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PUMP DRAINAGE IN CAROLINA BAYS[a]

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INTRODUCTION

After large rainstorms or periods of continuous rainfall, excess water is a problem throughout the coastal plains area of the southeastern states. Drainage is a major problem on 280,000 acres (approx 1.1 billion m^2) of land in South Carolina alone (9). Excess water problems are especially serious in areas affected by land-forms called Carolina bays. These saucerlike basins have no natural outlets. Water, draining from the rim to the lower elevations of these basins, causes prolonged flooding that interferes with farming operations and reduces production.

Description of Carolina Bays.—The Carolina bays are found throughout the southern coastal plains land resource area. Marschner (4) and Johnson (2) describe them fully and indicate that many thousands of these bay areas are found from southern Georgia to northern Virginia. Most bays have a symmetrical oval form that is smooth in outline and sharp in definition, with the major axis oriented northwest-southeast. The elevation difference between the rim and the bottom of these bays ranges up to 30 ft (approx 9 m). Drainage areas within individual bays range from less than 1 acre (4,100 m^2) to over 100 acres (410,000 m^2). The soils in the lower elevations of the Carolina bays are poorly drained, and usually are classified as the Coxville series in the thermic family of Typic Orchraquults. The soils on the rim of the bays may be any of those common to the area. Soils within the bays are well suited for production of corn, small grain, soybeans, pasture, and truck crops, and, with drainage, yields are relatively

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FIG. 1.—Aerial Photograph of Area Northwest of Dovesville, S.C., Showing Six Carolina Bays Studied. (Soil Conservation Service Aerial Photograph)

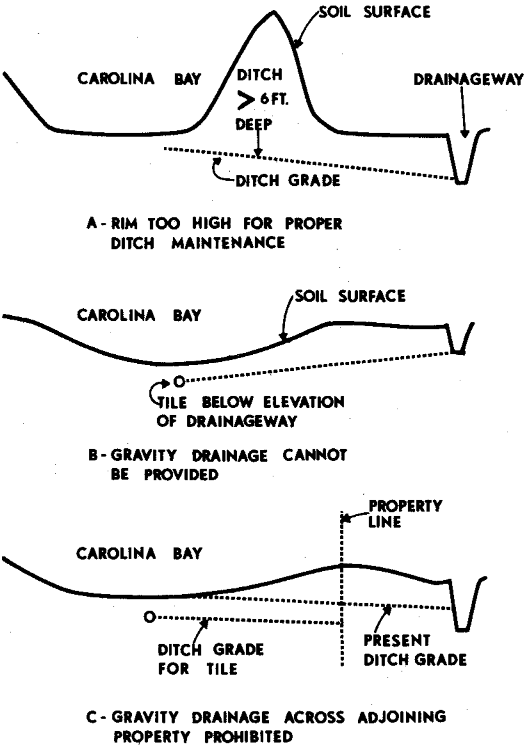

FIG. 2.—Three Situations Where Pump-Assisted Drainage Can Be Used to Achieve Proper Drainage Outlet

high (8). Bays in a small area near Dovesville, S.C., are shown in Fig. 1.

Drainage Problems Associated with Carolina Bays.—Three principal problems are encountered in drainage of the Carolina bays which make ditching or piping for gravity drainage infeasible:

1. When the rim is 6 ft to 8 ft (approx 1.8 m to 2.4 m) higher than the bottom of the bay [see Fig. 2(*a*)], a very large open ditch outlet is required. Large ditches are difficult to maintain because the sides cave in. Ditches deeper than 6 ft (approx 1.8 m) have been observed to fill at a rate of 1.5 ft (0.46 m) per yr and, because of the high cost of ditch maintenance, farming these areas may be uneconomical. The large ditches also reduce field size and interfere with the use of modern farm equipment.
2. Some of these bays are lower than the bottom of the accessible drainageway [see Fig. 2(*b*)], thus gravity drainage cannot be provided.
3. No drainageway is accessible, and frequently, a new drainageway must cross land owned by another party who will not allow its construction [see Fig. 2(*c*)].

Pump-assisted drainage is the only apparent solution for the drainage situations listed previously. Information on design of pumping plants, the storage requirements of sumps, and the cycling rates of pumps and pump efficiency was reported by Larson and Allred (3) and Sutton (9). Sanderson and Klingelhoffer (5) report that use of pump-assisted drainage in Michigan is expected to increase rapidly. Many areas of land already developed cannot be provided with proper gravity flow outlets.

