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Sugarcane and sugar yields in Louisiana (1911–2018): Varietal development and mechanization

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Abstract

Louisiana is the second largest producer of sugarcane (*Saccharum officinarum* L.) in the United States. New sugarcane cultivars better adapted for Louisiana have been in development since the inception of a three-way cooperative breeding program in the 1920s. Piecewise regression is used to determine the growth in both Louisiana sugarcane and sugar yields and how new sugarcane cultivars and mechanization have had a positive impact of yields. The analysis uses several breakpoints for periods between 1911 and 2018 to consider the impact of varietal development and mechanization. In most cases, new sugarcane cultivars and changes in mechanization in Louisiana have significantly increased the yield of sugarcane and sugar. From 1911 to 2018, raw sugar yield increased at an annual rate of 0.061 t ha^{-1}, while gross sugarcane yield increased by 0.47 t ha^{-1}. Prior to 1927, yield growth was either negative or highly variable; since 1927, yield growth for both raw sugar and gross sugarcane have been positive and significant.

1 | INTRODUCTION

Louisiana is the second largest sugarcane producer in the United States. The planting history of Louisiana sugarcane can be traced back to 1795 when New Orleans' first mayor, Étienne de Boré, produced the first known granulated sugar in the French colony. Granulated sugar spurred cultivation in Louisiana, and sugarcane became the colony's primary commodity crop. Commercial sugar production in Louisiana increased significantly during the first quarter of the 19th century, expanding from 5,000 t in 1815 to 33,000 t in 1830 (Gayarré, 1887).

Refined white sugar, which is produced from two sources in the United States, is either directly produced from sugarbeet (*Beta vulgaris* L. subsp. *vulgaris*) or is processed into raw sugar before being refined into white sugar from sugarcane (Salassi, Deliberto, & Legendre, 2010). In 2018, 55% of total U.S. sugar production came from sugarbeet and 45% came from sugarcane. In 2018, sugarcane was harvested in Louisiana on 181,501.5 ha of land, with an estimated 171,991 ha harvested for sugar (USDA–NASS, 2019). For the 2018–2019 fiscal year, Louisiana accounted for ~45% of total cane sugar production and 20% of total sugar production in the United States. According to the American Sugarcane League (2019):

> Sugarcane is produced on more than 400,000 acres of land in 22 Louisiana parishes – with production of approximately 13 million tons of cane yearly. About 17,000 employees are involved in the production and processing of sugarcane in Louisiana – and the state boasts 11 raw sugar factories. Suffice it to say that sugarcane production and processing is a major part of Louisiana's economy and a treasured way of life for hundreds of farming families in our state.

As sugar is a major economic crop in Louisiana, efforts are being made in developing new sugarcane cultivars that are more resistant to diseases and exhibit high yields. Cross-breeding enables cultivars to carry new combinations of genetics to increase agricultural performance, with multiple major sugarcane cultivars being developed in Louisiana since the 1950s.

In analyzing the dynamics of sugarcane and sugar yields in Louisiana from 1911 to 2018, we observe a statistically significant increase in both sugarcane and sugar yields over this period. Based on historical changes in the Louisiana sugarcane industry, we examine five scenarios with different combinations of periods. Scenario 1 is an overall summary for period 1911–2018. In Scenario 2, we use 1946 and 1996 as breakpoints based on the three alternative harvest techniques and separate the data into 1911–1945, 1946–1995, and 1996–2018. In Scenario 3, we use 1927, 1946, 1977, and 1996 as breakpoints based on five alternative eras of sugarcane cultivars and separate the data into 1911–1926, 1927–1945, 1946–1976, 1977–1995, and 1996–2018. In Scenario 4, we use 1996 as the breakpoint and separate the data into 1911–1995 and 1996–2018. Finally, given observations of significant changes in the 1920s and 1990s, in Scenario 5, we use 1927 and 1996 as breakpoints for the entire period 1911–2018.

