# SUGARCANE YIELDS AND SOIL ANALYSIS FOLLOWING APPLICATION OF PAPER-MILL SLUDGE

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## ABSTRACT

Industrial by-products can serve as soil amendments to improve agricultural soil fertility and provide a reasonable economic means of disposing of such by-products. The objective of this study was to determine the effect of paper-mill primary clarifier sludge in combination with various fertilizer treatments on cane and sugar yields of a sugarcane plant cane through second ratoon crop cycle. Sludge was applied to fallow fields subsequently planted to sugarcane (*Saccharum* spp. hybrids). The paper-mill sludge was applied at rates of 0, 22.5, and 44.7 Mt per hectare on whole plots. Spring (0-0-0, 90-0-0, and 180-0-0) and starter (0-0-0 and 17-50-50) fertilizer treatments (kg $ha^{-1}$) were subplots. Soil pH was raised 0.3 units at the 44 Mt per hectare paper-mill sludge rate when sampled the following spring after the fall application. At the end of the experiment, soil pH for the 44 Mt per hectare rate was 0.8 units higher than the control. Spring fertilizer treatments resulted in significantly higher cane and sugar yields in ratoon crops, but not in the plant cane crop. Sludge and starter fertilizer treatments did not affect sugarcane yields. In the first ratoon crop, the highest sludge and the highest spring fertilizer rates produced significantly less sucrose content, but did not affect total sugar yield. Excess nitrogen can delay the accumulation of sucrose (maturity) in sugarcane. Therefore, if sludge is applied to sugarcane in Louisiana, nitrogen fertilizer should be applied at the lower end of the recommended range to the first ratoon crop. In second-ratoon, sludge and spring fertilizer did not significantly affect sucrose content. The main effect of paper-mill sludge appears to be the ability to raise soil pH.

## INTRODUCTION

The organic matter content of most Louisiana soils is considered low by most standards. In general, increased organic matter in the soil will increase water and nutrient holding capacity, improve water percolation through the soil, improve tilth, and reduce erosion. These factors can cause improved plant survival and growth. The result can be increased yields with lowered fertilizer requirements and less soil, pesticide and nutrient loss in runoff.

Previous research has determined that several soil amendments affect sugarcane production. Viator et al. (2002) reported neutral effects of municipal compost on cane and sugar yields when subsoiled into the row rather than placed onto the row. They also determined that by-product gypsum did not affect cane and sugar yields when applied at rates of 2.24, 4.48, and 8.96 Mt $ha^{-1}$. Other research has shown cane and sugar yield increases following the addition of organic amendments to soils (Bevacqua and Mellano, 1994; Hallmark et al. 1995).

Golden (1983) summarized results from 1975 through 1979 for by-product gypsum experiments conducted in Louisiana. He found average cane yield increases ranging from 3.74 Mt $ha^{-1}$ for the plant-cane crop; 7.41 Mt $ha^{-1}$ for the first-ratoon crop; 8.36 Mt $ha^{-1}$ for the second-ratoon crop and 10.84 Mt $ha^{-1}$ for the third ratoon crop. Golden concluded that by-product gypsum was a suitable fertilizer source for S fertilizer. However, gypsum response can be erratic. Viator et al. (2002) determined that by-product gypsum did not significantly raise or lower cane and sugar yield when applied at rates of 2.24, 4.48, and 8.96 Mt $ha^{-1}$.

Golden (1975) reported on the application of filter press mud to sugarcane fields. Filter press mud is a by-product of sugar processing after juice clarification and primarily composed of field soil. Golden reported that filter press mud is high in total nitrogen, extractable phosphorus and potassium, calcium and magnesium. Application of filter press mud increased both cane and sugar yields in Louisiana. It was noted that weeds increased where filter press mud was applied. There can be other negative effects of soil amendments. Barry et al. (2001) noted increased phosphorus concentrations above plant requirements from repeated application of filter press mud application to sugarcane fields in Australia. They also noted that pH increased 1.5 units after the application of filter press mud.

Paper mills collect large volumes of short fiber (sludge) in the paper making process derived from waste water treatment plants. This material is primarily composed of partially digested cellulose and hemi-cellulose fibers and algae bodies with some residual lime. It is a convenient material to use and apply. The paper industry is seeking ways to use this material rather than landfill the large volumes it produces. Paper-mill fiber residue has been used as mulch, a lime source, and an amendment to increase soil organic matter content. The objective of this study was to determine the effect of paper-mill primary clarifier sludge on plant-cane through second ratoon cane and sugar yields when applied to fallow fields subsequently planted to sugarcane.