In this study, the cost and feasibility of using pumps in conjunction with tile and surface-drainage systems for removing excess water from Carolina bays are determined.

Procedure

Six Carolina bays, ranging from 9 acres to 27 acres (approx 36,000 m^2 to 110,000 m^2) in size and usually flooded to the extent that the lower portions were not tillable, were selected in the upper coastal plains near Dovesville, S.C. (Fig. 1). Three treatments, with two replications each, were applied to the bay areas. Bays 1 and 4 (Fig. 1) were left unaltered, without outlets to remove water. Bays 2 and 3 were surface drained and a pump and pipeline were used to discharge the runoff water. The land surfaces in these two bays were reshaped with a wheeled pan and a land level to provide unobstructed flow to a sump located at the lowest elevation. Bays 5 and 6 were tile drained with 8-in. (200-mm) mains and 6-in. (150-mm) laterals spaced 125 ft (38.1 m) apart. The main discharged into a sump and a 5-hp (3,700-W) electric pump was used to lift the water 6 ft (1.8 m). Water from bay 6 was pumped through 360 ft (approx 110 m) of 4-in. (100-mm) irrigation pipe to a gravity-flow drainage ditch. Water from bay 5 was pumped into an 8-in. (200-mm) tile and was discharged by gravity into an outlet ditch 1,000 ft (approx 310 m) away.

Electric pumps, equipped with a check valve to maintain the pump prime, were used at first, but were replaced by submersible pumps designed to pump water and mud continuously. The pump capacity for the tiled plots was based on the maximum flow, 292 gpm (approx 0.02 m^3/s), from an 8-in. (200-mm) tile on a 0.2% slope, flowing full without back pressure. The surface-drainage system pumps were designed to remove the total runoff from a maximum 10-yr return frequency storm of 2-hr duration within a 24-hr period. This required a pumping rate of 352 gpm and 454 gpm (approx 0.02 m^3/s and 0.03 m^3/s) for bays 2 and 3, respectively.

The amounts of water pumped and electricity used were measured daily during pumping periods with a 4-in. (100-mm) "Sparling" (trade names are used for identification purposes only and do not imply preference for this item) water meter and a kilowatt-hour meter at each pump location. Rainfall was measured with a recording rain gage. The water-table depth below the soil surface was measured with an ohm-meter device that deflected when terminals contacted the water table. The water table was measured on the tile-drained plots between three pairs of tile laterals at 1 ft, 5 ft, and 62.5 ft (0.3 m, 1.5 m, and 19.1 m) from a tile line. Water-table depths were measured in the lowest parts of the surface-drained and check treatment bays at several locations 100 ft (30 m) apart. Crop yields were determined by measuring the yield from the entire bay area in 1967 and by random sampling of small plots throughout the bay area in 1969.

Results and Analysis

Pump Performance.—The centrifugal pumps, equipped with check valves to maintain pump prime, had some distinct disadvantages. Trash and plant residues, which flowed into the sump in the runoff water or were blown into it by wind, clogged the check valves when pumping was needed. The entire pump system was above the ground surface and had to be covered or wrapped with electric heating cable to prevent freezing of pump and pipe.

Electric submersible pumps, designed to pump water and mud continuously without service, were installed and operated without problems. They were in the water and always primed, and since they were installed below the ground surface, protection from freezing was unnecessary. The motor controls, starter capacitors, run capacitors, etc. were located in a remote control panel that facilitated repair without removing the pump and disassembling the motor.

The design discharge head, the pump design capacity, and actual discharge during June, 1969 are shown in Table 1 for the submersible pumps at each installation. The same size pump was used at each location to facilitate cost comparison. Although the actual discharge for the surface-drained plots was less than design capacity, the excess water was removed from the sumps in less than 12 hr after the largest rainfall. The actual discharge from the tile-drained plot 6 was 12 gpm (approx 0.00076 m^3/s) less than design discharge. This pump operated continuously for approx 28 hr in June, 1969, following a 3.6-in. (91-mm) rainfall in 4 days, 1 in. (25 mm) of which fell in 40 min at the beginning of the pumping period.