2 | HISTORY OF SUGARCANE RESEARCH IN LOUISIANA

Louisiana sugarcane producers face the unique challenge of producing a tropical crop in a temperate or near-temperate zone. In addition, the industry has faced increased competition from beet sugar and scientific advancements in the post–Civil War era. Given this environment, the Louisiana Sugar Planters Association was established in 1877, with the goal of promoting the Louisiana sugarcane industry through legislation and science (Gravois, 2012a). Shortly thereafter, the Louisiana Sugar Experiment Station was established in 1885 (Gravois, 2012b) and, with the passage of the Hatch Act, evolved into the Louisiana Agricultural Experiment Station in 1887 (LSU AgCenter, 2012). Early research examined fertilization, drainage, and seedling cultivars to determine their impact on sugarcane yield (Gravois, 2012a). The addition of the Audubon Sugar School (now Audubon Sugar Institute) created an infrastructure that provides broad research capacity to benefit the Louisiana sugarcane industry at both the production and manufacturing levels (LSU AgCenter, 2012).

In the 1920s, a three-way research partnership was established involving industry (the American Sugar Cane League), the Louisiana Agricultural Experiment Station, and the USDA (Gravois, 2012a). The USDA established a presence in Louisiana in 1919 and established the USDA Sugarcane Research Laboratory in Houma, LA, in 1923 (Gravois, 2012a). The USDA–ARS Sugarcane Field Station at Canal Point, FL, was established in 1920 to supply true seed for the Louisiana sugarcane industry, with the first agreement to this effect made in 1924 between the USDA and Louisiana State University (LSU) (Stokes & Tysdal, 1962; Comstock et al., 2004).

After the Louisiana sugar industry was devastated by disease (mosaic and red-rot) in the 1920s, new sugarcane cultivars were introduced (Gravois, 2001). Among these, POJ (from Java) and CO (from India) cultivars replaced the previous Noble cultivars that had become increasingly susceptible to mosaic and red-rot. In addition, these POJ and CO cultivars served as the basis for a new breeding program located at the USDA–ARS facilities in Canal Point, FL, and Houma, LA (Gravois & Bischoff, 2001).

The nature of the Louisiana sugarcane industry relative to other sugarcane producing regions accounts for many of the difficulties and recent successes of the Louisiana breeding programs. One obstacle to sugarcane breeding in Louisiana was the lack of flowering because of low fall temperatures (Gravois, 2012a). Using photoperiod induction facilities on the LSU campus, artificial photoperiod schedules were established that allowed sugarcane to flower in Louisiana (Gravois, 2012b). Using this technology, sugarcane crossing was initiated in Baton Rouge, Louisiana in 1954, which decreased the reliance on facilities in Canal Point, Florida and allowed sugarcane crossing to be conducted locally (Gravois, 2012a). In 1982, photoperiod, crossing, and seedling facilities were constructed at the LSU AgCenter St. Gabriel Research Station, which is the only sugarcane research program that relies on photoperiod induction for crossing (Gravois & Bischoff, 2001). This served as the foundation for Louisiana-specific sugarcane research and the eventual establishment of the LSU AgCenter program in St. Gabriel, LA (Bischoff & Gravois, 2004; Todd, Glaz, Burner, & Kimbeng, 2015).

The establishment of an ongoing cooperative sugarcane breeding program has resulted in the development of numerous high-yielding, disease-resistant sugarcane cultivars (Figure 1). During the past 80 y, several sugarcane cultivars have dominated the industry (Figure 2). For example, from the 1940s to the 1970s, CP 36-105, CP 44-101, and CP 52-68 were the dominant cultivars, followed by CP 65-357 and CP 70-321 from the 1970s to the 1990s and LCP 85-384 and its progeny from the mid-1990s to present.

