Sugarcane Yield Response to Subsurface Drainage for an Alluvial Soil

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ABSTRACT

A field study was conducted on an alluvial soil in Louisiana to determine the yield response of sugarcane to various subsurface drainage treatments that included three drain spacings (6.1, 12.2, and 24.4 m) and two drain depths (0.9 and 1.4 m). Annual rainfall was above the long-term mean during one year (1975) of the three-year study and was much lower than mean annual rainfall during the other two years (1974, 1976). All subsurface drainage systems adequately controlled the water table. Sugarcane and sugar yields for the subsurface drained treatments were significantly higher than yields for the undrained treatment during the wet year (1975) when the water table in the undrained treatment was very high during much of the year.

The lower yield for the undrained treatment during the wet year was due primarily to lower plant population. Although yield increases were obtained for only one year, the magnitude of the increase for that year was large enough to defray a significant portion of the system installation cost.

INTRODUCTION

Sugarcane is grown on medium- to fine-textured soils in the southern portion of Louisiana where annual rainfall exceeds evaporatranspiration (ET). Rainfall is distributed fairly evenly throughout the year with mean annual rainfall ranging from 1350 to 1600 mm. Rainfall that occurs during the sugarcane dormant season (November-March) exceeds ET and often exceeds soil storage capacity. The combination of excessive rainfall, flat topography, and slowly permeable soils causes high, perched water tables in many soils, particularly during the dormant season.

Sugarcane is a perennial crop that is propagated commercially by planting whole stalks. In Louisiana, three crops of sugarcane (plant, first ratoon, and second ratoon) are normally harvested from each planting. Sugarcane is normally planted between August and October and is harvested during the following three autumns (October to December) (Matherne et al., 1972).

Precision land grading has significantly improved surface drainage in this region during the past 10 to 15 years. Carter and Floyd (1971, 1973) found that sugarcane yield and longevity were increased when the water table was controlled using subsurface drainage to prevent prolonged saturation of the root zone. The number of crops harvested from a single planting increased from three to five. These results were obtained on small, concrete-bordered plots where the water table was controlled precisely and any excess water in the root zone was removed quickly. Later, they (Carter and Floyd, 1975) found that by lowering the water table during the winter and early spring, when the sugarcane plant is dormant, the yield of the subsequent crop was increased. When the water table was maintained 105 cm below the soil surface during the dormant season, there was no difference in yield among the treatments which included water tables maintained at depths of 30, 75, and 120 cm below the soil surface during the growing season. When the water table was maintained at the same depths during both the dormant and growing seasons, sugarcane yield was 15.9 and 39.7 t/ha (22 and 54%) less for the two shallow water tables than for the deep (120 cm) water table.

Drainage systems that control the water table precisely and rapidly remove excess water, like those in small, bordered research plots, are generally not economically feasible on a large scale. In order to determine the drain spacing required for a field-size drainage system and to determine crop response to subsurface drainage in the field, several subsurface drainage systems were installed in 1972 on an alluvial soil using commercially available materials and procedures.

The water table management provided by these drainage systems was reported by Camp and Carter (1975). The objectives of this paper are: (a) to report the sugarcane yield response to the soil water regimes provided by these subsurface drainage systems during the three-year crop cycle (1973-1976) and (b) to compare these yield responses with those obtained for small, bordered plots.

EXPERIMENTAL PROCEDURE

A drainage system was designed using estimated values for soil, crop, and climate parameters. This design, along with drainage systems that included spacings both narrower and wider than the 12.2-m design spacing, were used in this study. The four systems included three drain spacings (6.1, 12.2 and 24.4 m) and two drain depths (0.9 and 1.4 m). Additional details regarding design calculations, experimental design, and installation procedure were reported by Camp and Carter (1975).

