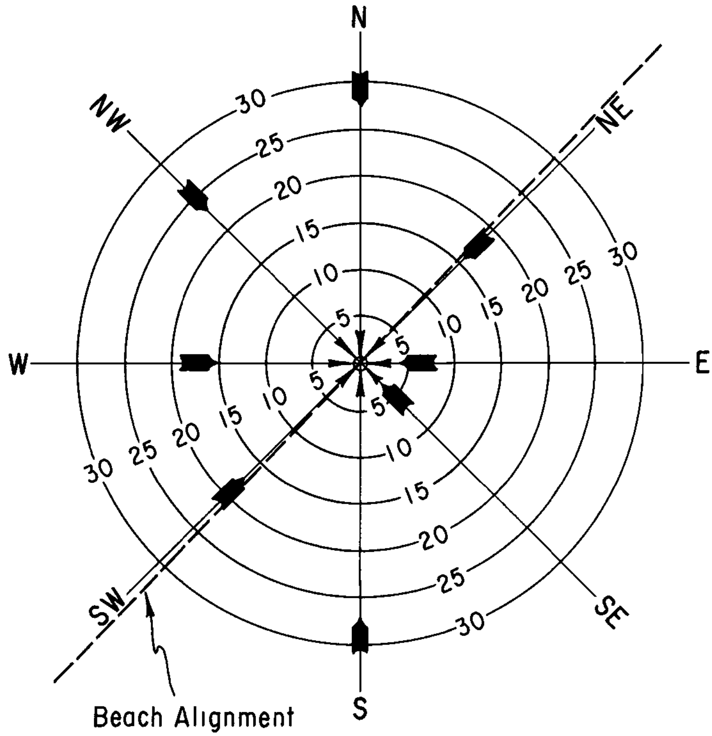
3. Woodhouse, W. W., Jr. and R. E. Hanes. (1967). Dune stabilization with vegetation on the Outer Banks of North Carolina. Technical Memorandum No. 22. U. S. Army Coastal Engineering Research Center, Washington, D.C.

4. Woodhouse, W. W., Jr., E. D. Seneca and A. W. Cooper. (1968). The use of Sea Oats for dune stabilization in the Southeast. Shore and Beach. Vol. 36, n. 2, (In Press).

5. Zak, J. M. and E. Bredakis. (1963). Dune stabilization at Provincetown, Mass. Shore and Beach. Vol. 31, n. 2. pp. 19-24.

FIGURE I. LOCATION MAP

Compiled from data furnished by the U.S Weather Bureau at Hatteras, N.C. for the period from Jan, 1953 to Dec, 1957



Capacity of the wind to transport sand assumed to be proportional to the wind velocity cubed

FIGURE 2. RELATIVE TRANSPORTING CAPACITY OF THE SAND MOVING WINDS IN THE STUDY AREA

FIGURE 3. EXPERIMENTAL PLOT OF AMERICAN BEACHGRASS
(OCEAN TO RIGHT)

