12-1999

Maximizing Economic Returns from Sugarcane Production Through Optimization of Harvest Schedule (Bulletin #868)

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December 1999 Bulletin Number 868

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INTRODUCTION

Sugarcane, a member of the grass family, is valued chiefly for the juices expressed from its stems. Raw sugar produced from these juices is later refined into white sugar. Sugarcane is a perennial crop. One planting will generally allow for three to six annual harvests before replanting is necessary. As a sugarcane plant matures throughout the growing season, the amount of sucrose in the cane increases. Most of this sucrose production occurs when the plant is fully mature and begins to ripen (Alexander, 1973). Several studies have developed models to predict the sucrose level in sugarcane. Crane et al. (1982) developed a stubble replacement decision model for Florida sugarcane producers. They reported that sugar accumulation is a function of both sucrose accumulation and vegetative growth. The study suggested that the accumulation of sugar may be approximated as a quadratic function of time. Chang (1995), in research on Taiwanese sugar-

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cane cultivars, suggested that individual cultivars have distinct sucrose maturation curves with different peak levels. This study concluded that the sugar content of a cultivar could be predicted as a function of time with reasonable accuracy and that the trend of sucrose accumulation within-season follows a second order curve.

During the harvest season, second stubble fields (sugarcane fields in their third year of harvest) and older fields (third or fourth stubble crops) are usually harvested first, followed by more recently planted fields, first stubble (sugarcane in its second year of harvest) and then plantcane (sugarcane field being harvested for the first time). Within this general order of crop harvest, producers estimate the sugar content of cane in the field in order to harvest fields at a point where the sugar content in the cane is at or near a maximum. Several methods have been developed for estimating sugar content in field cane. The core punch method uses a hand refractometer to estimate the Brix (percent soluble solids) of sugarcane, which is an indirect indication of sucrose concentration. More sophisticated methods of sampling whole stalks are available, but they require extensive equipment and labor (Barnes, 1974). If individual sugarcane cultivars have distinct sucrose maturation curves, which may vary up or down from year to year depending upon weather and other factors, then the sugar content of individual fields could be incorporated into a model which would determine an optimal order of harvest for all fields on a particular farm. This would maximize total sugar produced (or total net returns received) on the farm.

Applications of crop harvest scheduling models using some type of operations research procedure are most common in the timber industry. Most of these applications involve either linear programming or simulation models. Recent studies have investigated the use of Monte Carlo integer programming (Nelson, et al., and Daust and Nelson), bayesian concepts (Van Deusen), and tabu search procedures (Brumelle, et al.). Several studies have developed crop growth models to predict the harvest date of agricultural crops (Lass, et al., Malezieux, and Wolf). Most of these studies, however, use optimal harvest decision rules based upon agronomic characteristics of the crop rather than economic principles.

Several studies have addressed various aspects of sugarcane productivity and harvest operations. Millhollon and Legendre studied the use of glyphosate, an artificial crop ripener used in sugarcane production, on sugarcane yield. Glyphosate (trade name POLADO®) is labeled for use only on ratoon or stubble sugarcane crops in Louisiana, Florida, and Texas. Their study indicated that annual glyphosate ripener treatments on sugarcane will usually increase mean annual sugar yield, but the magnitude of the increase depended on cultivar tolerance to the treatments. Two studies have evaluated the economics of sugarcane stubble crop replacement in Florida (Crane, et al.) and Louisiana (Salassi and Milligan). These studies evaluated the optimal crop cycle length by comparing annualized future net returns from replanting to estimated returns from extending the current crop cycle for another year. Semenzato developed a simulation algorithm for scheduling sugarcane harvest operations at the individual farm level in such a way that the lapse of time between the end of burning and processing is minimized. The model calculated the maximum size of a field which could be harvested and have all of its cane processed within a specified period. This study focused on farm size and equipment availability to use limited resources efficiently and in a timely manner. A recent Australian study determined optimal sugarcane harvest schedules which maximized net returns using mathematical programming procedures (Higgins, et al., and Muchow, et al). The modeling framework in this study, however, encompassed many farms within a production region over a multi-year harvest period. Furthermore, the smallest unit of time within the harvest scheduling model was one month.

This bulletin presents a methodology for the incorporation of within-season sucrose accumulation in sugarcane into an optimal single-season, daily harvest scheduling model at the individual farm level. The objective of the general modeling procedure was to capture the dynamic effect of sucrose accumulation during the growing season and to use this information, within a mathematical program modeling framework, in determining when specific sugarcane fields should be harvested to maximize total farm net returns. Data were obtained from Agricultural Research Service, USDA experimental research tests conducted in Louisiana over several years. Sucrose levels were estimated as a function of time for major cultivars now produced commercially in the state. The data were then incorporated into a mathematical programming model which determined an optimal harvest schedule that maximizes whole farm net returns for a given farm situation. Production and harvest data collected from a commercial sugarcane farm in Louisiana in 1996 were used to evaluate the ability of the modeling procedure to improve farm returns by adjusting the actual harvest schedule.

Sugar Prediction Models

The amount of raw sugar in a field of sugarcane is a function of several variables. Two important measures of sugarcane yield include tons of sugarcane per acre and pounds of raw sugar produced per acre. The relationship between sugar per acre and factors influencing it can be stated as follows:

$$(1) \qquad S_A = TRS \times TONS = TRS \times POP \times STWT$$

where S_A is total pounds of raw sugar per acre, TRS is theoretical recoverable sugar in pounds of sugar per ton of cane, TONS is the tons of sugarcane produced per acre, POP is the per acre population of sugarcane stalks in the field, and STWT is the stalk weight. Although the population of sugarcane stalks within a field can be assumed to be constant throughout the harvest season, the same assumption cannot be made for the other factors in the relationship. Theoretical recoverable sugar and stalk weight both increase as the harvest season progresses. To incorporate this yield increase within a whole-farm mathematical programming harvest scheduling model, estimates must be obtained for the predicted levels of each of these factors for each variety of sugarcane produced on the farm for every day of the harvest season.

Sucrose maturity data developed at the ARS, USDA Sugar Cane Research Unit in Houma, Louisiana, were used in the analysis. Stalk weight and sugar content of the commercial sugarcane cultivars grown in Louisiana were sampled at intervals during the harvest season from 1981 to 1996. The data included measurements of theoretical recoverable sugar, sugar per stalk, and stalk weight by julian date for 3 to16 years, depending upon variety. Historically, the harvest season for sugarcane in Louisiana has run from the first of October through the end of December. Observations for each commercial cultivar ranged from julian date 255 to 346 or about mid September through mid December. The age of the crop (plantcane or stubble) also was included.

