SOIL AERATION, NUTRIENT UPTAKE AND YIELD OF SUGARCANE AS AFFECTED BY TILE DRAINAGE

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ABSTRACT

A field drainage experiment was conducted in fine-textured Low Humic Gley soil under a sub-tropical climate to evaluate the response of sugarcane to tile drainage. Tile drainage treatments were six combinations of two depths of 1.2m and 0.8m below soil surface, and three spacings of 15, 20 and 25m. A surface drained plot was added as check. After a heavy rain, water table levels in all tile-drained plots decreased much faster than in the surface-drained check. Forty-eight hours after the rain, the water table dropped to at least 60 cm in the drained plots and to 21 cm in the check. Oxygen concentration in surface-drained plot never exceeded 5% in the upper 30 cm depth during the whole rainy season. In all the tile-drained plots, oxygen contents however, seldom dropped to below 10%. The root development, nutrient uptake and sprouting of ratoon crop were substantially higher in the tile-drained plots than in the surface-drained plot. Increases of 17%, 40% and 34% in yield of plant, the first and second ratoon, respectively, were found in tile-drained plots.

INTRODUCTION

As in most sugarcane growing areas in the world, the climate of cane plantations in southern Taiwan is characterized by a clear wet season and a relatively long dry season. More than 1200 mm of rain are received from May to October. The water table rises to the level close to soil surface because of the flat topography and the poor internal drainage. The presence of shallow water table may cause poor soil aeration and restrict the rooting volume. Consequently, oxygen deficiency can cause a reduction in water and nutrient uptake and the formation of toxic products in the soil and plants (Wesseling, Williamson and Kriz). When such poor aeration condition occurs in the boom growth stage and persists for a long time, retardation of vegetative growth, and a decline in yield will result. Thus, the productivity of plantations with water table at high levels, is limited by excessive wetness.

To remove excessive water from the root zone, a good drainage system is needed. For some plantations with good internal drainage, surface drainage
should also be adequate. In areas with high water table, additional sub-surface drainage system is necessary. Tile drainage is not a general practice in Taiwan and so information on the response of sugarcane to sub-surface drainage was not available. In 1975, a field drainage experiment was conducted to evaluate the effect of sub-surface tile drainage on the growth and yield of sugarcane. The performance and its effect on soil aeration were also measured in the field.

MATERIALS AND METHODS

The tile drainage installation was located in Shin Juan Plantation near Annie Sugar Mill in fine textured Low Humic Gley soil. The ground surface is quite flat with an average slope of less than 0.2%. The soil has well-developed columnar structure containing high percentage of silt. The top soil was very compact, but deep shrinkage cracks were formed between the soil clods resulting in a relatively high hydraulic conductivity as measured in the field by auger hole method (Van Beers). The aeration porosity measured under 100 cm tension indicated that the top 35 cm layer had the lowest effective porosity, while the layer of 70 to 102 cm had the highest porosity at 6.3%. The profile description of this soil is given in Table 1.

TABLE 1. Major soil physical properties in the experimental field

<table>
<thead>
<tr>
<th>Depth cm</th>
<th>Mech. composition</th>
<th>Texture</th>
<th>Bulk density g/cm³</th>
<th>Effective porosity %</th>
<th>Hydraulic conductivity m/day</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-35</td>
<td>24 44 32</td>
<td>CL</td>
<td>1.75</td>
<td>2.73</td>
<td>4.6</td>
</tr>
<tr>
<td>35-70</td>
<td>19 40 41</td>
<td>SIC</td>
<td>1.56</td>
<td>4.80</td>
<td></td>
</tr>
<tr>
<td>70-102</td>
<td>28 54 18</td>
<td>SIC</td>
<td>1.52</td>
<td>6.30</td>
<td></td>
</tr>
<tr>
<td>&gt;102</td>
<td>14 52 34</td>
<td>SICL</td>
<td>1.51</td>
<td>4.86</td>
<td></td>
</tr>
</tbody>
</table>

*Measured by auger hole method.