FIGURE 4. SLAT-TYPE SAND FENCING

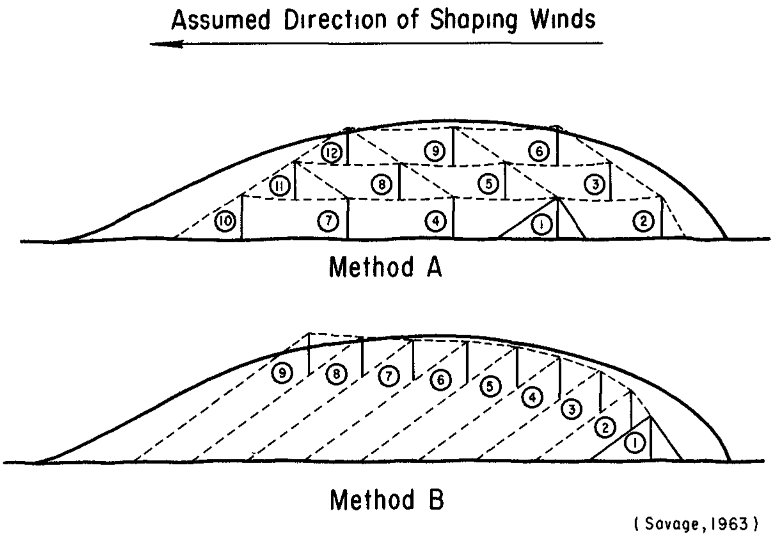


FIGURE 5 PROPOSED PROGRAMS FOR BUILDING A BARRIER DUNE

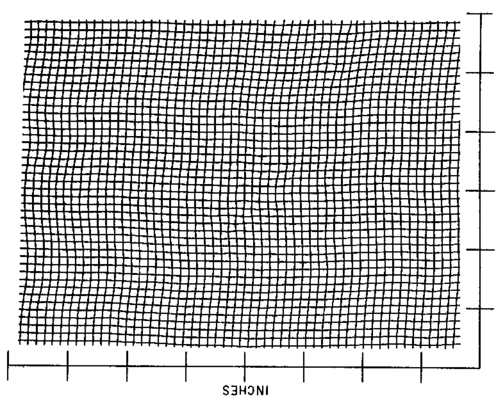


Figure 6a Fabric No 1 (Saran)
55% Porosity

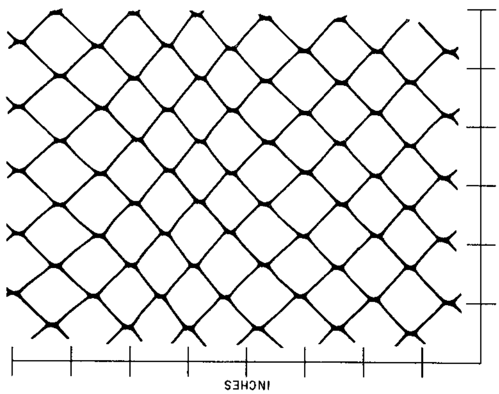


Figure 6b Fabric No 2 (Polyethylene)
86% Porosity

FIGURE 6. FABRICS USED AS FENCING

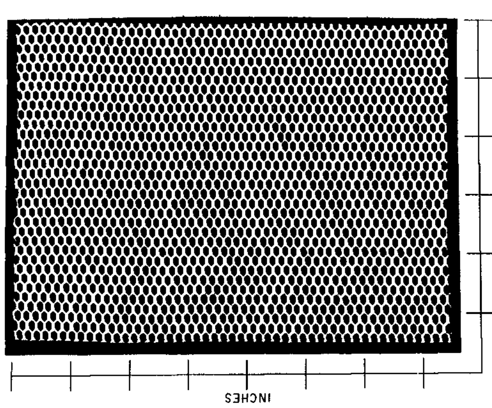


Figure 6c Fabric No 3 (Nylon)
48 % Porosity

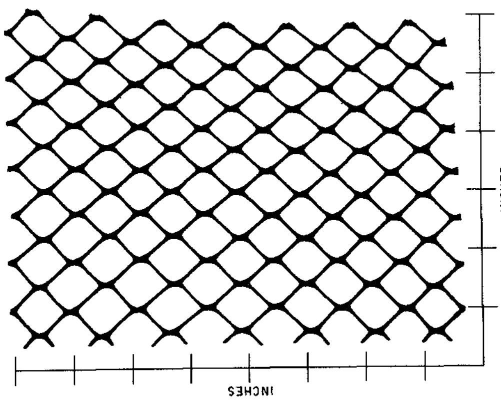


Figure 6d Fabric No 4 (Polyethylene)
82 % Porosity

FIGURE 6 FABRICS USED AS FENCING (Cont'd)