To predict the amount of sugarcane and raw sugar in the field for each day of the harvest season, models were estimated for stalk weight and sugar per stalk. Previous research suggests that a quadratic model can be used to model sugar accumulation (Crane, et al.). Graphical analysis of both the stalk weight as well as the sugar per stalk data suggested these variables could be estimated using a semi-log functional form. Biological response functions of stalk weight and sugar per stalk were estimated for each cultivar as follows:

$$STWT_{ct} = \beta_0 + \beta_1 \text{ LNJD} + \beta_2 \text{ CROP} + \sum_{i=81}^{95} \beta_i \text{ YEAR}_i + \varepsilon \qquad (2)$$

$$SPS_{ct} = \alpha_0 + \alpha_1 \text{ LNJD} + \alpha_2 \text{ CROP} + \sum_{i=81}^{95} \alpha_i \text{ YEAR}_i + \varepsilon \qquad (3)$$

where $STWT_{ct}$ represents stalk weight in pounds per stalk of cultivar *c* on day *t*, SPS_{ct} represents sugar per stalk in pounds of cultivar *c* on day *t*, LNJD is the natural log of julian date (numeric day of the year), CROP is a (0,1) indicator variable representing crop age as either plantcane or stubble crop, and $YEAR_i$ represents discrete indicator variables for different years. Only two categories of the indicator variable CROP were included in the model because stubble crops for a given variety generally have similar sucrose accumulation levels regardless of crop age. These stubble crop sucrose levels, however, are significantly different from plantcane sucrose levels. The annual indicator variables for year were included to capture the relationship that sugarcane cultivars have distinct sugar accumulation curves which shift vertically from year to year, depending on weather and other factors. The base year for comparison in this estimation was 1996, and the indicator variables adjust the sugar accumulation curve to factors in a given year by shifting the intercept of the prediction equation. All models were estimated using SAS (SAS Institute, version 6.12). The estimates of stalk weight and sugar per stalk were combined with stalk populations to estimate sugarcane and sugar yield for each field.

Estimated models of stalk weight and sugar per stalk for each sugarcane cultivar are shown in Tables 1 and 2. Julian date (LNJD) and crop age (CROP) were found to be highly significant in the stalk weight prediction models (Table 1). Positive signs on the julian date variable indicate that stalk weight increases throughout the harvest season. The signs on the significant crop age variables were negative, as expected, indicating that stalk weight tends to be higher for plantcane crops than for older stubble crops. Coefficients of determination for specific variety models ranged from 0.36 to 0.81. In several of the estimated equations, indicator variables for years were significant, implying that the stalk weight growth curves vary from year to year, depending on weather and other factors. Similar results were found for the sugar per stalk prediction models (Table 2). Julian date was highly significant, with positive coefficients indicating sugar accumulation increases during the harvest season; crop age was significant in six of the 10 equations estimated. The sign on the estimated coefficient for crop age was negative in each of the six equations in which it was significant. Coefficients of determination were very high in the sugar per stalk models ranging from 0.78 to 0.90. Durbin-Watson tests for autocorrelation either failed to reject the hypothesis of no autocorrelation or were inconclusive, indicating that the error terms from the model predictions were not correlated serially. The White test for heteroscedasticity (White) failed to reject the hypothesis of homoscedasticity for each cultivar tested, indicating that error terms from the model predictions have a constant variance. The absence autocorrelation and heteroscedasticity indicated that the estimated parameters in the prediction models were efficient (minimum variance) estimators.

Farm Level Production Estimates

The estimated stalk weight and sugar per stalk models can be used to predict the sugar yield on a given farm in a specific year. Prediction per day across a given harvest season may require an adjustment of the predicted values for the crop's stalk weight and sugar content in the current year. Stalk weight and sugar content can be obtained from samples taken in the field. A sample data set was developed from information collected from a commercial sugarcane farm in Louisiana for the 1996 harvest season. Characteristics of the farm are presented in Table 3. Stalk number estimates were collected on September 18-19 and October 2, 1996, from each field on the farm. The number of samples taken per field depended on the size of the field, but a target of one count was taken for every one and one-half acres. In a randomly selected area of the field, a 25-foot distance was measured between the middle of two rows, then the number of millable stalks within that distance was counted and converted to an estimate of stalk population number per acre and field. Sample stalk counts for each field were then averaged to estimate a mean stalk population per field. Ten-stalk samples were cut from randomly selected locations in each field on October 7 and 9, 1996. To obtain a juice sample, each stalk sample was weighed and milled. The average stalk weight and estimated theoretical recoverable sugar from the juice analysis were combined with field information to develop stalk weight and sugar per stalk measurements by field.

Prediction models of stalk weight and sugar per stalk were then adjusted to the 1996 crop year. The adjustments were calculated by subtracting the predicted value of stalk weight and sugar per stalk, $STWT_{Predicted}$ and $SPS_{Predicted}$, on the day of sampling from the actual field measurements, $STWT_{Actual}$ and SPS_{Actual} , as shown in equations 4 and 5. This adjustment was incorporated into each model as a parallel shift in the intercept.

$$(4) \qquad \beta_0' = \beta_0 + (STWT_{Actual} - STWT_{Predicted})$$

$$(5) \qquad \alpha_0' = \alpha_0 + (SPS_{Actual} - SPS_{Predicted})$$

Stalk weight and sugar per stalk were then estimated for each day of the harvest season using the estimated prediction models with adjusted intercepts.

Estimates of tons of sugarcane per acre and pounds of raw sugar per acre were calculated by multiplying stalk weight and sugar per stalk by stalk population as follows:

(6) $$CANE_{ft} = POP_f \times STWT_{ct} / 2000$$

(7) $$SUGAR_{ft} = POP_f \times SPS_{ct}$$

where $CANE_{ft}$ is the estimated tons of sugarcane per acre in field *f* on julian date *t*, POP_f is the estimated stalk population per acre in field *f*, $STWT_{ct}$ is the estimated stalk weight in pounds for cultivar *c* on julian date *t*, $SUGAR_{ft}$ is the estimated pounds of raw sugar per acre in field *f* on julian date *t*, and SPS_{ct} is the estimated sugar per stalk in pounds for cultivar *c* on julian date *t*. Since POP_f, $STWT_{ct}$ and SPS_{ct} are predicted values with associated variances, direct multiplication would cause the estimated variances of predicted cane and sugar yield estimates to be very large, making the confidence intervals for predicted values considerably wider (Griffths et al. 1993). As a result, the relationships in equations 6 and 7 were converted to natural log form for calculation. Estimated yields per field were then adjusted for field conditions (recovery and trash) and differences between theoretical recoverable sugar and commercial recoverable sugar (equations 8 and 9).

(8) $$ADJCANE_{ft} = CANE_{ft} \times (1 + TRASH_f) \times FIELDRECOVERY_f$$

(9) $$ADJSUGAR_{ft} = SUGAR_{ft} \times 0.8345 \times SCALEFACTOR$$

$ADJCANE_{ft}$ represents the tons of sugarcane actually harvested from the field and delivered to the mill for processing. $TRASH_f$ is a percentage estimate of leaf matter and other trash in the harvested cane, and $FIELDRECOVERY_f$ is a percentage estimate of the amount of sugarcane in the field actually recovered by harvest operations. Estimated levels of trash and field recovery were determined on an individual field basis from producer information. $ADJSUGAR_{ft}$ represents the actual pounds of raw sugar recovered from the processed cane. The estimated sugar yield is multiplied by a standard factor (0.8345) to convert theoretical recoverable sugar into commercially recoverable sugar. Sugar mills use this standard to estimate recovery since the actual liquidation factor will not be known until the end of season. Accounting for differences from the laboratory analysis to the fields, the estimated sugar per field is reduced by a scale factor. The assumed scaler factor is 92%.