## MATERIALS AND METHODS

Paper-mill primary clarifier sludge was obtained from Georgia-Pacific Corporation, Port Hudson Operations, 1000 West Mount Pleasant Road, Zachary, Louisiana. Paper-mill primary clarifier sludge is material derived from the kraft pulping and elemental free chlorine-free bleaching process with non-ink paper, bath tissue and towel machine operations. The material is clarified in two primary clarifiers and dewatered to about 60 % moisture content using screw press equipment.

The experimental design was a randomized complete block (four replications) with a split plot arrangement of treatments. Sludge treatments (0, 22.5, and 44.7 Mt $ha^{-1}$) were the whole plots. Starter fertilizer treatments, 0 and 17-50-50 (kg $ha^{-1}$), and spring nitrogen treatments (ammonium nitrate) at 0-0-0, 90-0-0, and 180-0-0 (kg $ha^{-1}$) were the subplots. The soil type at the experimental site was a Commerce silt-loam (*fine-silty, mixed, nonacid, thermic Aeric Fluvaquent*). Each of the 18 sub-plots per replication was two rows wide (3.7 m) by 7.3 m long with a 1.2 m alley (unplanted area) between plots. Sludge was broadcast over unopened rows and incorporated with a rotor tiller, and starter fertilizer treatments were applied in the open planting furrow prior to planting on October 16, 2000. Spring nitrogen treatments were applied in early April of each crop year (2001 – 2003). The experiment was planted with LCP 85-384, a cultivar that occupied 85 % of Louisiana's sugarcane acreage in 2002 (Legendre and Gravois, 2003). Standard cultural practices were applied to the experimental area with respect to cultivation and the control of weeds and insect pests (Legendre, 2001).

Ten-stalk samples, taken at random along the row, were removed from each plot on December 3, 2001 in the plant-cane crop, December 18, 2002 in the first-ratoon crop, and November 6, 2003 in the second-ratoon crop. All stalks were stripped of all leaves and topped approximately 10 to 12 cm below the apical meristem. Data collected and/or calculated included mean stalk weight, Brix by refractometer, sucrose by polarimetry, purity as the ratio of sucrose to Brix, and the yield of theoretical recoverable sugar per mass of cane (g $kg^{-1}$), which was termed sucrose content (Gravois and Milligan, 1992). Plots were harvested on the same dates by a cane combine (Cameco Model 2500) operating at approximately 5.6 kilometers per hour and an extractor fan speed of 950 rpm. All cane from each plot was weighed in a wagon fitted with load cells and the weights recorded. From these data, the cane yield (Mt $ha^{-1}$) and sugar yield (Mt $ha^{-1}$) were calculated for each plot. The data were analyzed with a mixed model analysis (SAS 9.0 PROC MIXED). Least square means were calculated and separated using least square mean probability differences (P = 0.05).

Chemical analysis of one sample of the primary clarifier paper-mill sludge was conducted at the Louisiana State University Soil Testing Laboratory (Sample No. AH01166). The soil at the experimental site was sampled prior to the application of the treatments (September 2000), seven months later (April 2001), and at the conclusion of the experiment (January 2004). The soil sample was an aggregate of 12 sub-samples for each whole plot treatment. Each sub-sample consisted of a 2.5–cm-diameter core collected through the top of the row to a depth of 15 cm. Soil samples were analyzed at the LSU Soil Testing Laboratory in the Agronomy Department, Baton Rouge, Louisiana. Data collected for various sludge and soil parameters included pH, macro- and micro-nutrient content, and organic matter content.

## RESULTS AND DISCUSSION

The paper-mill sludge was high in organic matter along with a relatively high pH (Table 1). With the exception of calcium, the macronutrient content of the paper-mill sludge was low. Iron, aluminum, copper, arsenic levels were moderately high.