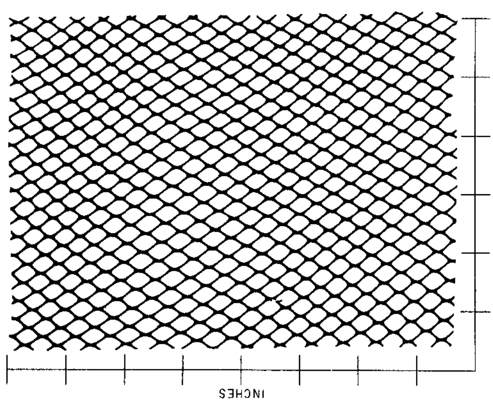


Figure 6e Fabric No 5 (Polyethylene)
68% Porosity

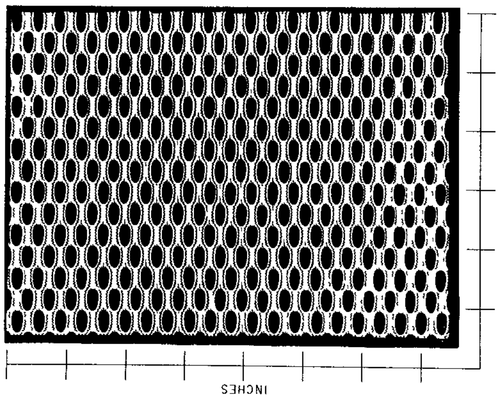


Figure 6f Fabric No 6 (Nylon)
40% Porosity

FIGURE 6 FABRICS USED AS FENCING (Cont'd)

