

## **MAXIMIZING ECONOMIC RETURNS FROM SUGARCANE PRODUCTION THROUGH OPTIMAL HARVEST SCHEDULING**

**Michael E. Salassi**

Department of Agricultural Economics and Agribusiness  
Louisiana Agricultural Experiment Station  
LSU Agricultural Center, Baton Rouge, LA 70803

**Lonnie P. Champagne**

Louisiana Sugar Cane Products Inc.  
Baldwin, LA 70514

**Benjamin L. Legendre**

Division of Plant Science  
Louisiana Cooperative Extension Service  
LSU Agricultural Center, Baton Rouge, LA 70803

### **ABSTRACT**

The long-term viability of the sugar industry depends upon finding ways to produce sugar more economically through production management decisions which can reduce production costs or increase returns. Harvest scheduling is one such practice which has a direct impact on net farm returns. Sugarcane cultivars have distinct sucrose maturation curves, which may vary up or down from year to year depending upon weather and other factors. A study was conducted on a commercial sugarcane farm to predict sugar per acre across the harvest season and to develop a programming model which could determine the order of harvest of fields on the farm which would maximize total sugar produced and net returns above harvest costs. Optimal adjustment of harvest of individual fields resulted in increased sugar yield per acre and total farm net returns.

### **INTRODUCTION**

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

During the harvest season, second stubble and older stubble fields are usually harvested first, followed by more recently planted fields, first stubble and then plantcane. Within this general order of crop harvest, producers attempt to 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. 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, which would maximize total sugar produced (or total net returns received) on the farm.

Applications of crop harvest scheduling models utilizing some type of operations research procedure are most common in the timber industry. Most of these applications involve the use of either linear programming or simulation models. Recent studies have investigated the use of Monte Carlo integer programming (Nelson et al., 1991; Daust and Nelson, 1993), bayesian concepts (Van Deusen, 1996), and tabu search procedures (Brumelle et al., 1998). Several studies have developed crop growth models to predict the harvest date of agricultural crops (Lass et al., 1993; Malezieux, 1994; Wolf, 1986). However, most of these studies utilize 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. Two studies have evaluated the economics of sugarcane stubble crop replacement in Florida (Crane et al., 1982) and Louisiana (Salassi and Milligan, 1997). 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 (1995) 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 of time. This study focused on farm size and equipment availability in order to efficiently utilize limited resources in a timely manner. A recent study in Australia did determine optimal sugarcane harvest schedules which maximized net returns using mathematical programming procedures (Higgins et al., 1998; Muchow et al, 1998). However, the modeling framework in this study 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.

The purpose of this study was to develop 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 utilize this information, within a mathematical program modeling framework, in determining when specific sugarcane fields should be harvested in order to maximize total farm net returns. Data for this analysis 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 currently produced commercially in the state. These data were then incorporated into a mathematical programming model which determined an optimal harvest schedule which 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 through adjustment of the actual harvest schedule.

## MATERIALS AND METHODS

### 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 which influence it can be stated simply as follows:

$$(1) \quad S_A = \text{TRS} \times \text{TONS} = \text{TRS} \times \text{POP} \times \text{STWT}$$

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. In order 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 to 16 years, depending upon variety. The harvest season for sugarcane in Louisiana has historically run from the first of October through the end of December. Observations for each commercial cultivar ranged from julian date 255 to 346 or approximately the middle of September through the middle of December. The age of the crop (plantcane or stubble) was also included.