Cost of Pump Drainage.—The initial installation cost of a pump system was approx $1,700 for a 5-hp (3,700-W) submersible pump and 360 ft (approx 110 m) of 4-in. (100-mm) irrigation pipe. But when using 1,000 ft (approx 310 m) of 8-in. (200-mm) clay tile instead of irrigation pipe, the installation cost was $2,050. At a 6% return on the investment and a 10-yr life of the pump, the installation costs varied from \$8.90/acre/yr to \$18.57/acre/yr (\$22.00/10,000 m^2/yr to \$45.89/10,000 m^2/yr) (Table 2). This cost will vary with the type of installation required and the size of the area drained.

TABLE 1.—Pump Design and Output for Greatest Runoff Period of Study

Bay number (1)	Drainage system (2)	Discharge head, in feet (meters) (3)	Design capacity, in gallons per minute (cubic meters per second) (4)	Actual pump discharge, in gallons per minute per acre (cubic meters per second per 10,000 m^2) (5)	Actual discharge, in gallons per minute (cubic meters per second) (6)
2	Surface	40 (12.19)	352 (0.022)	16.7 (0.00026)	300 (0.019)
3	Surface	10 (3.05)	454 (0.029)	13.9 (0.00022)	375 (0.024)
5	Tile	15 (4.57)	292 (0.018)	26.0 (0.00041)	390 (0.025)
6	Tile	35 (10.67)	292 (0.018)	10.8 (0.00017)	280 (0.018)

TABLE 2.—Cost of Pump Assistance for Drainage per acre per year (per 10,000 m^2 per yr)

Drainage system (1)	Acres drained (square meters) (2)	Pump installation cost, in dollars (3)	Electricity cost, in dollars (4)	Total cost, in dollars (5)
Tile	15 (60,702)	18.57[a] (45.89)	1.72 (4.25)	20.29 (50.14)
Surface	18 (72,843)	12.83[b] (31.70)	1.00 (2.47)	13.83 (34.17)
Tile	26 (105,218)	8.90[b] (22.00)	1.56 (3.85)	10.46 (25.85)
Surface	27 (109,265)	10.31[a] (25.48)	0.67 (1.66)	10.98 (27.14)

[a] 5-hp (3,700 W) pump and 1,000 ft (approx 310 m) of 8-in. (200-mm) clay tile.
[b] 5-hp (3,700 W) pump and 360 ft (approx 110 m) of 4-in. (100-mm) irrigation pipe.

The cost of electricity, shown in Table 2, was \$41.46/yr or \$1.56/acre/yr (\$3.85/10,000 m^2/yr) for the 26-acre tile-drained area. The pumping cost per acre per year for the 27-acre surface-drainage area was \$0.67 (\$1.66/10,000 m^2/yr). A minimum service charge (\$1.35 per month) accounted for 39% of the electricity cost of the tile-drainage system. However, June was the only month that the cost of electricity exceeded the minimum charge for the surface-drainage system.

The total cost of pump assistance for drainage, excluding cost of the tile or surface-drainage systems, ranged from about $10/acre/yr to $20/acre/yr ($24.71/10,000 m^2/yr to $49.42/10,000 m^2/yr), according to the size of the drainage area (see Table 2). The cost of installing the tile or surface-drainage systems was not studied.

Drainage Water Pumped from Tile and Surface-Drainage Systems.—Drainage occurred mainly in February-March and June-July of 1968 and 1969. Table 3 shows the amount of rainfall and resulting drainage water removed from each of the bay areas. The rainfalls in June and July, 1968 and February and March, 1969 were above average. The return frequencies of the rainfalls, 12.42 in. (315.5 mm) in June-July and 9.87 in. (251 mm) in February-March, are

TABLE 3.—Rainfall and Resulting Drainage Water Removed From Tile and Surface-Drainage Systems During Two Wet Periods in 1968 and 1969

	Rainfall, in inches (millimeters)		Drainage, in inches (millimeters)	
Period (1)	Measured (2)	Normal[a] (3)	Surface (4)	Tile (5)
February and March, 1968	2.42 (61.47)	7.28 (184.91)	0.00 (0.00)	0.07 (1.78)
June and July, 1968	12.42 (315.47)	11.09 (281.69)	0.66 (16.76)	1.47 (37.34)
February and March, 1969	9.87 (250.70)	7.28 (184.91)	0.02 (0.51)	2.73 (69.34)
June and July, 1969	8.99 (228.35)	11.09 (281.69)	0.52 (13.21)	1.68 (42.67)
Mean annual total	39.18 (995.17)	44.86 (1,139.44)	0.67 (17.02)	3.46 (87.88)

[a] 1926-1964 mean at Florence, S.C.