The experimental area was located about 4.8 km north of Houma, LA, on a 10-ha site of Mhoon silty clay loam

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(sicl) soil (Typic Fluvaquent, fine-silty, mixed, nonacid, thermic). The soil surface had been precision graded to surface slopes of 0.15 to 0.20% to provide uniform surface drainage before the subsurface drainage systems were installed. All but one subsurface drainage system consisted of four parallel, 100-mm diameter polyethylene drain lines connected to a 150-mm diameter main line. One system consisted of three parallel, 50-mm diameter drain lines installed 6.1 m apart and at a depth of 0.9 m. The drain lines in all but one system were installed without filters. In one system, drainage tubing with a spun nylon filter was used. Each drainage system was connected to a separate collection sump which contained an electric, submersible sump pump. Drainage water was automatically pumped from the sump into a surface drainage ditch when the water level in the sump reached a preset elevation.

The subsurface drainage treatment areas ranged from 0.4 to 2.3 ha in size depending on the number and spacing of drain lines. A 0.6-ha area without subsurface drainage, but with a precision graded surface to provide surface drainage similar to that at the subsurface drainage site, was located about 1600 m away. A closer site was selected initially, but an adjacent subsurface drainage system influenced the water table in the area. The second site was selected primarily because the soils at the two sites were very closely correlated. The areas with and without subsurface drainage are referred to as drained and undrained, respectively, in this paper although both areas have excellent surface drainage.

The subsurface drainage systems used in this study were (a) 1.4-m depth, 12.2-m spacing, (b) 1.4-m depth, 12.2-m spacing, spun nylon filter on drain line, (c) 1.4-m depth, 24.4-m spacing, (d) 0.9-m depth, 6.1-m spacing, and (e) no subsurface drainage. The subsurface drainage systems were installed in 1972 using a laser-controlled wheel-type trencher. The experimental area was planted to sugarcane in August 1973 with interspecific hybrid CP 52-68, and the first crop was harvested in December 1974. The cooperating grower performed normal planting, cultivating, pesticide, and harvesting practices (Matherne et al., 1972). Fertilizer requirements were determined annually by soil test except the grower determined the rate of nitrogen fertilzer to be applied. Fertilizer was applied in late April each year at the rate of 200, 45, and 90 kg/ha for N, P_2O_5 and K_2O, respectively.

Yields were determined for each treatment from samples collected in 3-row, 15-m long areas located directly over drain lines and midway between drain lines at three different locations along the surface slope which was coincident with row direction. Two yield samples were collected at each of the areas relative to the drain line giving a total of four samples for each location and twelve for each treatment. The three locations along the surface slope in each treatment were considered as position effects in the statistical analysis. Plant population was determined by counting all stalks within a sampling area at the time of harvest. Sugarcane yield was determined by weighing all sugarcane within the sampling area in the field using a tractor-mounted grab equipped with a hydraulic load cell. A 10-stalk sample was collected from each plot for determining sucrose and purity in the laboratory and for determining sugar per tonne of cane by the procedure described by Legendre (1976). All data were analyzed by analysis of variance procedure and individual treatment differences were determined using Tukey's honestly significant difference (HSD) procedure (Steel and Torrie, 1960).

Water table depth was measured weekly in wells installed in several sugarcane rows in each drained and in the undrained areas. Two lines of wells perpendicular to the row direction were installed at approximately the 1/4 and 3/4 points along the 230-m row length. The wells were about 13 mm in diameter and cased to a depth of 1.4 m. Water table data could not be collected during certain time periods when well casings were removed because of their interference with certain tillage and harvesting operations. Rainfall was measured continuously on site using a weighing-type recording rain gage.

RESULTS AND DISCUSSION

The subsurface drainage systems adequately controlled the water table in all drained treatments. For example, the water table between two drains spaced 24.4 m apart was 1.1 and 1.3 m below the soil surface 4 and 11 days, respectively, following 100 mm of rainfall. Furthermore, the water table in a border area adjacent to an exterior drain line was significantly affected at distances of 18 and 30 m away 4 and 11 days, respectively, following 100 mm of rainfall. During the same time period, the water table in the undrained treatment was approximately 66 cm above that in the drained treatments. This indicates that drain spacings of 36 m or more will provide adequate drainage for this soil. Additional details regarding water table control for the various subsurface drainage systems were reported by Camp and Carter (1975).