Mathematical Programming Formulation

The determination of a harvest schedule was formulated as a linear mathematical programming model which maximized producer net returns above harvest costs over total farm acreage. Farm returns were derived from the sale of sugar and molasses less a percentage of the total production as a “payment-in-kind” to the factory for processing and a percentage of the producer’s share paid to the land owner as rent. Since preharvest production costs were assumed to be independent of harvest operations, only harvest costs were included in the model. Harvest costs were assumed to be a function to the total tonnage of sugarcane harvested. The objective function for the model was defined as follows:

$$Z = (P_s \times S_p) + (P_m \times M_p) - (C_h \times T_t) \quad (10)$$

where Z represents total farm level producer net returns from sugar and molasses production above harvesting costs, P_s represents the price received per pound of sugar (cents per pound), S_p is the producer’s share of sugar produced (pounds), P_m is the price of molasses (dollars per gallon), M_p is the producer’s share of molasses (gallons), C_h is the cost of harvesting sugarcane (dollars per ton), and T_t is the total tons of sugarcane harvested.

The model consists of two sets of binding constraints and several transfer rows. The functional constraints of the model were defined as follows:

(11) $$\sum_{d=1}^{n} \sum_{f=1}^{m} (X_{df} \cdot S_{df}) - S_t = 0$$

(12) $$\sum_{d=1}^{n} \sum_{f=1}^{m} (X_{df} \cdot T_{df}) - T_t = 0$$

(13) $$0.029 \cdot S_t - M_t = 0$$

(14) $$a \cdot S_t - S_p = 0$$

(15) $$b \cdot M_t - M_p = 0$$

(16) $$\sum_{d=1}^{n} X_{df(1)} = 1$$

$$\sum_{d=1}^{n} X_{df(m)} = 1$$

$$(17) \quad \sum_{f=1}^{m} (X_{d(1)f} \cdot T_{d(1)f}) = Q_1$$

$$\sum_{f=1}^{m} (X_{d(n)f} \cdot T_{d(n)f}) = Q_n$$

All of the equations follow a similar format, with the subscripts *f* and *d* identifying the field and date of harvest, respectively. The model has *m* fields and *n* days. X_{df} is the percent of field *f* harvested on day *d*. The predicted yield of sugar (pounds) and sugarcane (tons) for field *f* on day *d* is S_{df} and T_{df}, respectively. S_t, T_t, and M_t are the total pounds of sugar, tons of sugarcane, and gallons of molasses produced on the farm. The producer's shares of sugar, S_p, and molasses, M_p, are calculated by taking the producer's share of sugar, *a*, and molasses, *b*, from the totals. The daily quota, Q_d, is the maximum tons of sugarcane that can be harvested and delivered to the mill each day. All dates are recorded using julian date.

The first two functional constraints are transfer rows that accumulate the total pounds of sugar produced (equation 11) and tons of sugarcane harvested (equation 12), respectively. Equation 13 calculates the gallons of molasses recovered by multiplying the pounds of sugar produced by a conversion factor of 0.029. Equations 14 and 15 calculate the producer's share of sugar and molasses, respectively. Equation sets 16 and 17 each represent a system of binding constraints. Equation 16 forces the model to choose each field exactly once during the harvest season. Each field has a constraint row. The model can harvest any percentage of a field on any available day. Harvest of individual fields was restricted to certain defined periods, based upon crop age, by including estimated daily sugar accumulation for only the days during which harvest of the field is permitted. Equation 17 creates a daily limit on the tons of sugarcane that maybe harvested in one day. Each day has a constraint row that limits the tons of cane harvested to less than a specified daily quota amount. Table 4 shows the sugarcane optimization program in a tableau format. *S* represents the pounds of sugar in a particular field on a given day, and *T* is the tons of sugarcane in a field on a given day. As with the constraint equations, the price of sugar, price of molasses, and cost of harvesting a ton of sugar cane are represented by P_s, $P_{m,}$ and *C*, respectively, and Q is the daily quota in tons of cane per day. The tableau shows fields (1 to *m*) and days (1 to *n*). The model can be expanded to handle any number of fields, and the days available for harvest can be customized to any particular harvest season length.

Results

Three different harvest scenarios were solved by the harvest scheduling model. The solution results for each of these different scenarios are shown in Table 5. The first solution represents results from simulating the producer's actual daily harvest schedule. After the 1996 harvest season ended, the producer provided information on the specific day each field was harvested as well as actual sugar yields. The actual harvest schedule solution in Table 5 is based on the date of actual harvest by field and the predicted sugarcane and sugar yields from the estimated prediction models. Sugarcane (tons) and sugar (pounds) yields per acre achieved by the producer closely matched predicted yields from the estimated models. Predicted total sugarcane production was 16,964 tons compared to the actual production of 16,639 tons reported by the producer. Estimated producer returns above harvest costs for the actual harvest schedule were $326,771. Average sugarcane yield over the whole farm was 30.5 tons per acre, resulting in an average sugar yield of 5,573 pounds per acre.

A second harvest scheduling model was solved for a scenario in which harvest dates for individual fields were constrained to specified intervals. In Louisiana, sugarcane harvest begins with fields containing the oldest stubble crops (second stubble and older), then proceeds to younger, first stubble crops. All stubble crop fields are usually harvested first. Within each stubble group, varieties are usually harvested in order of maturity class: very early, early, and mid-season (Faw). Finally, fields which are being harvested for the first time, containing plantcane, are harvested at the end of the harvest season to avoid damage of future stubble crops from early harvest. Plantcane fields are usually harvested beginning with varieties that deteriorate rapidly after a freeze and ending with harvest of varieties that deteriorate at a slower rate after a freeze (more freeze tolerant). An additional consideration affecting the harvest schedule is soil type. Extended periods of rain during the harvest season make harvest of sugarcane on heavy textured clay soils difficult. Harvest operations on excessively wet fields containing clay soils can severely rut a field and possibly damage the stubble crop, which would be harvested the following year. As a result, fields containing heavy textured clay soils would generally be harvested before fields containing lighter textured sandy soils.

In the constrained harvest model, possible harvest dates, which conformed to traditional harvesting practices, were specified for each field in the sample data set. Generally stated, these harvest date ranges began with second stubble harvest beginning on October 1 and continuing into November, first stubble harvest beginning in late October and continuing through November, and plantcane harvest beginning in late November and continuing through the end of December. Harvesting periods by crop age in the constrained harvest model also were adjusted for soil type. The resulting defined harvest periods included in the model were as follows: (a.) October 1- November 1: second stubble and older crops, all soil types; (b.) October 20 - November 15: first stubble crops, heavy soil; (c.) October 25 - November 25: first stubble crops, mixed soil; (d.) November 1 - December 31: first stubble crops, light soil; (e.) November 25 - December 31: plantcane crops, heavy soil; (f.) December 1 - December 31: plantcane crops, mixed soil; and (g.) December 10 - December 31: plantcane crops, light soil. These defined harvest periods were based on the distribution of soil types on the particular farm being analyzed. A farm with a different distribution of soil types would probably have had a slightly different set of defined harvest periods. Solution results from this model indicated that sugar production and net returns could be increased with relatively minor adjustments to the actual harvest schedule. Optimal adjustment of harvest of individual fields resulted in a projected increase in total farm net returns of

$17,360, or about $31 per harvested acre. Average harvested yield of sugarcane increased by 0.7 tons per acre, resulting in an increase in average sugar yield per acre of 263 pounds. Analysis of individual field results (Appendix Table 1) indicated that the optimal harvest date changed an average of 13 days from the actual harvest date, with some fields harvested earlier and others harvested later in the season.