Soil test results just prior to and following the application of the paper-mill sludge suggest that the pH of the soil increased at the 44.7 Mt $ha^{-1}$ rate approximately seven months following the application (Table 2). Further, there was an increase of over 35 % (1365 to 1855 ppm) in the available calcium from the 0 to the 44.7 Mt $ha^{-1}$ rate when sampled in April following the sludge application the previous October. There was also a 48 % increase (25 to 37 ppm) in available sodium comparing the 44.7 Mt $ha^{-1}$ rate to the control. The increase in available calcium and sodium for the 22.5 Mt ha$^{-1}$ rate was intermediate between the 0 and 44.7 Mt ha$^{-1}$ rate. There appeared to be no effect of paper-mill sludge on the availability of K, Mg, and P at either the 22.5 or 44.7 Mt ha$^{-1}$ rate. Further, there was a numeric increase for organic matter in the April 2001 sampling date. Paper-mill sludge applied at the 44.7 Mt ha$^{-1}$ rate increased organic matter from 0.97 % to 1.22 %. Paper mill sludge only slightly increased soil pH. February 2004 soil-test results showed a numeric increase in soil pH as sludge rates increased (7.0 to 7.8), which corresponded to an increased concentration of calcium. Thus, one application of paper-mill sludge resulted in a thee-year increase in soil pH. However, application of paper-mill sludge was not necessary because of the already higher soil pH at the beginning of the experiment. Increasing pH in soils with inherently high pH might cause other problems, such as rendering phosphorus or micronutrients unavailable to the sugarcane plant. However, soil micronutrient status was not greatly influenced by the application of paper-mill sludge (Table 3). In April 2001, Fe, Mn, and Zn increased only slightly at the 44.7 Mt ha$^{-1}$ paper-mill sludge rate. By the conclusion of the experiment, February 2004 soil tests indicated that macronutrients and organic matter content were not affected by the paper-mill sludge treatments.

Mixed model analysis of fixed effect terms for the experiments conducted at the St. Gabriel Research Station for the three crops of the sugarcane cultivar LCP 85-384 is shown in Table 4. The main effect, crop, in the analysis of variance was highly significant ($P \leq 0.01$) for sucrose yield, cane yield, and sucrose content. In this experiment, crop and year are confounded. Nutrient response can be both soil and crop specific (Golden and Abdol, 1977). They summarized that the greatest yield response is observed with nitrogen, followed by potassium on light to medium textured soils, and then phosphorus on medium-heavy to heavy textured soils. Plant-cane crops tend to respond less to nitrogen and potassium applications. The duration of this experiment included an unusually wet weather pattern during the 2002 harvest. Sucrose content in 2002 was low due to lodging. However, the test in 2002 was harvested under good harvest conditions, and we do not feel that wet conditions affected our results.

Spring fertilizer treatments produced highly significant responses for sugar yield, cane yield, and sucrose content ($P \leq 0.01$). In contrast, starter fertilizer treatments did not significantly affect any yield component. Response to starter fertilizer in sugarcane grown in Louisiana has been inconsistent. The crop-by-spring interaction was the only interaction that was significant for sugar yield, cane yield, and sucrose content. In addition, the three way interaction (crop-by-sludge treatment-by-spring fertilizer) was significant for sucrose content. Thus, means were reported by each main effect combination as the interaction dictated.

For the plant-cane crop, there were no significant sugar yield or cane yield differences due to spring nitrogen applications (Table 5). Both ratoon crops exhibited significant sugar yield and cane yield decreases when no nitrogen was applied. Cane and sugar yields were not significantly different at the 180 kg ha$^{-1}$ nitrogen rate when compared to the 90 kg ha$^{-1}$ nitrogen rate. This result is consistent with work done by Kennedy et al. 2003 showing that LCP 85-384 has greater nitrogen use efficiency at lower nitrogen rates than other Louisiana sugarcane cultivars, such as CP 70-321 and HoCP 91-555. Due to a nonsignificant spring fertilizer-by-sludge interaction, it appears that the paper-mill sludge was not a useful fertilizer supplement that affected either cane or sugar yield.

Means by crop, sludge treatment, and spring fertilizer application for sucrose content are reported in Table 6. In the plant-cane crop for the 0 and 22.1 Mt $ha^{-1}$ sludge rates, the 90-0-0 spring fertilizer treatment had significantly less sucrose content that the 180-0-0 treatment. In the first-ratoon crop for the 44.7 Mt $ha^{-1}$ sludge rate, the 180-0-0 spring fertilizer rate had significantly less sucrose content than the 0-0-0 and 90-0-0 spring fertilizer treatments. This indicated that the first-ratoon crop may have obtained additional nitrogen from the high sludge treatment. Excessive nitrogen can delay maturity in sugarcane resulting in lower sucrose content. These data indicated that nitrogen rates could be reduced to the lower end of recommended ranges when high rates of paper-mill sludge are applied to sugarcane to avoid delaying sugarcane maturity. In the second-ratoon crop, sludge and spring fertilizer rates did not significantly affect sucrose content.