Total annual rainfall in 1974 was 1060 mm, 600 mm lower than the long-term mean annual rainfall for the location. The water table in the undrained area was never closer than 40 cm to the soil surface during 1974 and apparently caused no damage to the sugarcane crop (Fig. 1). Low rainfall prior to mid-March resulted in below-average water table levels during the latter part of the sugarcane dormant season. The water table dropped rapidly in the spring as soon as significant sugarcane

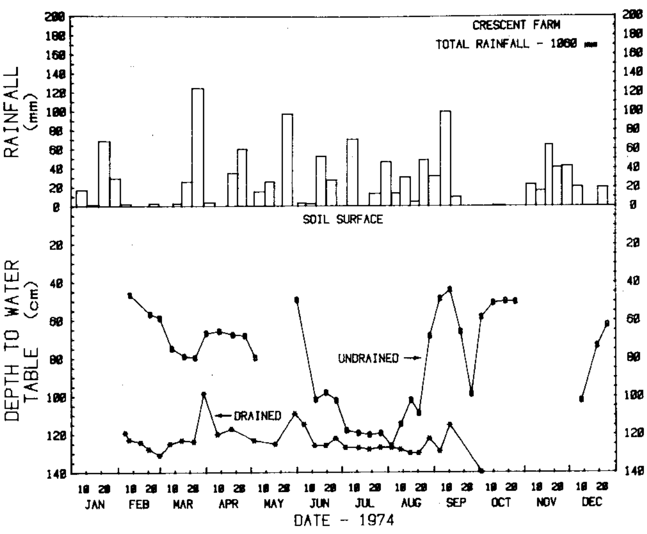

Fig. 1—Weekly rainfall and water table depths in an undrained site and midway between drains spaced 24.4 m apart in a drained site, both on an alluvial sicl soil in 1974.

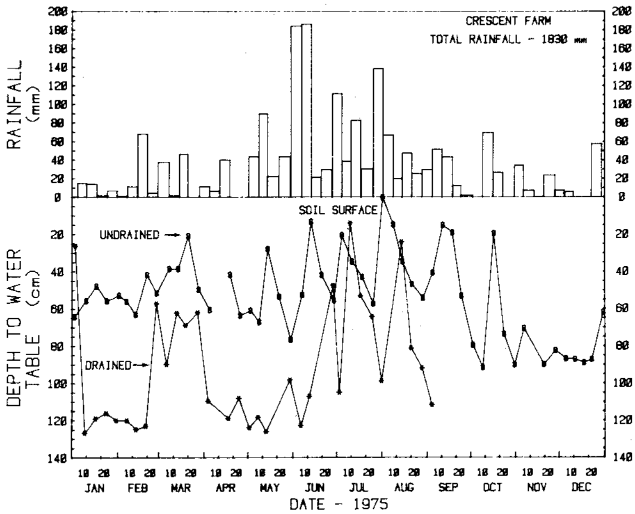

Fig. 2—Weekly rainfall and water table depths in an undrained site and midway between drains spaced 24.4 m apart in a drained site, both on an alluvial sicl soil in 1975.

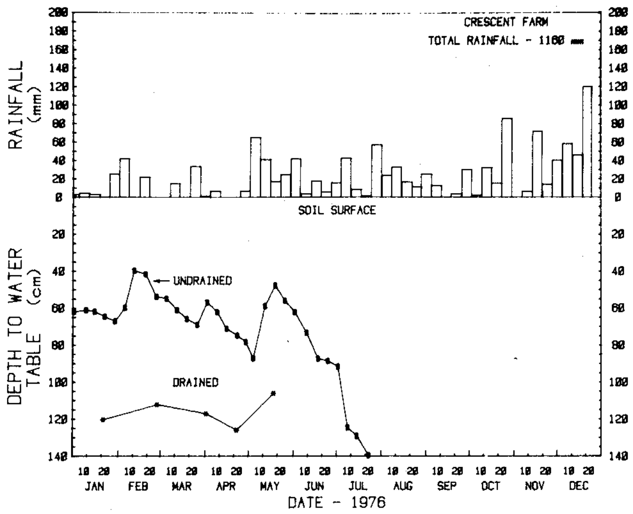

Fig. 3—Weekly rainfall and water table depths in an undrained site and midway between drains spaced 24.4 m apart in a drained site, both on an alluvial sicl soil in 1976.