The experiment consisted of the surface-drained only and the combination of surface-drained and tile-drained plots. Tile drainage treatments were six combinations of depths 1.2 and 0.8 meters below soil surface, and spacings of 15, 20 and 25 meters. Each of the six treatments consisted of four lines measured at 80 meters. Only the central two drains and the land area between the two were used to obtain experimental measurements. The schematic drawing of the tile lay-out for this experiment is shown in Fig. 1.

Slotted PVC pipe with 5.6 cm inside diameter and 2 mm thickness was used as laterals. A layer of 20 cm thick gravel acted as drain envelope on the top part of the pipe. All the drains were installed at 0.17% slope in the direction perpendicular to the main drain. After the tile were installed, the plots were smoothed several times. Sugar cane variety of T 160 was planted.
Soil oxygen concentration was measured during the growth period of plant cane from September, 1975 to December, 1976 in both tile-drained and surface-drained plots in depths of 20, 30, 50 and 70 cm from soil surface. A special air sampling tube and a Beckman model 715 process oxygen monitor were used for measuring soil oxygen concentration (Yang and Lin? ). Water table measurements were taken during the rainy season with 3.70 cm perforated PVC pipe installed as shown in Fig. 1. Leaf samples were collected every month in each treatment during the boom stage, for the analysis of N, P₂O₅ and K₂O concentration. Plant height and the number of tillers were measured periodically. Plant cane was harvested 18 months after planting and allowed to grow for two ratoon crops. At harvest, the length and the number of millable stalks and yield were determined. For ratoon crop, the sprouting percentage were measured one month after harvest. To determine the effect of drainage on sugarcane root development, soil samples were taken in each treatment by using 10x10x10 cm metal sampler in increments of 10 cm from soil surface to 60 cm. The roots contained were picked, washed and dried for comparison.

RESULTS AND DISCUSSION

Water Table Levels

Measurements of water table levels was made following the heavy rainstorm from July 2 to 5. In this period, a total rainfall of 230 mm was recorded. The results showed that water table levels midway between drains in all tile-
drained plots, decreased much faster than those in surface-drained plot (Fig. 2 and 3). Forty-eight hours after starting the measurement, the level of water table in tile-drained plots dropped at least 65 cm from soil surface. Only a 21 cm drop was observed in the surface-drained plot. Among the tile-drained treatments, 1.2 meter depth lowered the water table faster than the one at 0.8 meter depth. The narrower the spacing the more effective is the drain in lowering the water table.

The fluctuations of the water table midway between the tile-drains and the surface-drained plot for the whole rainy season starting from May to September, are shown in Fig. 4. Obviously, the water table levels in the tile-drained plot was consistently lower than the surface-drained plot. In more than half of the rainy season, the water table in surface-drained plot was higher than 50 cm. In August, the water table was maintained close to the surface for more than three weeks. Under such prolonged drainage condition, the growth of cane definitely would be affected. In the tile-drained plots, the water table did rise to the surface, but it dropped to 60-80 cm below the soil surface within 48 hours.

**FIGURE 2.** Water table positions for 1.2 m drain depth after rainstorm.
Oxygen concentrations

Fluctuations in oxygen concentration at different soil depth in the growth period of plant cane between September, 1975 to December, 1976 are shown in Fig. 5. Since the drainage efficiency between different treatments of tile-drained plots was basically the same, only the data obtained from tile spacing of 25 m with 1.2 m depth is shown. The figure indicates clearly that no difference in oxygen concentration between tile-drained and surface-drained plots were observed during the dry season. Oxygen concentration at the upper 30 cm soil layer was always 10% higher than in both treatments. Soil aeration therefore, is not a limiting factor to plant growth in this period. However, during the rainy season, the O₂ concentration in the surfaced-drained plot dropped markedly. It never exceeded 5% because of excessive water contained in the soil pores. While in the tile-drained plot, the soil oxygen concentration dropped after heavy rain or irrigation, but it returned rapidly to above 10% level. Such short-term deficiency may not cause great damage to cane plants. Yet, if oxygen deficiency persists for a long time as the case of surface-drained plot, root development, nutrient uptake and the growth of sugarcane would be affected. Experimental results shown by Carter² indicated that sugarcane can tolerate soil wetness for up to 7 days during the growing season without adversely affecting cane and sugar yield.