An analysis of the specific adjustments in the harvest schedule for the constrained optimal solution are shown in Table 6. These results indicate the specific changes in the harvest schedule, on a field by field basis, required to maximize the producer's net income while still maintaining the defined harvest periods for each sugarcane variety, crop age, and soil type. Since the linear programming model was developed after the conclusion of the harvest season, the optimal estimated harvest schedule was not available to the producer. As a result, this study represents an ex post analysis of scheduling fields for harvest to maximize returns. Thirty-eight of the 112 fields, or 34%, required a change in harvest date of within 5 days of the actual harvest day. On 18 fields the optimal harvest date was 6 to 15 days earlier than the actual harvest date, and on another 18 fields the optimal harvest date was 6 to 15 days later than the actual harvest date. The optimal harvest date was moved forward more than 15 days for 11 fields (10%) and was moved more than 15 days later in the harvest season on 27 fields (24%). This adjustment of harvest date to later in the season is, in part, because some slack time was available within the harvest season given the farm size and daily quota used in this analysis. Since sucrose accumulation generally increases as the harvest season progresses, sugar production can be increased by harvesting fields as late in the harvest season as possible.

An unconstrained harvest scheduling model also was solved for comparison purposes. In this model, no constraints were placed on days in which fields could be harvested. Any field on the farm was allowed to be harvested on any day within the harvest season. Estimated net returns were $378,147, or $51,376 higher than the actual harvest schedule, and $34,016 higher than the constrained optimal solution schedule. This unconstrained solution is not realistic in the sense that plantcane would generally not be harvested before stubble crops. Early harvest of plantcane may increase sugar production in the current year, but it would have a significant adverse effect on sugar yields of future stubble crops. Estimation of this unconstrained model, however, gives some indication of the current returns forgone to maximize future returns by harvesting plantcane and first stubble crops later in the season.

One factor which would significantly affect an optimal harvest schedule determination to maximize returns is related to harvest travel costs. Harvest travel cost, the cost of moving sugarcane harvesting equipment from one field to another on the farm during the harvest season, significantly affects net returns above harvest costs for farms on which individual fields are located considerable distances from one another. Added returns from the harvest of fields in a specific sequence may be offset by increased travel costs in moving harvesting equipment from field to field. Travel costs were not included in this analysis, but they could be incorporated easily into the model by restricting harvest of fields within close proximity to each other to one defined harvest period and restricting fields in another locality to a different harvest period.

Summary and Conclusions

With constantly increasing input costs, the profit margins of sugarcane producers will continue to narrow. The long-run viability of the sugar industry will depend upon finding ways to produce sugar more economically by reducing production costs and managing available resources efficiently. Maximizing net returns for a whole farm, rather than trying to produce the maximum amount of sugar per field, should be a primary goal of producers. The purpose of this study was to develop a methodology to help schedule the sequence in which sugarcane fields are harvested to maximize producers' economic returns. The specific objectives were to develop models that estimate the increase in stalk weight and accumulation of sugar per stalk within the harvest season and to develop a mathematical programming algorithm that selects a harvesting schedule which maximizes net returns from sugar production above harvest costs.

Estimating the effect of time on the vegetative growth and sucrose accumulation in sugarcane was accomplished with least squares regression. Models which predicted stalk weight and sugar per stalk by cultivar were estimated as a function of julian date and crop age as well as indicator variables representing years of production with different growing conditions. These models were then used to predict sugar yields by cultivar and field for a sample farm. The optimization linear programming model used the estimated accumulation of stalk weight and sugar per stalk with field information to generate yield predictions. The predicted yields were used to select a harvest schedule subject to constraints that maximized producers' net returns above harvest costs. The optimization model predicted reasonable estimates of production on a commercial sugarcane farm in Louisiana.

The ability to predict sugarcane tonnage and raw sugar yields allows producers and mill personnel to more effectively plan the harvest of a sugarcane crop based on the current status of that crop. The type of harvest scheduling model developed here, although somewhat complex, could be standardized to allow for easy imputation of sucrose and tonnage accumulation data as well as individual farm data. Potentially, a producer, or crop consultant, could analyze the yield of each cultivar of sugarcane in the farm's crop mix and make decisions about harvest and future plantings. Optimization of harvest schedules could potentially recover more sugar from the fields, directly increasing the sugar recovered by the mills. Knowledge of the size and maturity stage of the crop could allow mills to more effectively assign delivery quotas among producers and plan the harvest schedule to maximize sugar production. Interest in site-specific farming using global positioning satellites (GPS) and global information system (GIS) is growing among sugarcane producers, but the limiting factor is the ability to attribute yield to location. The model developed in this study allows for the possibility of predicting sugar yield for individual fields. This information can be useful in designing fertility programs, weed control programs and in making crop replacement decisions on an individual field basis.

REFERENCES

Alexander, Alex G. (1973), “Chapter 11 - Maturation and Natural Ripening in Sugarcane Physiology,” *A Comprehensive Study of the Saccharum Source-to-Sink System*, Elsevier.

Barnes, A.C. (1974), *The Sugar Cane,* New York: John Wiley & Sons, Inc.

Brumelle, Shelby, Daniel Granot, Merja Halme, and Ilan Vertinsky, “A Tabu Search Algorithm for Finding Good Forest Harvest Schedules Satisfying Green-up Constraints,” *European Journal of Operational Research*, 106 (1998): 408-424.

Chang, Y.S. (1995), “The Trend of Sucrose Accumulation During Maturation of Sugarcane with Special Reference to the Maturity of Sugarcane Cultivars,” *Report of the Taiwan Sugar Research Institute*, 148:1-9.

Crane, Donald R., T.H. Spreen, J. Alvarez and G. Kidder (1982), *An Analysis of the Stubble Replacement Decision for Florida Sugarcane Growers,* Agricultural Experiment Station, Institute of Food and Agricultural Sciences, University of Florida. Bulletin 822.

Daust, David K., and John D. Nelson, “Spatial Reduction Factors for Strata-Based Harvest Schedules,” *Forest Science*, 39 (1993): 152-165.

Faw, Wade F., *1998 Sugarcane Harvesting Schedule*, Sugarcane Circular Letter No. 11-98, Louisiana Cooperative Extension Service, Louisiana State University Agricultural Center.

Griffiths, W.E, R.C. Hill and G.G. Judge (1993), *Learning and Practicing Econometrics,* New York: John Wiley & Sons, Inc.

Higgins, A.J., R.C. Muchow, A.V. Rudd, and A.W. Ford, “Optimising Harvest Date in Sugar Production: A Case Study for the Mossman Mill Region in Australia - I. Development of Operations Research Model and Solution,” *Field Crops Research*, 57(1998):153-162.

Lass, L.W., R.H. Callihan, and D.O. Everson, “Forecasting the Harvest Date and Yield of Sweet Corn by Complex Regression Models,” *Journal of the American Society for Horticultural Science*, 118(1993): 450-455.

Malezieux, E., “Predicting Pineapple Harvest Date in Different Environments, Using a Computer Simulation Model,” *Agronomy Journal*, 86(1994): 609-617.