Models were estimated for stalk weight and sugar per stalk in order to predict the amount of sugarcane and raw sugar in the field for each day of the harvest season. Previous research suggests that a quadratic model can be used to model sugar accumulation (Crane et al., 1982). Graphical analysis of both the stalk weight as well as the sugar per stalk data suggested that 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:

$$(2) \quad \text{STWT}_{\alpha} = \beta_0 + \beta_1 \text{LNJD} + \beta_2 \text{CROP} + \sum_{i=81}^{95} \beta_i \text{YEAR}_i + \epsilon$$

$$(3) \quad \text{SPS}_{ct} = \alpha_0 + \alpha_1 \text{LNJD} + \alpha_2 \text{CROP} + \sum_{i=81}^{95} \alpha_i \text{YEAR}_i + \epsilon$$

where  $\text{STWT}_{ct}$  represents stalk weight in pounds per stalk of cultivar  $c$  on day  $t$ ,  $\text{SPS}_{ct}$  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  $\text{YEAR}_i$  represents discrete indicator variables for different years. Only two categories of the indicator variable CROP were included in the model as 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 than plant cane 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 upon weather and other factors. The base year for comparison in this estimation was 1996 and the indicator variables served the purpose of adjusting 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 cane 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 greater 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, which implies that the stalk weight growth curves vary from year to year depending upon 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 and crop age was found to be significant in six of the seven 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 0.86 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 serially correlated. The White test for heteroskedasticity (White, 1980) failed to reject the hypothesis of homoskedasticity for each cultivar tested, indicating that error terms from the model predictions have a constant variance. The absence of autocorrelation and heteroskedasticity indicated that the estimated parameters in the prediction models were efficient (minimum variance) estimators.

### Farm Level Production Estimates

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 of the fields on the

farm. The number of samples taken per field depended upon the size of the field, but a target of one count was taken for every one and half acres. In a randomly selected area of the field, a twenty-five foot distance was measured between the middle of two rows. Then, the number of millable stalks within that distance was counted and then 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. Each stalk sample was weighed and milled to obtain a juice sample for analysis. 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. This adjustment was incorporated into each prediction model as a parallel shift in the intercept. 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:

$$(4) \quad \text{CANE}_{ft} = \text{POP}_f \times \text{STWT}_{ct} / 2000$$

$$(5) \quad \text{SUGAR}_{ft} = \text{POP}_f \times \text{SPS}_{ct}$$

where  $\text{CANE}_{ft}$  is the estimated tons of sugarcane per acre in field  $f$  on julian date  $t$ ,  $\text{POP}_f$  is the estimated stalk population per acre in field  $f$ ,  $\text{STWT}_{ct}$  is the estimated stalk weight in pounds for cultivar  $c$  on julian date  $t$ ,  $\text{SUGAR}_{ft}$  is the estimated pounds of raw sugar per acre in field  $f$  on julian date  $t$ , and  $\text{SPS}_{ct}$  is the estimated sugar per stalk in pounds for cultivar  $c$  on julian date  $t$ . Estimated yields per field were then adjusted for field conditions (recovery and trash) and differences between theoretical recoverable sugar and commercial recoverable sugar as follows:

$$(6) \quad \text{ADJCANE}_{ft} = \text{CANE}_{ft} \times (1 + \text{TRASH}_f) \times \text{FIELDRECOVERY}_f$$

$$(7) \quad \text{ADJSUGAR}_{ft} = \text{SUGAR}_{ft} \times 0.8345 \times \text{SCALEFACTOR}$$

$\text{ADJCANE}_{ft}$  represents the tons of sugarcane actually harvested from the field and delivered to the mill for processing.  $\text{TRASH}_f$  is a percentage estimate of leaf matter and other trash in the harvested cane, and  $\text{FIELDRECOVERY}_f$  is a percentage estimate 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.  $\text{ADJSUGAR}_{ft}$  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. This standard is used by sugar mills 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 scale 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 of the total tonnage of sugarcane harvested. The objective function for the model was defined as follows:

$$(8) \quad Z = (P_s \times S_p) + (P_m \times M_p) - (C_h \times T_t)$$

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 functional constraints in the model consist of two sets of binding constraints and several transfer rows. The first three functional constraints are transfer rows that accumulate the total pounds of sugar produced, tons of sugarcane harvested, and gallons of molasses recovered, respectively. The first set of binding constraints forces the model to choose each field exactly once during the harvest season. The model can harvest any percentage of a field on any available day. Harvest of individual fields were 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. The second set of binding constraints creates a daily limit on the tons of sugarcane that may be 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. 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 AND DISCUSSION