Growth and nutrient uptake

Excessive soil wetness caused by high water table during the boom stage

![Figure 3](image-url)
FIGURE 4. Fluctuation of water table in surface drained and the drained plots during the rainy season in 1977.

of plant and ratoon cane depressed both growth and nutrient uptake. The difference in stalk elongation between tile-drained and surface-drained plots was found to be more than 10 cm per month for June, July and August. At the end of the rainy season, the stalk length in surface-drained plot was 29 cm, 21 cm and 58 cm shorter than the tile-drained plots for plant, first ratoon and second ratoon, respectively (Fig. 6). Such growth retardation was caused mainly by oxygen deficiency which in turn, affected the nutrient uptake due to the fact that oxygen controls respiration and metabolism in
FIGURE 5. Fluctuation of soil oxygen concentration at 20, 30, 50 and 70 cm soil depth in the field with tile (with 25m tile spacing and 120 cm tile depth) and without tile in An-Nei.

TABLE 2. Nitrogen concentrations in cane leaf in relation to drainage treatments

<table>
<thead>
<tr>
<th>Treatment</th>
<th>June</th>
<th>July</th>
<th>August</th>
<th>September</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1st</td>
<td>2nd</td>
<td>1st</td>
<td>2nd</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1st</td>
<td>2nd</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1st</td>
<td>2nd</td>
</tr>
<tr>
<td>Surface drained</td>
<td>2.39</td>
<td>2.05</td>
<td>2.44</td>
<td>2.22</td>
</tr>
<tr>
<td>Tile drained</td>
<td>2.24</td>
<td>2.02</td>
<td>2.32</td>
<td>2.04</td>
</tr>
<tr>
<td>15m x 1.2m</td>
<td>2.31</td>
<td>2.11</td>
<td>2.34</td>
<td>1.96</td>
</tr>
<tr>
<td>20m x 1.2m</td>
<td>2.58</td>
<td>2.08</td>
<td>2.54</td>
<td>2.13</td>
</tr>
<tr>
<td>25m x 1.2m</td>
<td>2.43</td>
<td>2.17</td>
<td>2.30</td>
<td>2.04</td>
</tr>
<tr>
<td>15m x 0.8m</td>
<td>2.58</td>
<td>2.08</td>
<td>2.37</td>
<td>1.96</td>
</tr>
<tr>
<td>20m x 0.8m</td>
<td>2.45</td>
<td>2.04</td>
<td>2.24</td>
<td>2.24</td>
</tr>
<tr>
<td>25m x 0.8m</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

roots of intact plants (Grable\textsuperscript{4}, Wesseling\textsuperscript{5}). As shown in Table 2, the nitrogen concentration of +1 leaf in the surfaced-drained plot decreased steadily from the start of raining season in June to the lowest level in September. Although the nitrogen deficiency was recovered to the same level as the tile-drained
plot in October, it was too late for cane growing in surfaced-drained plot to catch up with normal growth since the boom stage has already passed. The uptake of P₂O₅ and K₂O showed less response to drainage condition. There was no significant difference between tile-drained and surface-drained plots.

**FIGURE 6.** Effect of tile drainage on stalk elongation of sugarcane during the booming stage.

Root development

Root growth and activity were closely related to the aeration status in the root zone. Root system in tile-drained and surface-drained plots were examined after cane was harvested. The root system in Fig. 7 shows that root density in tile-drained plot was considerably higher and roots could penetrate to a depth of 80 cm below soil surface. In surface-drained plot, less root proliferation was observed and penetration depth was restricted to 60 cm. In addition to visual examination, roots in 1,000 cm³ volume of soil in each 10 cm segment were washed and weighed for quantitative determination. The results as shown in Fig. 8 indicate clearly that total dry root per unit soil volume in tile-drained plot was much higher than that in the surface-drained plot. A total dry weight of 2.59 g was contained in 6,000 cm³ soil volume in tile-drained area and only 0.4 g was measured in the same volume of soil in surface-drained plot. The extensive and deep root system explores a large soil volume for water and nutrients. During the dry season, the deep roots may withdraw water from the capillary fringe of ground water. If the root development is inhibited because of poor drainage such as in the surface-drained plot used in this study, cane growth may suffer from water shortage at later period of drought when irrigation is not applied properly.