It is interesting to note that there was no significant deleterious effect of the paper-mill sludge on any of the yield components. This, in itself, is considered positive as many un-stabilized organic amendments can actually show a negative impact on crop yield the year of application. The paper-mill sludge could be applied to increase soil pH with no apparent effect on the sugarcane crop. Also, the use of paper-mill sludge could allow the use of nitrogen fertilizer rates in the first-ratoon crop at the lower end of recommended ranges to avoid lowering the sucrose content of the crop.

## ACKNOWLEDGMENTS

This study was funded in part by a grant from Integrated Technical Services of Baton Rouge, Louisiana.

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Table 1. Chemical analysis of the primary clarifier paper-mill sludge as analyzed by the Louisiana State University Soil Testing Laboratory.

| Analytical Parameter | Amount (Unit) |
|---|---|
| Moisture content | 56 % |
| Organic matter (primarily pulp fiber) | 43 % |
| pH | 9.2 |
| Nitrogen | 0.045 % |
| Phosphorus | 0.029 % |
| Potassium | 0.051 % |
| Calcium | 3.050 % |
| Magnesium | 0.108 % |
| Sulphur | 0.148 % |
| Sodium | 0.081 % |
| Chloride | 0.002 % |
| Copper | 6.12 ppm |
| Manganese | 287 ppm |
| Iron | 1359 ppm |
| Zinc | 14.8 ppm |
| Boron | 2.46 ppm |
| Arsenic | 357 ppb |
| Nickel | 5.79 ppm |
| Cadmium | 0.22 ppm |
| Chromium | 4.25 ppm |
| Aluminum | 289 ppm |
| Molybdenum | 5.90 ppm |

Table 2. Soil-test results (Ph, macronutrients, bases, and organic matter) conducted at the Louisiana State University Soil Testing Laboratory for the experimental area (Commerce silt-loam) before and after paper-mill sludge was applied at three rates at the St. Gabriel Research Station.

| Sample date | Sludge (Mt/ha) | pH | Ca | K | Mg | Na | P | Bases (meq/100g) | Organic Matter (%) |
|---|---|---|---|---|---|---|---|---|---|
| | | | ------------------ | | ppm | | --------------- | | |
| Sept. 2000† | 0 | 7.1 | 1455 | 94 | 317 | 26 | 349 | 10.2 | 1.21 |
| April 2001 | 0 | 7.3 | 1365 | 95 | 315 | 25 | 324 | 9.8 | 0.97 |
| April 2001 | 22.5 | 7.4 | 1510 | 91 | 307 | 33 | 326 | 10.4 | 1.13 |
| April 2001 | 44.7 | 7.4 | 1855 | 108 | 347 | 37 | 333 | 12.6 | 1.22 |
| February 2004 | 0 | 7.0 | 1552 | 97 | 328 | 35 | 253 | 10.9 | 1.10 |
| February 2004 | 22.5 | 7.4 | 1673 | 99 | 320 | 30 | 269 | 11.4 | 0.99 |
| February 2004 | 44.7 | 7.8 | 2062 | 102 | 317 | 35 | 289 | 13.3 | 1.20 |

† The soil was sampled prior to the application of the paper-mill sludge.

Table 3. Soil-test results (micronutrients) conducted at the Louisiana State University Soil Testing Laboratory for the experimental area (Commerce silt-loam) before and after paper-mill sludge was applied at three rates at the St. Gabriel Research Station.

| Sample date | Sludge (Mt/ha) | As | Cd | Cu | Fe | Mn | Ni | Pb | Zn |
|---|---|---|---|---|---|---|---|---|---|
| | | ------------------ | | | | ppm | | | ------------------ |
| Sept. 2000† | 0 | 0.67 | 0.07 | 1.08 | 22.75 | 7.39 | 2.17 | 1.96 | 4.47 |
| April 2001 | 0 | 0.71 | 0.05 | 0.99 | 18.84 | 6.16 | 2.23 | 1.99 | 3.78 |
| April 2001 | 22.5 | 0.72 | 0.07 | 0.97 | 19.64 | 6.08 | 2.49 | 1.77 | 4.61 |
| April 2001 | 44.7 | 0.70 | 0.08 | 1.04 | 23.27 | 7.43 | 2.55 | 1.66 | 4.67 |
| February 2004 | 0 | 0.20 | 0.18 | | | | 2.17 | 0.85 | 2.70 |
| February 2004 | 22.5 | 0.46 | 0.22 | | | | 2.01 | 2.88 | 2.62 |
| February 2004 | 44.7 | 0.49 | 0.27 | | | | 3.20 | 0.81 | 3.47 |

† The soil was sampled prior to the application of the paper-mill sludge.