Adoption of LCP 85-384 transformed the Louisiana sugarcane industry. By 2004, LCP 85-384 accounted for 91% of Louisiana sugarcane acreage (Gravois & Bischoff, 2008). LCP 85-384 has since then been replaced by HoCP 96-540 and L 01-299, respectively, as the dominant sugarcane varieties in Louisiana. The USDA–ARS and LSU AgCenter sugarcane research programs are currently developing new cultivars derived from crosses with LCP 85-384 as the parent, with the objective of attaining even greater yields combined

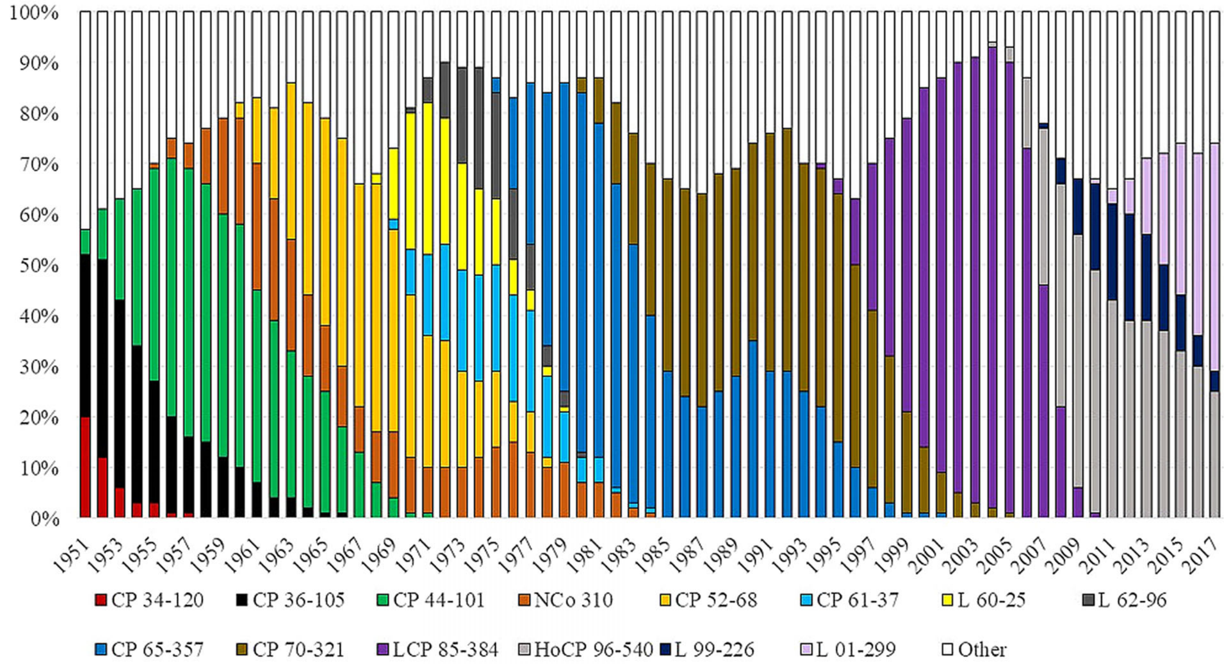

FIGURE 1 Composition of Louisiana sugarcane acreage by variety, 1951–2017 (Source: Sugarcane variety census, The Sugar Bulletin and Sugarcane research annual progress report, LSU AgCenter, Baton Rouge, LA)