Sprouting of reatton crop

The sprouting of stubble crop is considered critical for achieving a successful reatton production. It determines not only the density and the uniformity
of crop stand but also relates indirectly to the planting expenses which include the labor cost for re-planting. Poor sprouting of ratoons is always a serious problem in areas with high water table in Taiwan. Installation of tile drainage system not only increases the yield of plant cane but also improves the sprouting of stubble crop and thus the ratoon yield. The average sprouting percentage of first and second ratoon in the tile-drained plots were 17% and 33%, respectively. These values were higher than the surface-drained plot (Fig. 9). The treatments with deeper drains, especially the treatment of 25 x 1.2 meters, had higher sprouting rate than the shallow drains. The higher sprouting percentage of ratoon crop in tile-drained plots may not relate to soil aeration but to the deep and highly proliferated root system since harvest is in the dry season.

Cane yield

This experiment was continued for 3 crop years. The plant cane was harvested in February, 1977. The first ratoon in February, 1978 and second ratoon in February, 1979. The yield data are listed in Table 3. Because of the improved aeration status in the root zone, the number and the length of millable cane stalks, and the cane yield were higher in the tile-drained treatments. The yield of stubble crop responded more sensitively to drainage condition than the plant cane because of the relatively short growth season. On the average, plant cane, first ratoon and second ratoon in tile-drained plots yielded 17%, 40% and 34%, respectively, more than that in surface-drained plot. In the rainy season of 1977, the boom stage of the first ratoon, an extremely high rainfall of 26.73 mm occurred causing serious water logging condition. Typhoon Thelma hit Taiwan in July and damaged sugarcane in experimental areas especially in the treatments of 20 m x 1.2 m and 20 m x 0.8 m. As a result, the yields from these two treatments were relatively lower than normal.
FIGURE 8. Root distribution in tile drained and surface drained plots
The difference in yield between tile-drained treatments was irregular and not significant. Such small difference in yield between treatments can be explained by the fact that all the drainage treatments, irrespective of drain depth and
spacing, were sufficient to improve aeration condition in the root zone during the rainy season.

Despite the fact that many experimental results from other countries (Camp and Carter\textsuperscript{1}, Escolar and Allison\textsuperscript{3}) showed an increase in sugar yield after installation of sub-surface drainage system, no relation was found between sugar yield and drainage in Taiwan. Probably, this is because of the climatic condition. During the harvest season, the weather was relatively cool and dry which was favorable for sugarcane ripening. Drainage problems occurred only in the rainy season between May to September which was the booming stage for cane growth. Therefore, improving drainage can only increase the per unit area cane production but not the sucrose percentage.

REFERENCES


RESUMEN

Se llevó a cabo un experimento de drenaje de campo en terreno de textura fina y humedad baja en clima sub-tropical, para evaluar los efectos de drenaje profundo en caña de azúcar. El drenaje profundo consistió de seis combinaciones de dos profundidades – 1.2 y 0.8 metros bajo la superficie del terreno, y tres espacimientos de 15, 20 y 25 metros. Para comprobación se añadió un lote con drenaje de superficie. Después de lluvias fuertes, el nivel freático en todos los lotes con drenaje profundo disminuyeron mucho más rápido que en el lote para comprobación con drenaje de superficie. Cuarenta y ocho horas después de la lluvia, el nivel en lotes con drenaje profundo bajo por lo menos 60 cm, mientras que en el lote de comprobación bajo solamente 21 cm. Durante toda la temporada de lluvia concentración de oxígeno en el lote con drenaje de superficie en ningún excedió 5% en los 30 cms de profundidad superiores, pero en terrenos con drenaje profundo el contenido de oxígeno raramente bajo a menos de 10%. En terrenos con drenaje profundo el desarrollo de la raíz, la absorción de nutrientes y el brote de retoños fue substancialmente superior a los resultados que se obtuvieron en terrenos con drenaje de superficie. En terrenos con drenaje profundo hubo un aumento de 17%, 40% y 43% en la producción de plantas, primer y segundo retoño respectivamente.