Millhollon, R.W., and B.L. Legendre, “Sugarcane Yield as Affected by Annual Glyphosate Ripener Treatments,” *American Society of Sugar Cane Technologists Journal*, 16 (1996): 7-12.

Muchow, R.C., A.J. Higgins, A.V. Rudd, and A.W. Ford, “Optimising Harvest Date in Sugar Production: A Case Study for the Mossman Mill Region in Australia - I. Sensitivity to Crop Age and Crop Class Distribution,” *Field Crops Research*, 57(1998):243-251.

Nelson, John, J. Douglas Brodie, and John Sessions, “Integrating Short-Term, Area-Based Logging Plans with Long-Term Harvest Schedules,” *Forest Science*, 37 (1991): 101-122.

Salassi, M.E., and S.B. Milligan, “Economic Analysis of Sugarcane Variety Selection, Crop Yield Patterns, and Ratoon Crop Plow Out Decisions,” *Journal of Production Agriculture*, 10(1997):539-545.

Semenzato, R., “A Simulation Study of Sugar Cane Harvesting,” *Agricultural Systems*, 47(1995):427-437.

Van Deusen, Paul C., “Habitat and Harvest Scheduling Using Bayesian Statistical Concepts,” *Canadian Journal of Forest Research*, 26 (1996): 1375-1383.

White, H., “A Heteroskedasticity-Consistent Covariance Matrix Estimator and a Direct Test of Heteroskedasticity,” *Econometrica*, 48(1980):817-838.

Wolf, S., “Predicting Harvesting Date of Processing Tomatoes by a Simulation Model,” *Journal of the American Society for Horticultural Science*, 111(1986): 11-16.

TABLES

Table 1. **Parameter Estimates for Stalk Weight Prediction Models**

	Sugarcane Varieties									
VAR	LCP 82-89	LHo 83-153	CP 79-318	CP 70-321	CP 65-357	CP 72-370	CP 74-383	LCP 85-384	LCP 85-454	HoCP 85-845
INT	-7.717** (-5.10)	-6.747** (-4.68)	-8.868** (-6.51)	-6.672** (-6.92)	-6.884** (-6.92)	-5.550** (-6.34)	-6.718** (-4.60)	-9.192** (-3.53)	-13.976** (-5.07)	-9.419** (-3.85)
LNJD	1.805** (6.81)	1.621** (6.41)	2.040** (8.57)	1.652** (9.82)	1.718** (9.89)	1.441** (9.40)	1.608** (6.31)	1.988** (4.35)	2.985** (6.16)	2.075** (4.83)
CROP	-0.373** (-7.46)	-0.312** (-6.56)	-0.295** (-6.50)	-0.330** (-10.27)	-0.352** (-10.53)	-0.389** (-13.44)	-0.192** (-4.00)	-0.158* (-1.88)	-0.296** (-3.30)	-0.202** (-2.57)
1981	- -	- -	- -	0.190** (2.56)	0.097 (1.32)	0.107 (1.47)	- -	- -	- -	- -
1982	- -	- -	- -	0.091 (1.19)	-0.294** (-3.85)	0.013 (0.17)	- -	- -	- -	- -
1983	- -	- -	- -	-0.154** (-2.02)	-0.372** (-4.86)	-0.109 (-1.46)	-0.052 (-0.56)	- -	- -	- -
1984	- -	- -	- -	-0.233** (-3.13)	-0.474** (-6.39)	-0.090 (-1.22)	0.020 (0.22)	- -	- -	- -
1985	- -	- -	- -	-0.215** (-2.90)	-0.610** (-8.27)	-0.152** (-2.09)	-0.108 (-1.20)	- -	- -	- -

1986	-	-	-	-0.227**	-0.397**	-0.144*	-0.081	-	-	-
	-	-	-	(-3.06)	(-5.37)	(-1.98)	(-0.90)	-	-	-
1987	-	-	-0.347**	-0.483**	-0.509**	-0.392**	-0.278**	-	-	-
	-	-	(-3.53)	(-5.80)	(-6.07)	(-4.88)	(-2.68)	-	-	-
1988	-	-	-0.055	0.001	-0.181**	-0.138*	0.088	-	-	-
	-	-	(-0.64)	(0.01)	(-2.46)	(-1.89)	(0.98)	-	-	-
1989	-	-	-0.101	0.092	-0.037	0.016	0.181*	-	-	-
	-	-	(-1.13)	(1.20)	(-0.48)	(0.21)	(1.94)	-	-	-
1990	0.214**	-	0.187**	0.259**	0.034	0.212**	-	-	-	-
	(2.55)	-	(2.15)	(3.50)	(0.41)	(2.91)	-	-	-	-
1991	-0.862**	-0.813**	-0.637**	-0.981**	-0.985**	-0.805**	-	-	-	-
	(-9.99)	(-10.65)	(-7.11)	(-12.79)	(-12.87)	(-10.77)	-	-	-	-
1992	-0.459**	-0.372**	-0.317**	-0.483**	-0.572**	-0.364**	-0.329**	-	-	-
	(-5.47)	(-5.02)	(-3.64)	(-6.52)	(-7.75)	(-5.00)	(-3.65)	-	-	-
1993	-0.374**	-0.400**	-0.375**	-0.280**	-0.359**	-0.293**	-0.312**	-	-	-
	(-4.46)	(-5.40)	(-4.31)	(-3.77)	(-4.87)	(-4.03)	(-3.46)	-	-	-
1994	-0.009	-0.160**	-0.025	-0.098	-0.287**	-0.109	-0.146	-0.061	-0.027	-0.090
	(-0.11)	(-2.15)	(-0.29)	(-1.32)	(-3.89)	(-1.49)	(-1.63)	(-0.62)	(-0.26)	(-0.97)
1995	-0.161*	-0.130*	-0.081	-0.000	-0.222**	-0.116	-	0.061	-0.093	-0.033
	(-1.92)	(-1.75)	(-0.93)	(-0.01)	(-3.01)	(-1.59)	-	(0.62)	(-0.89)	(-0.36)
Adj. R^2	0.81	0.79	0.73	0.80	0.78	0.80	0.49	0.36	0.59	0.44
n	72	62	98	158	158	153	118	36	33	36
DW	1.77	2.03	1.89	1.94	2.25	1.84	1.55	2.42	1.87	2.18
White prob.	0.340.89	0.74	0.41	0.34	0.87	0.87	0.36	0.93	0.75	

Notes: Number in parenthesis are *t*-values. Single and double asterisks (*) denote statistical significance at the 10% and 5% level, respectively, *n* is the sample size, *DW* is the Durbin-Watson statistic, and *White prob.* is the probability level of the White test for heteroscedasticity.