4 yr and 8 yr, respectively. These are, therefore, considered representative of the expected rainfall for the area.

The tile-drainage system removed considerably more water than the surface-drainage system during each of these major periods and on an annual basis. During February and March, 16% of the annual rainfall caused 45% of the annual tile drainage, but only 1% of the annual surface drainage. During June and July, 28% of the annual rainfall caused 44% of the annual tile flow and 88% of the annual surface drainage. During these four months, 44% of the annual rainfall caused 89% of the excess water removed by both the tile and surface-drainage systems. Annually, the tile-drainage system removed an average of 3.46 in. (87.9 mm) of water, or 8.8% of the rainfall; the surface-drainage system removed only 0.67 in. (17 mm) of water, or 1.7% of the rainfall. Removing these small amounts of water by either system converted the waterlogged bays into useful crop areas within the larger fields.

The water table in each bay reflected the amount of water held above the aquiclude under that bay, and apparently was not related to any other bay.

TABLE 4.—Change in Soil Water Storage to Depth of 6 ft (1.83 m) and Drainage Water Removed by Two Drainage Systems During June and July, 1968

Type of drainage (1)	June, 1968		July, 1968	
	Change[a] in soil water, in inches (millimeters) (2)	Drainage, in inches (millimeters) (3)	Change[a] in soil water, in inches (millimeters) (4)	Drainage, in inches (millimeters) (5)
Surface	0.6 (15.24)	0.01 (0.25)	2.4 (60.96)	0.75 (19.05)
Tile	−0.1 (−2.54)	0.40 (10.16)	−0.4 (−10.16)	1.11 (28.19)

[a]The minus sign shows that the water content of the soil profile was less at the end of the month than at the beginning of the month.

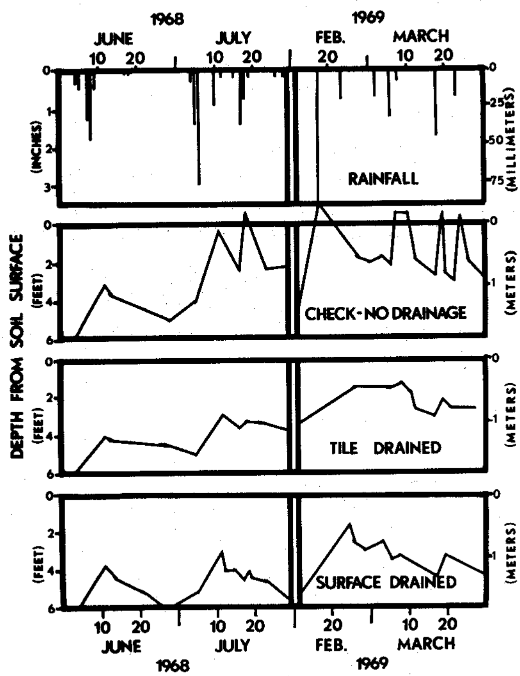

FIG. 3.—Rainfall and Average Depth to Water Table Below Soil Surface with Time for Different Drainage Treatments

The soil surface elevations, where the water-table depths were measured, were approx 181 ft, 183 ft, and 185 ft (55.2 m, 55.8 m, and 56.4 m) above mean sea level in the bottoms of the check, and the tile and surface-drained areas, The water table in each bay reflected the amount of water held above the aquiclude under that bay, and apparently was not related to any other bay.

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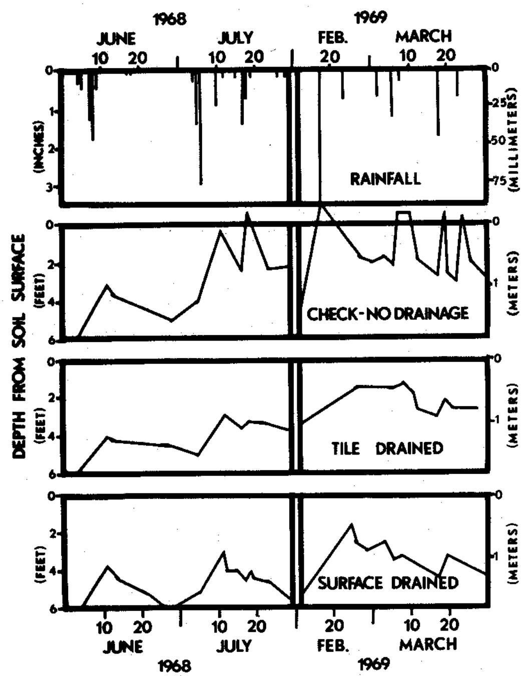