Two different harvest scenarios were solved by the harvest scheduling model. The solution results for each of these two scenarios are shown in Table 4. 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 obtained. The actual harvest schedule solution in Table 4 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 of sugarcane 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 solution in which harvest dates for individual fields were constrained to specified intervals. In Louisiana, sugarcane harvest begins with fields which contain 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, 1998). Finally, fields containing plantcane which are being harvested for the first time are harvested at the end of the harvest season in order 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 end with harvest of varieties that deteriorate at a slower rate after a freeze (more freeze tolerant). An additional consideration which impacts the harvest schedule is soil type. Extended periods of rain during the harvest season makes 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 were specified for each field in the sample data set which conformed to traditional harvesting practices. Generally stated, these harvest date ranges began with second-stubble harvest beginning on October 1<sup>st</sup> 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 were also 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 approximately \$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 indicated that the optimal harvest date changed an average of 13 days from the actual harvest date with some fields being harvested earlier and other fields harvested later in the season.

One factor which would have an effect on optimal harvest schedule determination to maximize net returns would be related to harvest travel costs. Harvest travel cost, i.e., the cost of moving sugarcane harvesting equipment from one field to another on the farm during the harvest season, would significantly impact net returns above harvest costs for farms on which individual fields are located at considerable distances from one another. Although harvest travel costs were not included in the analysis presented here, they should be considered when comparing alternative harvest schedules with the purpose of maximizing

net returns. The relevant cost measure to consider in this decision analysis would be the change in travel costs among different schedules. For a specific change from one harvest schedule to another, this change in travel cost could be positive or negative. Inclusion of travel costs in the analysis should be considered in a whole farm basis. Whole farm harvest travel costs can be minimized 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.

## CONCLUSIONS

The long- term viability of the sugar industry will depend upon finding ways to produce sugar more economically through reduction of production costs and efficient management of available resources. Maximizing net returns for a whole farm, rather than trying to produce the maximum amount of sugar per field, should be the primary goal of producers. The purpose of this study was to develop a methodology to assist in scheduling the sequence in which sugarcane fields are harvested to maximize producers' economic returns. 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 producer net returns above harvest cost.

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. A producer, or crop consultant, could potentially analyze the yield of each cultivar of sugarcane in the farm's crop mix and make decisions concerning harvest as well as future plantings. Optimization of harvest schedules could potentially recover more sugar from the fields, which directly increases 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.

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

VAR	Sugarcane Varieties						
	LCP 82-89	LHo 83-153	CP 79-318	CP 70-321	CP 65-357	CP 72-370	LCP 85-384
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)	-9.192** (-3.53)
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)	1.988** (4.35)
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)	-0.158* (-1.88)
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)	-
1984	-	-	-	-0.233** (-3.13)	-0.474** (-6.39)	-0.090 (-1.22)	-
1985	-	-	-	-0.215** (-2.90)	-0.610** (-8.27)	-0.152** (-2.09)	-
1986	-	-	-	-0.227** (-3.06)	-0.397** (-5.37)	-0.144* (-1.98)	-
1987	-	-	-0.347** (-3.53)	-0.483** (-5.80)	-0.509** (-6.07)	-0.392** (-4.88)	-
1988	-	-	-0.055 (-0.64)	0.001 (0.01)	-0.181** (-2.46)	-0.138* (-1.89)	-
1989	-	-	-0.101 (-1.13)	0.092 (1.20)	-0.037 (-0.48)	0.016 (0.21)	-
1990	0.214** (2.55)	-	0.187** (2.15)	0.259** (3.50)	0.034 (0.41)	0.212** (2.91)	-
1991	-0.862** (-9.99)	-0.813** (-10.65)	-0.637** (-7.11)	-0.981** (-12.79)	-0.985** (-12.87)	-0.805** (-10.77)	-
1992	-0.459** (-5.47)	-0.372** (-5.02)	-0.317** (-3.64)	-0.483** (-6.52)	-0.572** (-7.75)	-0.364** (-5.00)	-
1993	-0.374** (-4.46)	-0.400** (-5.40)	-0.375** (-4.31)	-0.280** (-3.77)	-0.359** (-4.87)	-0.293** (-4.03)	-
1994	-0.009 (-0.11)	-0.160** (-2.15)	-0.025 (-0.29)	-0.098 (-1.32)	-0.287** (-3.89)	-0.109 (-1.49)	-0.061 (-0.62)
1995	-0.161* (-1.92)	-0.130* (-1.75)	-0.081 (-0.93)	-0.000 (-0.01)	-0.222** (-3.01)	-0.116 (-1.59)	0.061 (0.62)
<i>Adj. R<sup>2</sup></i>	0.81	0.79	0.73	0.80	0.78	0.80	0.36
<i>n</i>	72	62	98	158	158	153	36
<i>DW</i>	1.77	2.03	1.89	1.94	2.25	1.84	2.42
<i>White prb</i>	0.34	0.89	0.74	0.41	0.34	0.87	0.36