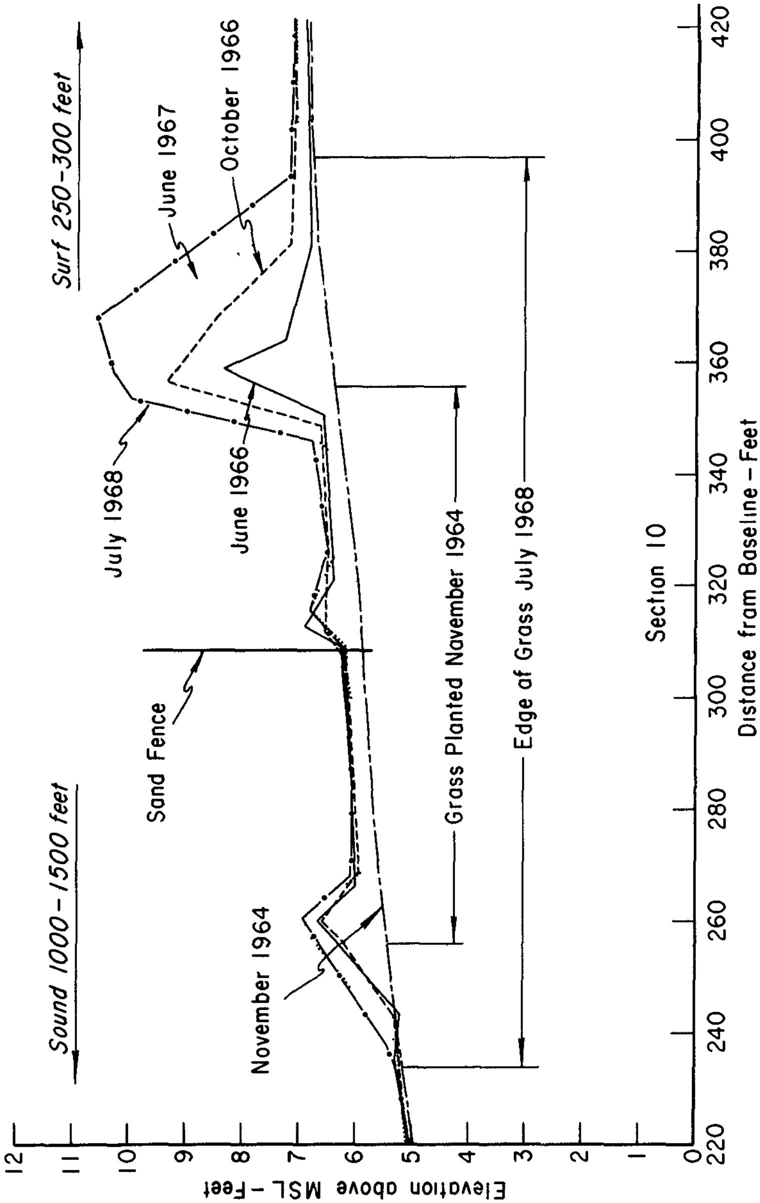


FIGURE 7. DUNE GROWTH — PORTSMOUTH ISLAND

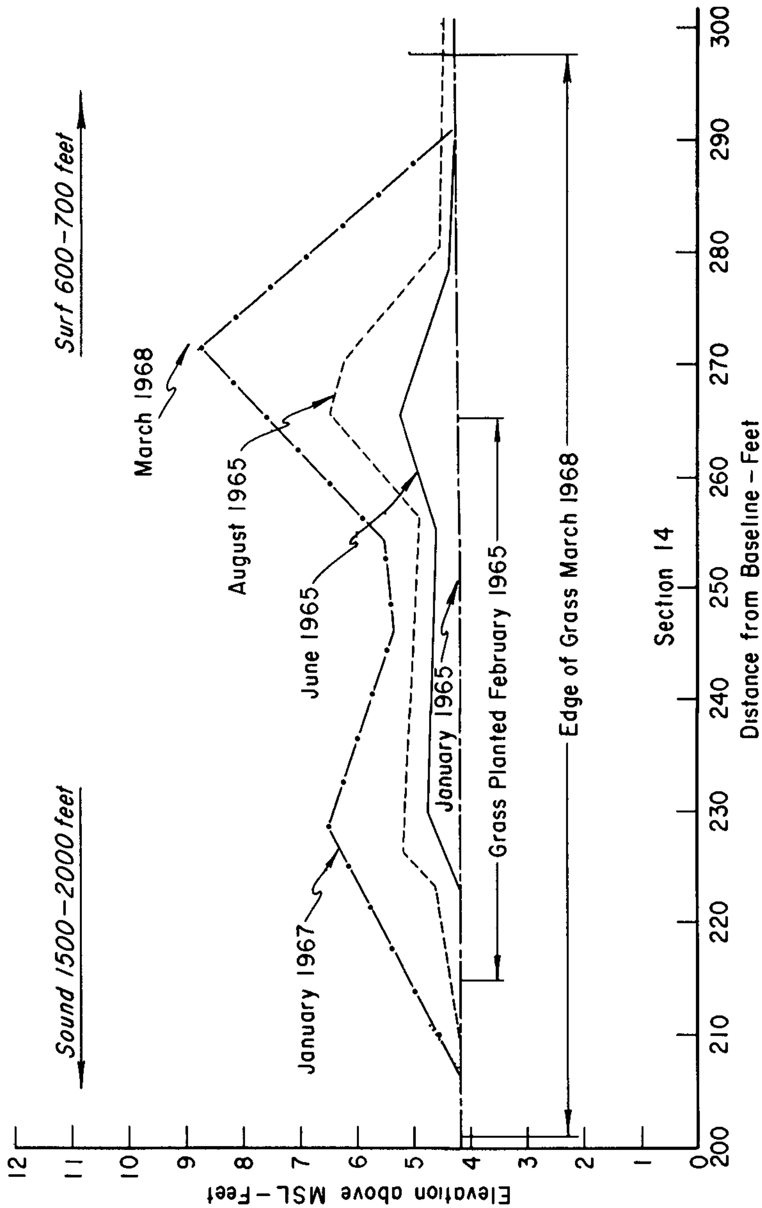