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The average depth to the water table in one replication of each treatment for the two major excess water periods is shown in Fig. 3. The water table

TABLE 5.—Yields of Oats and Soybeans from Pump-Assisted Surface and Tile-Drained Carolina Bays

Drainage method (1)	Location within bay (2)	Yield of Crop, in Bushels Per Acre (kilograms per 10,000 m²)		
		Oats	Soybeans	
		1967 (3)	1967 (4)	1969 (5)
Surface	Bottom	32 (2,152)	31 (2,085)	27 a[a] (1,816)
	Rim	—	—	26 a (1,749)
Tile	Bottom	22 (1,479)	26 (1,749)	22 b (1,480)
	Rim	—	—	30 a (2,018)
Check	Bottom	—	0 (0.00)	0 c (0.00)
	Rim	—	30 (2,018)	26 a (1,749)

[a] 1969 soybean yields followed by the same letter are not significantly different at the 5% level.

TABLE 6.—Additional Income Derived in 1969 from Soybeans by Use of Pump-Assisted Drainage Systems

Drainage system (1)	Additional production, in dollars per acre[a] (dollars per 10,000 m²) (2)	Pumping cost, in dollars per acre (dollars per 10,000 m²) (3)	Additional income, in dollars per acre (dollars per 10,000 m²) (4)
Surface	81.00 (200.15)	12.40 (30.64)	68.60 (169.51)
Tile	66.00 (163.09)	15.37 (37.98)	50.63 (125.11)

[a] Based on soybeans at $3.00 per bu (approx $0.11 per kg).

in the check plot rose to the surface after each large rain. During the cropping season, the water table was 3 ft (approx 1 m) or more below the soil surface in both drainage treatment areas. The surface drainage system controlled the water table as well as the tile during February and March. These results from surface and tile drainage are similar to those reported by Hermsmeier (1) and Schwab and Thiel (7), who showed that surface drainage controlled the water table almost as well as tile drainage in Minnesota and Ohio soils. Schwab, et al. (6) reported that the surface-drainage system gave the greatest benefit per dollar invested in the drainage system. In summary, this study showed that pump-assisted tile and surface-drainage systems each controlled the water table at a safe distance below the surface in these Carolina bays.

Soil moisture measurements (by neutron probe) showed that the water content of the 6-ft (1.8-m) soil profile increased in the surface-drained bays but decreased in the tile-drained bays during the June and July rainy period. Concurrently, less drainage water was removed from the surface-drained bays than from the tile-drained bays (Table 4). The excess water was removed from the surface-drained bays in 12 hr or less after a rain, but the water table continued to drop. This drop indicates internal drainage by deep seepage. But, as the runoff accumulated in the center of the bays, however, some water infiltrated into the soil and formed a mound of subsurface water. This mound receded in the center of the bay as the water moved through the soil and spread laterally within the bay area. This recession was reflected in the water-table measurements. The mounding was more pronounced in the surface-drained bays than in the tile-drained bays, because the soil surface was sloped to the center and no subsurface water was removed. These data imply that either the tile system may have overdrained the soil profile, or the water-holding capacities of the soils from the bay areas may vary.

Maintenance of a pump-assisted surface-drainage system is essential for adequate removal of excess water. The water table rose to within a few inches of the soil surface when a foot valve caused a pump malfunction, and crop production in the bay area was considerably reduced. On another occasion beds were inadvertently constructed across a waterway during a cultivation, water ponded behind the beds, and the water table rose to within a foot of the surface.