Table 2. **Parameter Estimates for Sugar per Stalk Prediction Models**

	Sugarcane Varieties									
VAR	**LCP 82-89**	**LHo 83-153**	**CP 79-318**	**CP 70-321**	**CP 65-357**	**CP 72-370**	**CP 74-383**	**LCP 85-384**	**LCP 85-454**	**HoCP 85-845**
INT	-3.511** (-18.62)	-3.296** (-14.40)	-4.064** (-24.19)	-3.470** (-25.99)	-3.932** (-29.80)	-2.442** (-19.95)	-3.05** (-16.89)	-4.081** (-15.74)	-4.50** (-13.68)	-3.273** (-12.30)
LNJD	0.664** (20.08)	0.626** (15.58)	0.764** (26.05)	0.663** (28.49)	0.741** (32.17)	0.486** (22.68)	0.576** (18.27)	0.757** (16.64)	0.849** (14.70)	0.623** (13.35)
CROP	-0.024** (-3.86)	-0.014* (-1.86)	-0.017** (-2.96)	-0.029** (-6.54)	-0.027** (-6.11)	-0.041** (-10.07)	-0.005 (-0.85)	0.004 (0.43)	0.006 (0.59)	-0.006 (-0.67)
1981	- -	- -	- -	0.018* (1.77)	0.027** (2.71)	0.010 (0.96)	- -	- -	- -	- -
1982	- -	- -	- -	-0.011 (-1.00)	-0.037** (-3.60)	-0.009 (-0.86)	- -	- -	- -	- -
1983	- -	- -	- -	-0.028** (-2.62)	-0.022** (-2.17)	-0.035** (-3.37)	-0.005 (-0.43)	- -	- -	- -
1984	- -	- -	- -	-0.041** (-3.93)	-0.042** (-4.31)	-0.021** (-2.04)	0.012 (1.10)	- -	- -	- -
1985	- -	- -	- -	-0.037** (-3.65)	-0.052** (-5.29)	-0.034** (-3.35)	-0.012 (-1.07)	- -	- -	- -
1986	- -	- -	- -	-0.032** (-3.09)	-0.003 (-0.32)	-0.022** (2.15)	0.006 (0.50)	- -	- -	- -

1987	- -	- -	-0.005 (-0.44)	-0.033** (-2.87)	-0.008 (-0.68)	-0.038** (-3.40)	0.011 (0.88)	- -	- -	- -
1988	- -	- -	-0.004 (-0.35)	-0.006 (-0.56)	-0.004 (-0.44)	-0.022** (-2.20)	0.032** (2.87)	- -	- -	- -
1989	- -	- -	0.001 (0.12)	0.003 (0.26)	0.028** (2.81)	-0.014 (-1.34)	0.035** (3.07)	- -	- -	- -
1990	0.011 (1.06)	- -	0.005 (0.46)	0.006 (0.58)	0.009 (0.80)	0.003 (0.33)	- -	- -	- -	- -
1991	-0.097** (-9.02)	-0.113** (-9.36)	-0.070** (-6.32)	-0.147** (-13.85)	-0.079** (-7.76)	-0.108** (-10.34)	- -	- -	- -	- -
1992	-0.034** (-3.27)	-0.044** (-3.74)	-0.017 (-1.58)	-0.047** (-4.54)	-0.014 (-1.43)	-0.047** (-4.58)	-0.013 (-1.13)	- -	- -	- -
1993	-0.047** (-4.54)	-0.064** (-5.42)	-0.039** (-3.68)	-0.049** (-4.79)	-0.012 (1.20)	-0.033** (-3.29)	-0.033** (-2.96)	- -	- -	- -
1994	0.004 (0.35)	-0.020 (-1.66)	0.012 (1.11)	-0.021** (-2.05)	-0.008 (-0.78)	-0.011 (-1.04)	-0.006 (-0.52)	-0.008 (-0.84)	-0.001 (-0.09)	-0.019* (-1.83)
1995	-0.019* (-1.79)	-0.017 (-1.43)	-0.008 (-0.76)	0.005 (0.49)	-0.015 (1.50)	-0.014 (-1.41)	- -	-0.005 (-0.46)	-0.007 (-0.53)	-0.017 (-1.70)
Adj. R^2	0.89	0.86	0.90	0.89	0.89	0.86	0.78	0.89	0.87	0.83
n	72	62	98	158	158	153	118	36	33	36
DW	2.01	2.44	2.13	1.99	2.23	1.88	1.76	2.74	1.49	2.31
White prob. 0.37	0.39	0.86	0.20	0.82	0.74	0.88	0.14	0.56	0.39	

Notes: Number in parenthesis are *t*-values. Single and double asterisks (*) denote statistical significance at the 10% and 5% level, respectively, *n* is the sample size, *DW* is the Durbin-Watson statistic, and *White prob.* is the probability level of the White test for heteroscedasticity.

Table 3. Sample Farm Acreage and Production Characteristics

Farm data:

Farm size (harvestable acreage)	556.9
Number of fields	112
Smallest field (acres)	0.3
Largest field (acres)	19.6

Variety data:

LCP 82-89	plantcane	1 field	1.3 acres
LCP 82-89	stubble crop	13 fields	44.0 acres
LHo 83-153	plantcane	2 fields	6.7 acres
LHo 83-153	stubble crop	6 fields	31.8 acres
CP 79-318	stubble crop	4 fields	14.2 acres
CP 70-321	plantcane	12 fields	74.2 acres
CP 70-321	stubble crop	43 fields	228.9 acres
CP 65-357	stubble crop	7 fields	38.0 acres
CP 72-370	plantcane	3 fields	13.6 acres
CP 72-370	stubble crop	14 fields	61.7 acres
LCP 85-384	plantcane	5 fields	37.3 acres
LCP 85-384	stubble crop	2 fields	5.2 acres

Table 4. **Linear Programming Tableau for Sugarcane Harvesting Problem.**

	Field 1					Field 2					. . .	Field m										
	Days					Days						Days					TOTAL					RHS
	1	**2**	**3**	**. . .**	**n**	**1**	**2**	**3**	**. . .**	**n**	**. . .**	**1**	**2**	**3**	**. . .**	**n**	**SUG**	**MOL**	**SUG**	**CANE**	**MOL**	
MAX																			P_s	$-C_h$	P_m	
PRO-SUG																	a		-1			= 0
PRO-MOL																		b			-1	= 0
TOT-SUG	S	S	S	. . .	S	S	S	S	. . .	S	. . .	S	S	S	. . .	S	-1					= 0
TOT-TON	T	T	T	. . .	T	T	T	T	. . .	T	. . .	T	T	T	. . .	T				-1		= 0
TOT-MOL																	0.029	-1				= 0
Field 1	X	X	X	. . .	X																	= 1

Field 2		X X X . . . X				=1
Field *m*			. . .	X X X . . . X		=1
Day 1	T	T		T		<=Q
2	T	T		T		<=Q
3	T	T	. . .	T		<=Q
.	.	.		.		.
.	.	.		.		.
.	.	.		.		.
n	T	T		T		<=Q

Table 5. Comparison of actual harvest schedule with optimal harvest schedules

Solution Summary	Actual harvest schedule[1]	Constrained optimal harvest schedule	Unconstrained optimal harvest schedule
Returns above harvest costs[2]	$326,771	$344,131	$378,147
Returns above harvest costs per acre	$587	$618	$679
Total sugar (pounds)	3,103,709	3,250,056	3,527,466
Total cane (tons)	16,964	17,373	17,927
Total molasses (gallons)	90,008	94,252	102,297
Acres	556.9	556.9	556.9
Average CRS (pounds sugar/ton)	183.0	187.1	196.8
Sugar per acre (pounds)	5,573	5,836	6,334
Cane per acre (tons)	30.5	31.2	32.2

[1] This schedule includes the producer's actual harvest schedule with total sugar and cane production estimated from prediction models. Producer records report actual production of 16,639 tons of sugarcane and 2,961,500 pounds of sugar.