FIGURE 8. DUNE GROWTH — OCRACOKE ISLAND

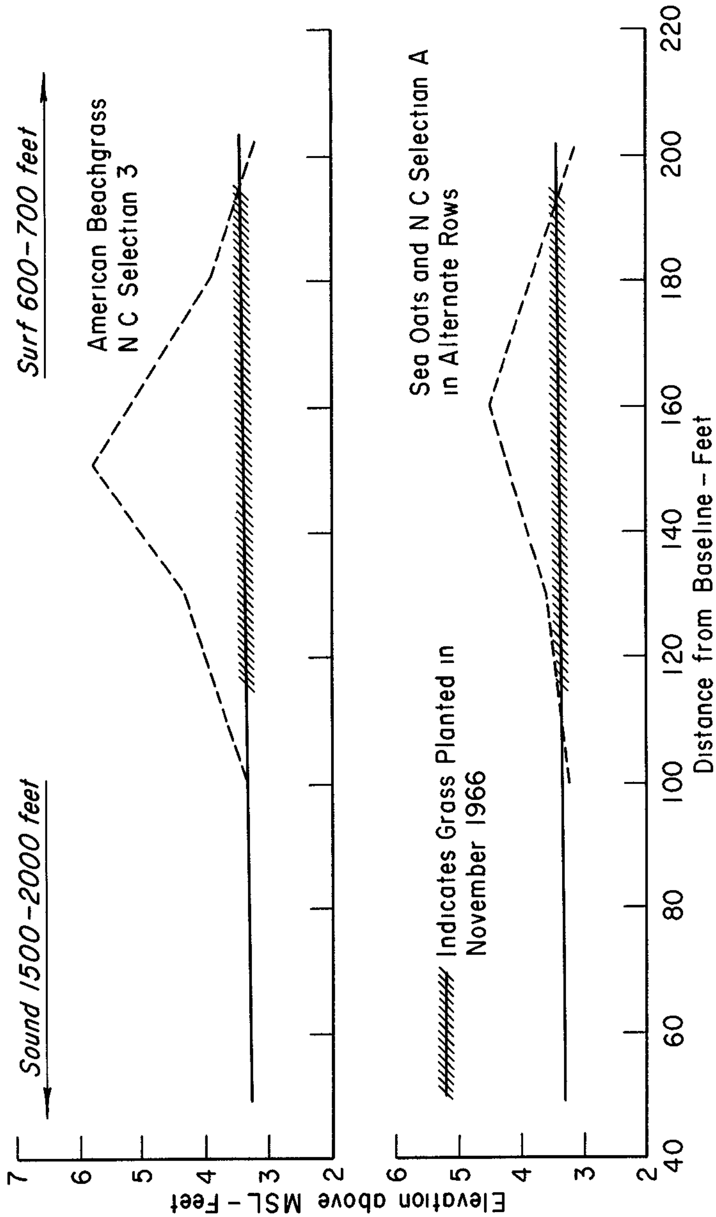


FIGURE 9 DUNE GROWTH BETWEEN NOVEMBER 1966 AND MARCH 1968 – OCRACOKE ISLAND