Crop Yield.—Table 5 shows that oat and soybean yields were significantly greater in the bottom of the bay from the surface-drained bays than from the tile-drained bays. Oat yields from the surface-drained bays were about 45% more than those from the tile-drained bays during the spring of 1967. Soybean yields were 5 bu/acre (approx 336 kg/10,000 m^2) higher from the surface-drained bays than those from the tile-drained bays in 1967 and 1969. Soybean yields were not obtained in 1968, but the growth in the surface-drained bays appeared to be superior to that in the tile-drained. Although these yield differences may reflect factors other than the influence of drainage systems, e.g., soil fertility, they show that pump-assisted tile and surface-drainage systems in Carolina bays resulted in a farmable field on which average production was possible.

Soybean yields in the bottom of the bay, where water normally stood, and on the higher elevations of the surrounding rim of the surface-drained bays were about equal, but those in the bottom of the tile-drained bays were less than the yields from the rim (Table 5). This reduction in yield in the bottom of the tile-drained bays may be due to excess water in the root zone before drainage was complete, the removal of the additional 2.79 in. (70.9 mm) of drainage water through the tile system, or from an imbalance of plant nutrients. There was no production in the lower portions of the undrained bays.

As shown in Table 6, the additional income derived from the soybean crop in 1969, above the pumping cost of the pump-assisted drainage system, was approx \$69/acre (approx \$170/10,000 m^2) for the surface-drained bays, and \$51/acre (approx \$126/10,000 m^2) for the tile-drained bays. The cost of the pump-assisted drainage systems for the Carolina bays could be amortized within a few years, if yields were consistently maintained or improved.

Summary and Conclusions

The Carolina bays located in the southern coastal plains of the United States can be drained with low horsepower submersible pumps at a reasonable cost where drainage ditches are not practical or feasible. Results from field installations show that tile and surface-drainage systems, using small submersible pumps for removing excess water from the bays, can restore the productive efficiency of the bays. A gross return above pumping cost of \$51/acre to \$69/acre (\$125/10,000 m^2 to \$170/10,000 m^2) per yr can be realized on soybeans.

In the bays studied, 89% of the excess water occurred during February and March and June and July. The tile-drainage system removed an annual average of 3.5 in. (89 mm) of water, or 8.8% of the rainfall, while the surface-drainage system removed only 0.7 in. (18 mm) of water, or 1.7% of the rainfall.

Pump-assisted surface and tile-drainage systems controlled the water table in the bays at depths that did not adversely affect plant growth. The bays were farmable all year. Maintenance was essential to ensure adequate drainage of the entire soil surface of the surface-drained area. The choice between pump-assisted tile drainage and surface drainage in the Carolina bays should be based on the comparative cost of installation of the two systems, anticipated additional income resulting from drainage, and the ability of the operator to maintain the drainage systems.

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Appendix.—References

1. Hermsmeier, L. F., "Yield of Tile and Surface Drains and Their Effect on the Water Table in a Wet Soil," *Transactions of the American Society of Agricultural Engineers*, Vol. 11, 1968, pp. 87-93.
2. Johnson, D., *The Origin of Carolina Bays*, Columbia University Press, New York, N.Y., 1942.
3. Larson, C. L., and Allred, E. R., "Planning Pump Drainage Outlets," *Agricultural Engineering*, Vol. 37, No. 1, 1956, pp. 38-40.
4. Marschner, F. J., *Land Use and Its Patterns in the United States*, Agriculture Handbook No. 53, U.S. Dept. of Agriculture, 1959.
5. Sanderson, R. A., and Klengelhofer, K. R., "Farm Drainage by Pumping," *Agricultural Engineering*, Vol. 39, No. 12, 1958, pp. 754-757, 766.

6. Schwab, G. O., et al., "Crop Response from Tile and Surface Drainage," *Soil Science Society of America Proceedings*, Vol. 30, 1966, pp. 634-637.
7. Schwab, G. O., and Thiel, T. J., "Hydrologic Characteristics of Tile and Surface Drainage Systems with Grass Cover," *Transactions of the American Society of Agricultural Engineers*, Vol. 6, 1963, pp. 89-92.
8. "Soil Survey Darlington County, South Carolina, Series 1957," United States Department of Agriculture, Soil Conservation Service, 1960.
9. *South Carolina Soil and Water Conservation Needs Inventory*, The South Carolina Needs Committee; South Carolina Association of Soil Conservation District Supervisors, Sept., 1961.
10. Sutton, J. G., "Pumping Plants for Land Drainage," *Agricultural Engineering*, Vol. 36, No. 4, 1955, pp. 243-246.