[2] Returns above harvest costs is calculated as the producer's share of gross income (after mill and landlord charges have been deducted) less harvesting costs and represents returns available to cover costs of planting, cultivation, and other production expenses.

Table 6. Harvest day changes under constrained optimal harvest schedule

	Change in harvest day from actual harvest day					
	More than 15 days earlier	6 to 15 days earlier	5 days earlier to 5 days later	6 to 15 days later	More than 15 days later	Total fields
LCP 82-89 - plantcane	-	-	-	-	1	1
LCP 82-89 - first stubble	2	-	2	1	1	6
LCP 82-89 - second stubble and older	-	3	3	1	-	7
LHo 83-153 - plantcane	-	-	-	1	1	2
LHo 83-153 - first stubble	1	1	-	1	1	4
LHo 83-153 - second stubble and older	-	-	1	1	-	2
CP 79-318 - first stubble	-	-	-	2	-	2
CP 79-318 - second stubble and older	-	-	-	1	1	2
CP 70-321 - plantcane	-	1	6	4	1	12

CP 70-321 - first stubble	1	2	6	2	3	14
CP 70-321 - second stubble and older	6	8	12	1	2	29
CP 65-357 - first stubble	-	-	1	1	2	4
CP 65-357 - second stubble and older	-	-	-	2	1	3
CP 72-370 - plantcane	-	-	-	-	3	3
CP 72-370 - first stubble	-	1	1	-	5	7
CP 72-370 - second stubble and older	1	2	4	-	-	7
LCP 85-384 - plantcane	-	-	-	-	5	5
LCP 85-384 - first stubble	-	-	2	-	-	2
Total fields	**11**	**18**	**38**	**18**	**27**	**112**

Appendix table 1. Actual and optimal harvest dates by field.

				Actual Harvest Date			Optimal Harvest Date			
Field Number	Variety	Acres	Crop Age	Julian Date	Came (tons)	Sugar (lbs)	Julian Date	Percent Harvested	Cane (tons)	Sugar (lbs)
1	321	3.6	ST	282	85.8	12,028	288	100.0	93.5	14,287
2	370	3.3	ST	282	81.4	15,466	280	31.2	26.4	4,149
							281	68.8	57.2	9,220
3	321	1.0	ST	283	18.7	2,854	288	100.0	20.9	3,108
4	370	2.0	ST	283	49.5	8,746	281	100.0	47.3	7,619
5	89	2.5	ST	283	70.4	7,924	295	100.0	74.8	11,652
6	321	5.3	ST	283	143.0	20,089	284	62.0	95.7	13,805
							285	38.0	59.4	8,577
7	318	3.3	ST	284	47.3	7,284	294	100.0	71.5	11,138
8	321	8.1	ST	284	221.1	37,092	287	100.0	206.8	31,141
9	357	7.1	ST	284	165.0	26,065	302	100.0	188.1	32,093
10	318	4.9	ST	285	108.9	18,023	319	100.0	136.4	24,858
11	370	4.4	ST	285	127.6	24,426	281	100.0	119.9	19,333
12	370	6.6	ST	285	103.4	19,317	279	55.0	95.7	14,895
							280	45.0	78.1	12,316
13	370	6.8	ST	285	92.4	16,032	280	100.0	155.1	24,414
14	321	5.2	ST	286	106.7	16,136	285	100.0	129.8	18,837
15	321	4.5	ST	286	81.4	12,837	285	100.0	92.4	13,503
16	321	3.1	ST	286	73.7	13,190	316	100.0	93.5	16,990
17	321	1.9	ST	286	39.6	5,429	284	100.0	51.7	7,512

18	370	5.0	ST	286	91.3	15,814	279	100.0	110.0	17,232
19	321	8.9	ST	287	262.9	42,147	287	0.9	2.2	318
							293	94.7	220.0	34,925
							294	4.4	9.9	1,629
20	321	2.5	ST	288	50.6	6,053	284	100.0	40.7	5,850
21	357	2.5	ST	288	68.2	10,611	301	100.0	74.8	12,540
22	357	7.2	ST	288	188.1	31,650	301	60.0	129.8	21,729
							302	40.0	86.9	14,604
23	321	2.5	ST	292	56.1	9,632	292	100.0	61.6	9,753
24	153	11.3	ST	292	300.3	56,078	305	100.0	331.1	55,677
25	89	1.0	ST	292	16.5	3,023	287	100.0	19.8	2,780
26	370	4.5	ST	293	138.6	22,390	313	51.8	73.7	13,746
							314	48.2	68.2	12,876
27	321	9.4	ST	293	242.0	39,940	292	100.0	247.5	38,908
28	321	6.6	ST	293	182.6	28,536	281	65.1	125.4	17,591
							285	34.9	68.2	9,935
29	370	4.4	ST	294	128.7	20,502	314	100.0	129.8	24,401
30	370	3.3	ST	294	92.4	16,748	315	100.0	91.3	17,302
31	370	5.8	ST	294	130.9	21,505	314	88.9	151.8	28,434
							315	11.1	18.7	3,560
32	321	7.6	ST	295	172.7	26,637	295	100.0	171.6	27,183
33	370	7.0	ST	295	225.5	36,350	315	57.4	116.6	21,775
							316	42.6	86.9	16,286
34	89	2.0	ST	296	70.4	8,823	295	100.0	66.0	10,234
35	89	3.8	ST	298	136.4	21,387	301	100.0	130.9	20,939

Appendix table 1. Actual and optimal harvest dates by field.

				Actual Harvest Date			Optimal Harvest Date			
Field Number	Variety	Acres	Crop Age	Julian Date	Came (tons)	Sugar (lbs)	Julian Date	Percent Harvested	Cane (tons)	Sugar (lbs)
36	321	5.7	ST	298	152.9	24,032	284	100.0	144.1	20,822
37	321	5.7	ST	298	199.1	28,717	284	11.0	16.5	2,395
							286	89.0	135.3	19,856
38	321	19.6	ST	301	757.9	121,474	298	58.1	349.8	56,684
							299	41.9	254.1	41,370
39	321	2.5	ST	302	95.7	15,718	300	100.0	77.0	12,704
40	321	6.5	ST	302	191.4	30,550	294	28.2	56.1	8,877
							295	6.6	13.2	2,085
							299	1.5	3.3	507
							300	63.7	129.8	21,331
41	321	2.9	ST	303	73.7	13,742	293	100.0	89.1	14,200
42	321	2.5	ST	303	86.9	13,183	286	38.5	31.9	4,583
							287	61.5	50.6	7,420
43	321	2.9	ST	303	105.6	16,058	354	100.0	94.6	20,046
44	321	1.4	ST	303	16.5	2,465	293	100.0	26.4	4,126
45	153	3.1	ST	303	80.3	13,170	302	80.5	75.9	12,394
							305	19.5	18.7	3,103
46	89	0.7	ST	303	17.6	3,063	295	100.0	24.2	3,757
47	321	8.6	ST	305	200.2	36,499	288	99.9	235.4	35,799
							294	0.1	0.0	24
48	321	6.3	ST	305	129.8	25,462	355	100.0	196.9	42,928