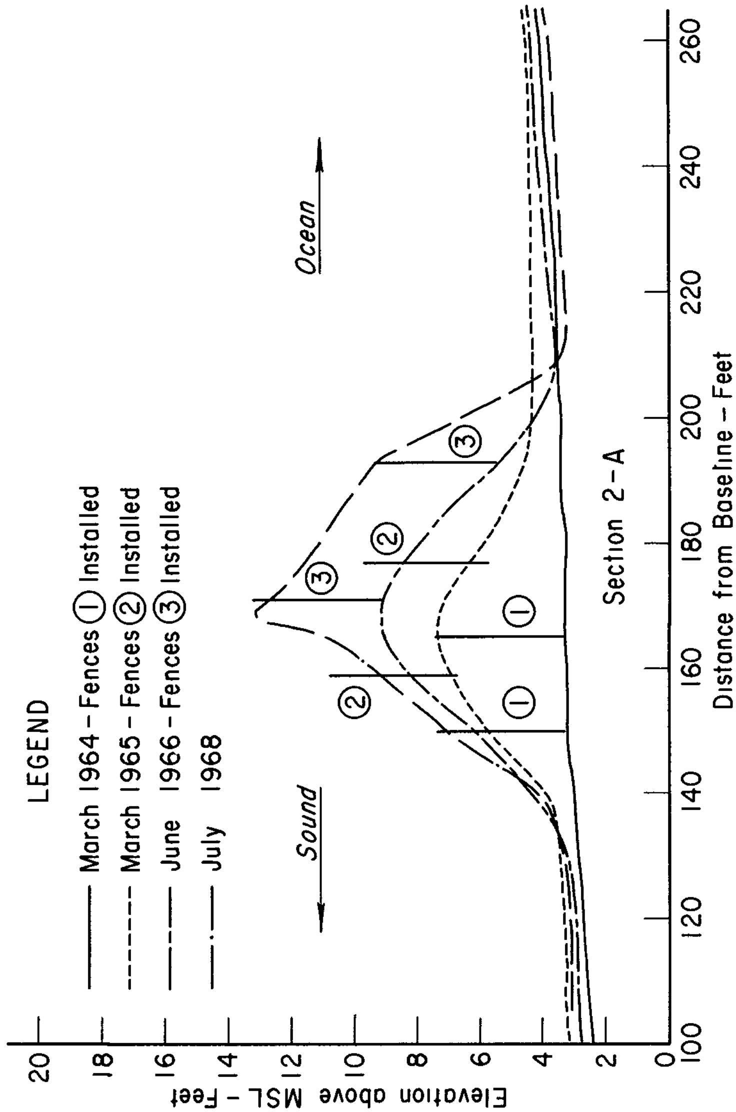


FIGURE 10. SAND ACCUMULATION OF MULTIPLE FENCES - METHOD A

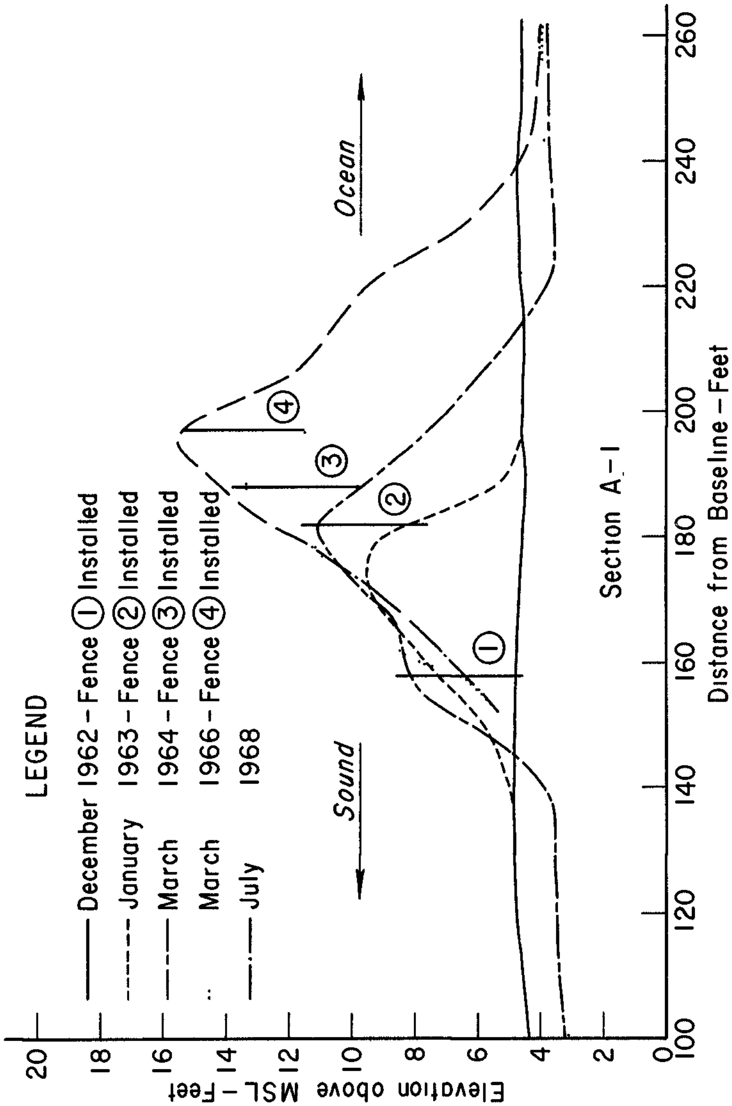