Table 4. Probabilities of F values derived from mixed model analysis of fixed effect terms for an experiment conducted from plant-cane through second-ratoon crops at the St. Gabriel Research Station with sugarcane cultivar LCP 85-384.

| Source | Numerator df | Denominator df | Sugar yield | Cane Yield | Sucrose content |
|---|---|---|---|---|---|
| | | | | Pr > F | |
| Crop | 2 | 25 | <0.001 | <0.001 | <0.001 |
| Sludge | 2 | 25 | 0.59 | 0.45 | 0.25 |
| Starter | 1 | 125 | 0.58 | 0.36 | 0.91 |
| Spring | 2 | 125 | <0.001 | <0.001 | 0.01 |
| Crop*Sludge | 4 | 25 | 0.73 | 0.91 | 0.47 |
| Crop*Starter | 2 | 125 | 0.31 | 0.46 | 0.23 |
| Crop*Spring | 4 | 125 | <0.001 | <0.001 | 0.04 |
| Sludge*Starter | 2 | 125 | 0.95 | 0.60 | 0.41 |
| Sludge*Spring | 4 | 125 | 0.44 | 0.44 | 0.42 |
| Starter*Spring | 2 | 125 | 0.50 | 0.54 | 0.59 |
| Crop*Sludge*Starter | 4 | 125 | 0.61 | 0.41 | 0.15 |
| Crop*Sludge*Spring | 8 | 125 | 0.66 | 0.60 | 0.04 |
| Crop*Starter*Spring | 4 | 125 | 0.44 | 0.33 | 0.07 |
| Crop* Sludge*Starter*Spring | 12 | 125 | 0.72 | 0.53 | 0.82 |

Table 5. Cane yield and sugar yield responses of sugarcane cultivar LCP 85-384 to spring fertilizer treatment averaged across starter fertilizer and sludge treatments for the plant-cane through second ratoon crops grown at the St. Gabriel Research Station.

| Spring Fertilizer Rate (kg $ha^{-1}$) | Cane yield | | Sugar Yield | |
|---|---|---|---|---|
| | ---Mt $ha^{-1}$--- | | | |
| *Plant-cane* | | | | |
| 0-0-0 | 98.8 | A | 9.57 | A |
| 90-0-0 | 98.7 | A | 9.36 | A |
| 180-0-0 | 96.7 | A | 9.46 | A |
| *First-ratoon* | | | | |
| 0-0-0 | 66.5 | B | 8.94 | B |
| 90-0-0 | 73.5 | A | 9.61 | A |
| 180-0-0 | 76.5 | A | 9.80 | A |
| *Second-ratoon* | | | | |
| 0-0-0 | 45.5 | B | 5.44 | B |
| 90-0-0 | 78.6 | A | 9.22 | A |
| 180-0-0 | 81.4 | A | 9.60 | A |

Table 6. Sucrose content of sugarcane cultivar LCP 85-384 to spring fertilizer and paper-mill sludge treatments averaged across starter fertilizer treatments for the through second ratoon crops grown at the St. Gabriel Research Station.

| | ---Sludge Rate (Mt $ha^{-1}$)--- | | | | | |
|---|---|---|---|---|---|---|
| Spring Fertilizer Rate (kg $ha^{-1}$) | 0 | | 22.1 | | 44.7 | |
| | ---Sucrose Content (g $kg^{-1}$)--- | | | | | |
| *Plant-cane (0-0-0)* | 99.4 | AB | 95.4 | AB | 96.1 | A |
| *Plant-cane (90-0-0)* | 96.4 | B | 92.2 | B | 96.4 | A |
| *Plant-cane (180-0-0)* | 100.4 | A | 97.9 | A | 95.3 | A |
| *First-ratoon (0-0-0)* | 133.7 | A | 134.8 | A | 135.4 | A |
| *First-ratoon (90-0-0)* | 127.8 | A | 133.9 | A | 130.2 | AB |
| *First-ratoon (180-0-0)* | 133.2 | A | 129.4 | A | 121.6 | B |
| *Second-ratoon (0-0-0)* | 121.7 | A | 119.4 | A | 118.7 | A |
| *Second-ratoon (90-0-0)* | 119.0 | A | 117.0 | A | 116.3 | A |
| *Second-ratoon (180-0-0)* | 116.9 | A | 116.6 | A | 119.7 | A |