growth occurred, even with frequent rainfall, and remained low throughout most of the summer. Frequent rainfall and reduced ET in September and October caused the water table to rise to a level near 40 to 50 cm below the soil surface. While the water table in the undrained plot remained below the 60-cm depth for most of the season, the water table in the drained treatment with drain lines spaced 24.4 m apart remained below the 120-cm depth for most of the season (Fig. 1).

In 1975 the rainfall amount and water table level in the undrained area were much higher than in 1974 (Fig. 2). The total annual rainfall was 1820 mm, 150 mm above the long-term average rainfall for the location. Rainfall distribution during this year was unusual in that rainfall was relatively low during the winter months, but very high during the growing season (May-August). Increased rainfall during late February and March caused the water table in the undrained plots to rise to within 20 cm of the soil surface by the end of March. With the initiation of sugarcane growth in the spring, the water table fluctuated about the 60-cm depth. The water table level rose and fluctuated widely with the heavy rainfall during the period May through September. The water table was near the soil surface on several occasions and water was observed in row middles. In October rainfall decreased, and the water table fell to a depth of about 90 cm during harvest (November-December). Throughout most of the year, the water table in the undrained treatment fluctuated between the soil surface and the 60-cm depth, while the water table in the drained treatment with drain lines spaced 24.4 m apart fluctuated nearer the soil surface than it did in 1974, but generally remained below the 60-cm depth (Fig. 2).

The following year, 1976, was very dry with a total annual rainfall of 1160 mm, 500 mm below the long-term average. Again, the water table in the undrained area was low during the dormant season and dropped even lower when sugarcane growth was initiated. The water table level dropped to depths greater than 140 cm in late July and did not rise above that level before harvest even though significant rainfall occurred during the period October through December. Rainfall and water tables were low enough during this growing season for potential reduction of sugarcane yields due to plant water stress, an unusual situation for sugarcane in Louisiana. The water table in the drained treatment with drain lines spaced 24.4 m apart was similar to that measured in 1974 when the water table remained below 120-cm for most of the season (Fig. 3). Water table measurements were discontinued during the last half of the growing season because the water table was below the bottom of the well most of the time. The weather during 1976 was also abnormal because of a severe, early freeze that occurred in November, approximately two weeks before harvest, and caused dessication of the entire sugarcane plant and sugar inversion. Consequently, all measured yields (sugarcane and sugar) were lower than they would have been if the crop had been harvested before the

TABLE 1. PLANT POPULATION, SUGARCANE YIELD, AND SUGAR YIELD FOR A THREE-YEAR (1974-76) SUGARCANE CROP CYCLE ON AN ALLUVIAL SICL SOIL WITH FOUR SUBSURFACE DRAINED TREATMENTS AND ONE TREATMENT WITH NO SUBSURFACE DRAINAGE.

Treatment		Plant population, stalks/ha			Sugarcane yield, t/ha			Sugar yield, kg/ha		
Drain depth m	Drain spacing m	Plant 1974	First ratoon 1975	Second ratoon 1976	Plant 1974	First ratoon 1975	Second ratoon 1976	Plant 1974	First ratoon 1975	Second ratoon 1976
1.4	12.2	74700 ab*	94600 a	77200 a	81.6 a	84.9 a	54.7 a	8680 a	9840 a	6280 a
1.4†	12.2	73700 ab	95100 a	76800 a	85.0 a	77.5 a	59.3 a	8470 a	9000 a	5940 a
1.4	24.4	69800 b	89500 a	74000 a	86.3 a	80.1 a	55.1 a	8820 a	9510 a	5650 a
0.9	6.1	70800 b	86600 a	78000 a	85.8 a	82.6 a	52.6 a	8670 a	9550 a	5670 a
None		84800 a	73900 b	66500 a	87.9 a	66.2 b	54.4 a	9050 a	7900 b	6340 a
HSD		12800	9200	21600	13.6	8.0	15.9	1570	1000	1780

* Means within a column followed by the same letter are not significantly different at the 5% level according to Tukey's HSD procedure.
† Drain installation included spun nylon filter material on outside surface of drain tubing.

freeze and should be used for comparisons among treatments during this year only.