FIGURE 11. SAND ACCUMULATION OF MULTIPLE FENCES—
METHOD B

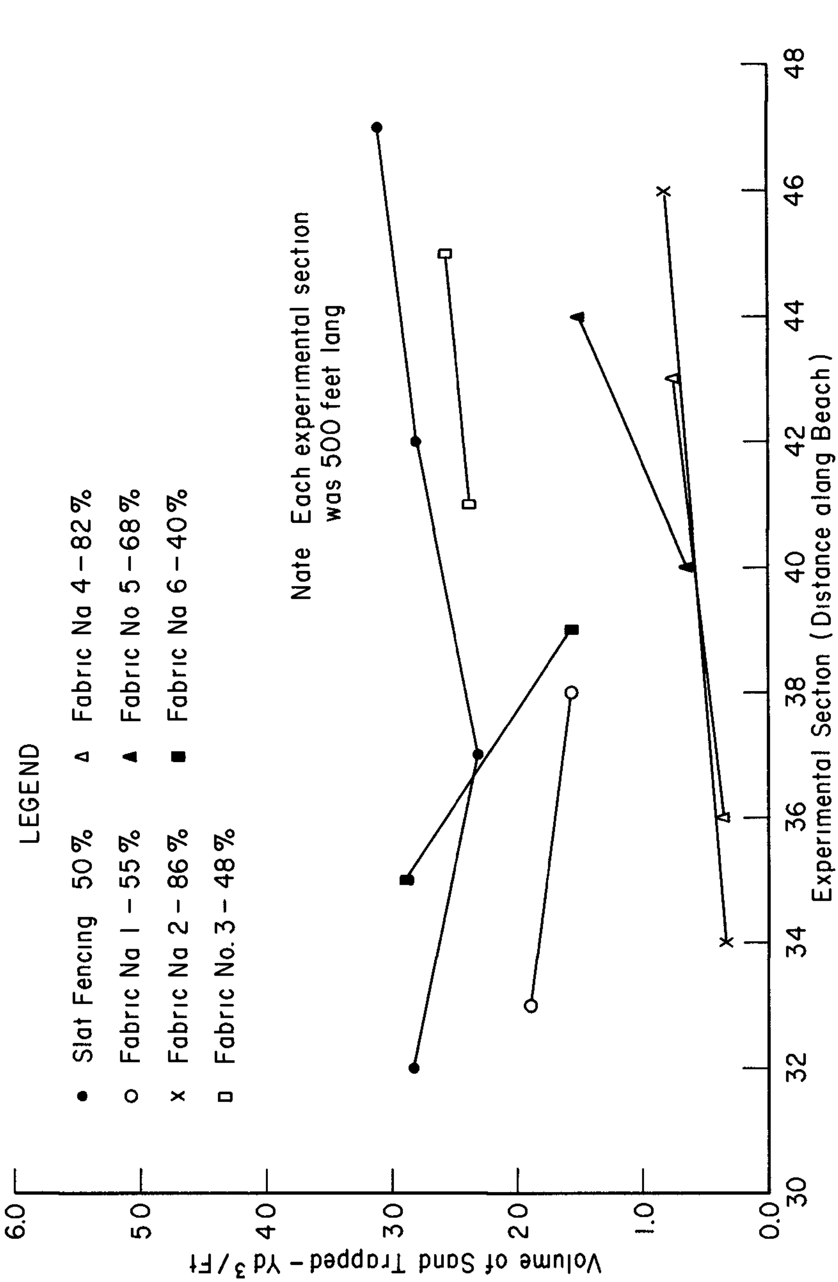


FIGURE 12 VOLUME OF SAND TRAPPED