49	321	7.0	ST	306	123.2	25,025	291	92.9	180.4	28,133
							293	7.1	14.3	2,187
50	321	8.6	ST	307	149.6	30,501	292	16.1	40.7	6,337
							294	83.9	211.2	33,774
51	321	6.3	ST	308	178.2	37,347	291	100.0	169.4	26,420
52	321	2.7	ST	308	77.0	11,001	287	100.0	70.4	10,255
53	370	3.3	ST	308	102.3	16,966	280	100.0	91.3	14,143
54	321	7.9	ST	309	209.0	34,639	286	100.0	182.6	26,297
55	370	4.0	PC	310	118.8	22,639	341	2.5	3.3	644
							342	97.5	122.1	25,301
56	370	5.9	PC	311	202.4	37,594	341	100.0	190.3	39,754
57	89	4.0	ST	312	129.8	21,631	300	88.9	108.9	17,252
							301	11.1	13.2	2,170
58	321	3.2	ST	312	127.6	19,803	299	100.0	93.5	15,227
59	89	1.0	ST	312	41.8	7,378	300	100.0	34.1	5,437
60	318	3.0	ST	313	116.6	18,330	322	100.0	97.9	17,895
61	318	3.0	ST	313	116.6	19,090	321	96.3	102.3	18,572
							322	3.7	4.4	724
62	321	10.2	ST	315	332.2	58,918	322	53.6	172.7	32,416
							327	30.3	99.0	19,059
							328	16.1	52.8	10,165
63	384	2.2	ST	315	122.1	25,005	316	34.7	50.6	9,377
							319	65.3	95.7	18,096

Appendix table 1. Actual and optimal harvest dates by field.

				Actual Harvest Date			Optimal Harvest Date			
Field Number	Variety	Acres	Crop Age	Julian Date	Came (tons)	Sugar (lbs)	Julian Date	Percent Harvested(tons)	Cane (lbs)	Sugar
64	89	11.2	ST	316	365.2	67,843	322	9.8	37.4	6,861
							323	90.2	349.8	63,967
65	370	1.3	ST	316	48.4	7,974	316	100.0	38.5	7,131
66	357	5.3	ST	317	159.5	26,677	328	100.0	167.2	32,417
67	370	3.7	PC	319	85.8	17,411	341	100.0	100.1	20,900
68	153	7.7	ST	319	176.0	36,190	329	100.0	206.8	40,067
69	384	12.4	PC	320	427.9	94,095	361	26.4	133.1	32,522
							363	12.2	61.6	15,185
							364	61.4	311.3	77,064
70	321	3.9	ST	322	123.2	21,410	320	100.0	121.0	22,686
71	321	4.1	ST	322	130.9	26,385	326	100.0	134.2	25,781
72	321	7.4	ST	322	245.3	50,400	322	15.1	37.4	7,123
							326	84.9	215.6	41,356
73	321	3.2	ST	323	126.5	20,390	327	100.0	91.3	17,584
74	357	4.8	ST	324	166.1	33,829	357	100.0	155.1	34,624
75	321	3.7	ST	324	151.8	28,601	356	100.0	130.9	28,405
76	89	1.6	ST	324	59.4	10,167	354	100.0	53.9	11,209
77	357	10.4	ST	326	284.9	59,581	357	5.6	19.8	4,465
							365	94.4	342.1	78,370
78	370	4.0	ST	327	184.8	30,750	315	100.0	123.2	22,946

79	321	2.8	ST	328	92.4	16,420	316	100.0	80.3	14,434
80	357	0.7	ST	328	29.7	4,587	328	100.0	24.2	4,691
81	384	8.0	PC	329	269.5	57,862	362	6.7	20.9	5,105
							363	93.3	288.2	71,135
82	384	8.2	PC	330	284.9	56,456	362	100.0	295.9	72,569
83	384	7.8	PC	331	327.8	62,724	358	39.0	138.6	32,220
							361	61.0	216.7	51,235
84	321	4.0	PC	333	156.2	29,945	351	100.0	150.7	30,941
85	153	1.2	PC	333	48.4	9,156	358	100.0	47.3	9,875
86	321	6.2	PC	334	205.7	39,466	342	37.7	80.3	15,839
							343	62.3	133.1	26,350
87	384	0.9	PC	334	36.3	8,049	362	100.0	34.1	8,314
88	321	5.0	ST	335	138.6	30,596	327	100.0	159.5	30,823
89	153	2.0	ST	335	51.7	7,987	329	100.0	48.4	9,328
90	321	6.0	PC	336	240.9	42,607	350	38.8	82.5	16,755
							351	61.2	129.8	26,529
91	89	1.3	PC	336	35.2	7,682	364	100.0	38.5	9,407
92	321	3.6	PC	336	124.3	20,419	348	82.3	96.8	19,537
							350	17.7	20.9	4,251
93	321	9.2	ST	338	413.6	81,973	355	6.2	22.0	4,791
							356	53.0	191.4	41,434
							357	40.8	147.4	32,102
94	321	6.0	PC	340	180.4	42,498	344	97.7	211.2	42,403
							348	0.3	4.4	1,008
95	321	4.4	PC	340	147.4	28,011	344	100.0	138.6	27,952

Appendix table 1. Actual and optimal harvest dates by field.

				Actual Harvest Date			Optimal Harvest Date			
Field Number	Variety	Acres	Crop Age	Julian Date	Came (tons)	Sugar (lbs)	Julian Date	Percent Harvested	Cane (tons)	Sugar (lbs)
96	321	3.8	PC	340	112.2	22,155	347	100.0	128.7	26,133
97	89	8.6	ST	342	290.4	54,425	320	67.1	198.0	36,104
							321	32.9	97.9	17,876
98	321	2.8	PC	343	85.8	18,873	347	100.0	97.9	19,980
99	321	3.6	ST	343	116.6	24,868	355	100.0	117.7	25,734
100	153	0.3	ST	343	9.9	1,857	365	100.0	7.7	1,696
101	321	4.6	PC	343	138.6	27,693	342	100.0	147.4	29,484
102	153	7.4	ST	344	190.3	40,098	328	53.0	105.6	20,360
							329	47.0	94.6	18,234
103	321	10.7	PC	348	413.6	90,164	347	33.2	123.2	25,092
							348	66.8	248.6	50,749
104	153	5.5	PC	348	174.9	34,230	357	14.2	27.5	5,625
							358	85.8	163.9	34,236
105	321	4.6	ST	349	155.1	32,727	319	79.0	117.7	21,988
							320	21.0	30.8	5,879
106	89	4.6	ST	349	165.0	33,507	321	100.0	149.6	27,481
107	321	11.7	PC	351	433.4	82,210	349	82.0	349.8	71,072
							350	18.0	77.0	15,702
108	321	10.4	PC	352	376.2	80,412	343	56.4	216.7	43,012
							350	43.6	169.4	34,642

109	384	3.0	ST	353	207.9	39,858	351	38.0	69.3	14,246
							354	62.0	113.3	23,598
110	89	0.4	ST	353	12.1	2,657	355	100.0	12.1	2,608
111	89	2.6	ST	354	100.1	21,829	354	99.3	88.0	18,291
							355	0.6	1.1	126
112	321	0.7	ST	354	35.2	7,247	356	100.0	28.6	6,113
Total Acres		**556.9**			**16,964**	**3,103,709**			**17,373**	**3,250,056**

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Entire bulletin to be printed in one color ink - pms#732