Plant population, sugarcane yield, and sugar yield for the plant, first ratoon, and second ratoon crops (1974-76) are included in Table 1 for four subsurface drainage treatments and one treatment where no subsurface drainage was provided. In 1974 there were significant differences in plant population between some drained treatments and the undrained treatment, but there were no differences among the drained treatments. However, in 1975, the first ratoon crop, plant population in the undrained treatment was significantly lower than all of the drained treatments. The drastic decline in plant population (10,900 stalks/ha) between the plant and first ratoon crops for the undrained treatment is not normal and apparently reflects the adverse soil water conditions that existed in that treatment during 1975. In the second ratoon crop (1976) there were no significant differences in plant population among the treatments, probably due to the absence of adverse water table conditions and the extreme data variations caused by the early freeze and adverse conditions at harvest.

Sugarcane yields were good for all treatments during the plant crop (1974), ranging from 81.6 to 87.9 t/ha, but there were no significant treatment differences. In the first ratoon crop (1975) all drained treatments produced good yields, similar to those produced during the plant crop, but sugarcane yield in the undrained treatment declined from that produced in the plant crop (87.9 to 66.2 t/ha) and was significantly lower than those for the drained treatments. In the second ratoon crop (1976), sugarcane yields for all drained treatments were much lower than the yields for 1975, and the yield for the undrained treatment was slightly lower than for 1975. This was due primarily to the crop damage caused by freezing temperatures two weeks prior to harvest. There were no significant differences among treatments.

Sugar yield reflects the combination of quantity or mass (sugarcane yield) and quality (sucrose content) and is the major factor in determining the price a grower is paid for a crop. Sugar yields for the plant crop (1974) were good for all treatments, ranging from 8470 to 9050 kg/ha, but there were no differences among treatments. Sugar yields were higher for all drained treatments in 1975 (9000-9840 kg/ha) than they were in 1974, but sugar yield for the undrained treatment (7900 kg/ha) declined and was significantly lower than the drained treatments. Sugar yields for all treatments were lower for the second ratoon crop (1976), were not significantly different, and ranged from 5650 to 6340 kg/ha. This reflected both the reduced sugarcane yield and poor juice quality caused by freezing temperatures and subsequent sugar inversion.

The lack of sugarcane and sugar yield differences among the various drainage treatments for 1974, the plant crop, is not surprising since the water table in the undrained area was never high enough to cause adverse conditions. Although water table measurements were not made continuously, based on experience with these soils, it is very unlikely that a high water table existed for time periods sufficiently long to adversely affect yield. Carter (1977a) found that high water tables maintained for up to 7 days did not adversely affect sugarcane yields, but if the water table was maintained at a high level for 14 days or more, yields were adversely affected. Although there were significant differences in plant population among the drainage treatments, the differences in sugarcane and sugar yield were not significant.

The reduced sugarcane and sugar yield for the undrained treatment in the first ratoon crop (1975) resulted primarily from a 13% reduction in plant population from the plant to the first ratoon crop. Plant population for the undrained treatment was highest of all treatments in 1974 (not significantly different from some treatments), but was significantly lower than all treatments in 1975. Although the water table was not high during the dormant season except for a short period in March, it was extremely high during most of the growing season. The high water table in March may have been severe enough to reduce yield as Carter (1977b) found that wet soil during February and March was most closely correlated with reduced sugarcane yields. A high water table during the growing season does not normally reduce yield, but the prolonged nature of the high, fluctuating water table in 1975 may have caused conditions severe enough to cause the population and yield reductions.

As in 1974, the lack of sugarcane and sugar yield differences among drainage treatments in 1976 is not surprising since the water table was never very near the soil surface and was lowest during the growing season of any period during the three-year period of the study. Unfortunately, valid comparisons of yield and plant population data among the three years cannot be made due to the crop damage caused by adverse weather factors in 1976.