BY FABRIC FENCE TEST SECTIONS

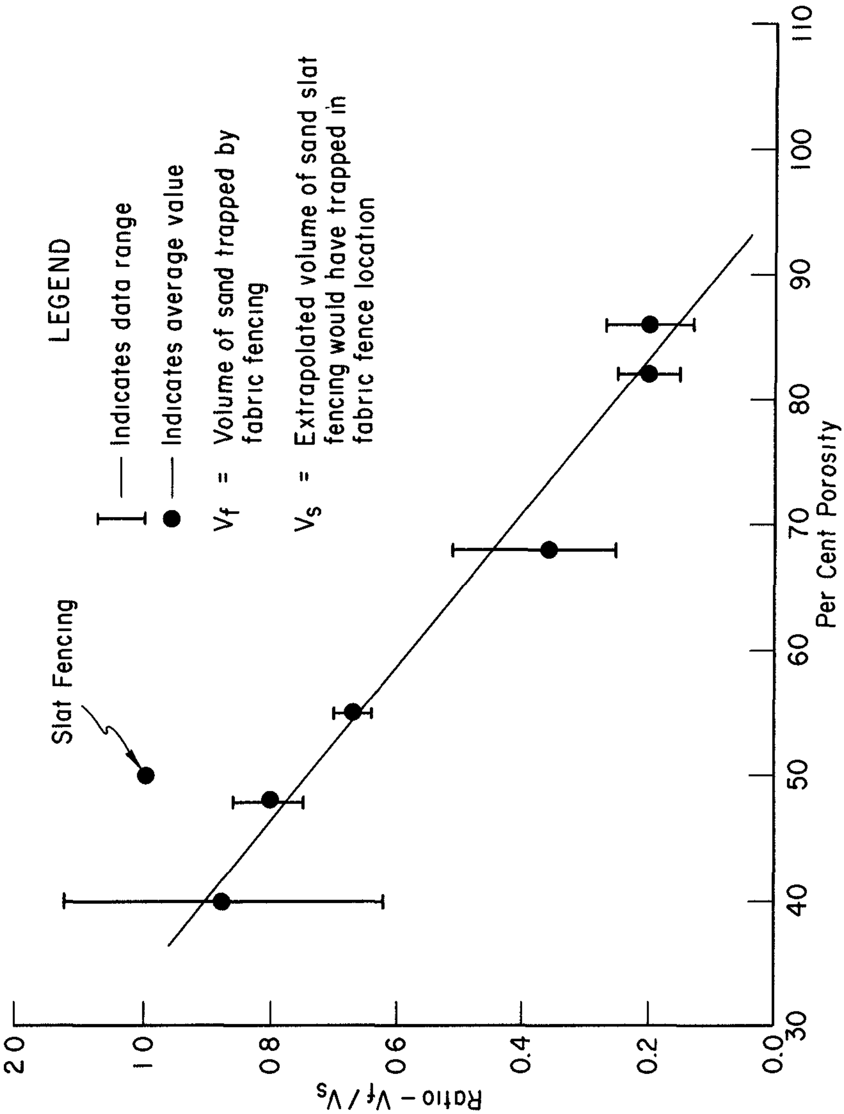


FIGURE 13 EFFECT OF FABRIC FENCE POROSITY ON VOLUME OF SAND TRAPPED