*Notes:* Numbers in parentheses are *t*-values. Single and double asterisks (\*) denote statistical significance at the 10% and 5% levels, respectively, *n* is the sample size, *DW* is the Durbin-Watson statistic, and *White prb* is the probability level of the White test for heteroskedasticity.

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

VAR	Sugarcane Varieties						
	LCP 82-89	LHo 83-153	CP 79-318	CP 70-321	CP 65-357	CP 72-370	LCP 85-384
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)	-4.081** (-15.74)
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)	0.757** (16.64)
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)	0.004 (0.43)
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)	-
1984	-	-	-	-0.041** (-3.93)	-0.042** (-4.31)	-0.021** (-2.04)	-
1985	-	-	-	-0.037** (-3.65)	-0.052** (-5.29)	-0.034** (-3.35)	-
1986	-	-	-	-0.032** (-3.09)	-0.003 (-0.32)	-0.022** (2.15)	-
1987	-	-	-0.005 (-0.44)	-0.033** (-2.87)	-0.008 (-0.68)	-0.038** (-3.40)	-
1988	-	-	-0.004 (-0.35)	-0.006 (-0.56)	-0.004 (-0.44)	-0.022** (-2.20)	-
1989	-	-	0.001 (0.12)	0.003 (0.26)	0.028** (2.81)	-0.014 (-1.34)	-
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)	-
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)	-
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)	-0.008 (-0.84)
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)
<i>Adj. R<sup>2</sup></i>	0.89	0.86	0.90	0.89	0.89	0.86	0.89
<i>n</i>	72	62	98	158	158	153	36
<i>DW</i>	2.01	2.44	2.13	1.99	2.23	1.88	2.74
<i>White prb</i>	0.37	0.39	0.86	0.20	0.82	0.74	0.14

*Notes:* Numbers in parentheses are *t*-values. Single and double asterisks (\*) denote statistical significance at the 10% and 5% levels, respectively, *n* is the sample size, *DW* is the Durbin-Watson statistic, and *White prb* is the probability level of the White test for heteroskedasticity.

**Table 3.** Sample Farm Acreage and Production Characteristics

Farm data:			
Farm size (harvested 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.** Comparison of actual harvest schedule with optimal harvest schedules

Solution Summary	Actual harvest schedule <sup>1</sup>	Constrained optimal harvest schedule
Returns above harvest costs	\$326,771	\$344,131
Returns above harvest costs per acre	\$587	\$618
Total sugar (pounds)	3,103,709	3,250,056
Total cane (tons)	16,964	17,373
Total molasses (gallons)	90,008	94,252
Acres	556.9	556.9
Average CRS (pounds sugar/ton)	183.0	187.1
Sugar per acre (pounds)	5,573	5,836
Cane per acre (tons)	30.5	31.2

<sup>1</sup> 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.