In 1976 plant population and yield of sugarcane and sugar were significantly higher for locations over the drain line than for locations at the midpoint between drain lines, regardless of drain line spacing. Since low rainfall and relatively dry soil conditions prevailed during this year, it is unlikely that the conditions during this year caused the measured differences. Rather, it is more likely that the yield differences were caused by a cumulative effect resulting from conditions that existed during the previous two years of the study, particularly during 1975 when very wet soil conditions existed. The higher plant population and higher yields over the drain line for 1976 probably resulted from the improved soil environment immediately surrounding the drain line.

There appears to be no advantage among the various subsurface drainage system designs from the sugarcane and sugar yield standpoint based upon these results. Also, the spun nylon filter material used on one of the drainage systems did not provide a yield advantage over the other systems during the term of this experiment. However, drain line plugging and subsequent deterioration of drainage system performance might not become evident for several years. When yields for drainage systems with drains installed at the same depth are compared, it is also apparent that the narrower spacings offer no advantage over the wider spacing.

The sugarcane and sugar yield increases obtained from drained treatments over undrained treatments during 1975, the only wet year during the three-year term of the study, are comparable to those reported by Carter and Floyd (1975) for small, bordered plots. They reported sugarcane yield increases of 16 to 40 t/ha (20 to 118%) and sugar yield increases of 170 to 1450 kg/ha (6 to 98%) when adequate water table control was provided during both the dormant and growing seasons. The mean sugarcane yield for all drained treatments in this study was 3.2 t/ha (3.5%) lower and 15.1 and 1.0 t/ha (23 and 1.8%) higher than for the undrained treatment in 1974, 1975, and 1976, respectively. Sugar yield differences were 390 kg/ha lower, 1580 kg/ha higher, and 460 kg/ha lower (4.3, 20, and 7.2%), respectively, for the same comparisons. The overall effect for the three-year period is a mean annual yield increase of 6.2% for sugarcane and 3.1% for sugar.

SUMMARY AND CONCLUSIONS

Subsurface drains spaced up to 24.4 m apart at a depth of 1.4 m adequately drained this alluvial sicl soil. Sugarcane and sugar yields for drained treatments were significantly higher one year of the study, when rainfall exceeded the long-term mean annual rainfall for the location. The yield reduction for the undrained treatment was largely due to a significant decline in plant population which was probably caused by a high water table during the latter part of the dormant season and most of the growing season. Rainfall was below the long-term mean annual rainfall during the remaining two years of the study, and the water table was never high enough to adversely affect sugarcane yield. Consequently, there were no differences in yield among the drainage treatments for these years. One year (1976), the water table was extremely low during most of the growing season, but yields for the drained treatments were apparently not adversely affected by any drought stress that may have occurred.

The ultimate acceptance of a land improvement practice such as subsurface drainage depends, in large part, on the system cost in relation to expected benefits or increased returns. For medium-textured soils such as this alluvial sicl, drain spacings of 24.4 to 36 m appear to be reasonable while fine-textured, poorly drained clay soils may require drain spacings of 6 to 12 m. Camp and Carter (1977) reported estimated system installation costs for sugarcane on this soil. As is evident from these results, increased return resulting from higher yields probably will not occur every year since yield-reducing high water tables in this region are the result of excess rainfall. Although the frequency of occurrence for high water tables must be determined before a reliable estimate of economical feasibility can be determined, the magnitude of the sugar yield increase due to drainage during the wet year in this study was large enough to pay the installation cost for a system with drains spaced 36 m apart and to pay 69% of the installation cost for a system with drains spaced 24.4 m apart. Additional research will be necessary to determine the maximum drain line spacing for this soil. The economic evaluation of subsurface drainage for these conditions could be accomplished through the use of simulation models coupled with experimental data or by long-term field studies. A complete economic analysis based on current costs, crop prices, and interest rates would be required to determine the feasibility of installing subsurface drainage at a specific site.

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