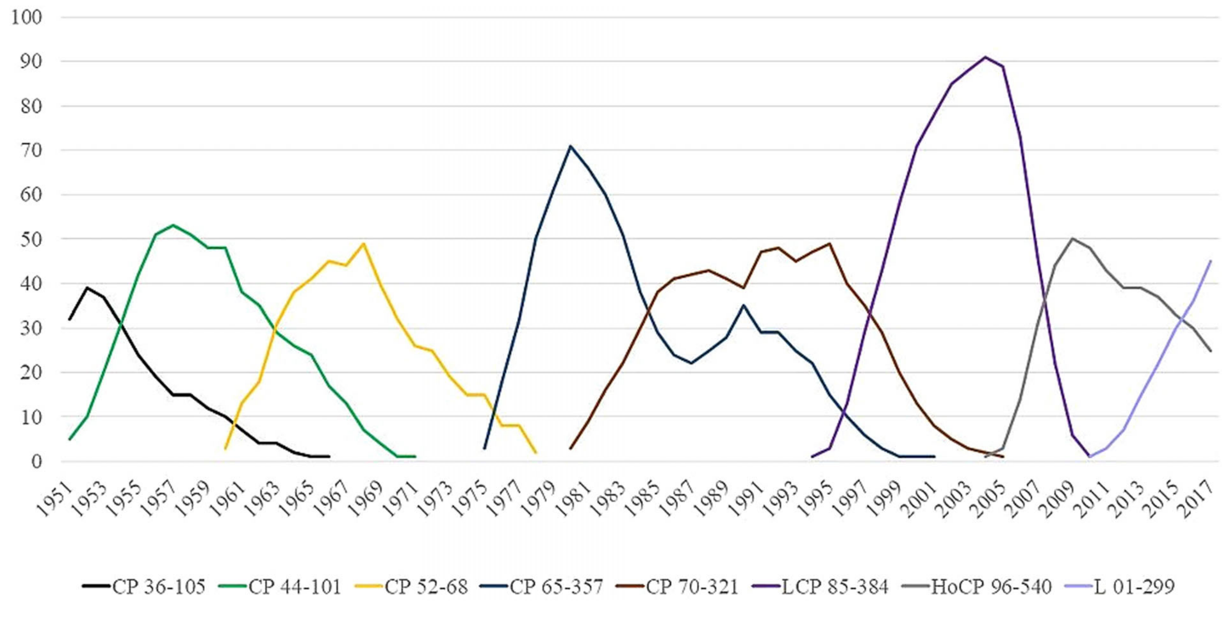

FIGURE 2 Percentage of Louisiana sugarcane acreage by variety, 1951–2017 (Source: Sugarcane variety census, The Sugar Bulletin and Sugarcane research annual progress report, LSU AgCenter, Baton Rouge, LA)

with disease and insect resistance (Gravois, 2018, Gravois & Bischoff, 2001).

While varietal development has contributed to increased yields, it is not the only factor. Other factors include the impact of natural ripening on sucrose yield and advances in harvesting techniques (Burner, Legendre, Boykin, & Duet, 2015). Prior to the 1940s, all Louisiana sugarcane was harvested by hand. Mechanized harvesting of sugarcane did not commence until World War II (Burrows & Shlomowitz, 1992). The first mechanized harvest system was whole-stalk, or soldier, harvesting, which was the predominant method used in Louisiana from 1943 to 1995 (Spillman, 2003). The introduction of the LCP 85-384 cultivar contributed to the transfer from whole-stalk (soldier) to combine harvesting in Louisiana given the cultivar's high tonnage and lodging characteristics (Gravois, 2001; Spillman, 2003).

TABLE 1 Chow test for chosen breakpoints for Louisiana raw sugar and gross cane yields per acre, 1911–2018.[a]

Breakpoint	Raw sugar yield[a]			Gross cane yield		
	t-statistics	df	*P*	*t*-statistics	df	*P*
1945 (Scenario 2)	0.64	81	.53	0.34	81	.71
1995 (Scenario 2)	9.49	69	.00	1.38	69	.26
1926 (Scenario 3)	6.86	31	.00	8.25	31	.00
1945 (Scenario 3)	1.55	46	.22	2.70	46	.08
1976 (Scenario 3)	0.07	46	.93	5.74	46	.01
1995 (scenario 3)	1.15	38	.33	2.73	38	.08
1995 (Scenario 4)	21.61	104	.00	1.14	104	.32
1926 (Scenario 5)	5.40	81	.01	7.57	81	.00
1995 (Scenario 5)	16.56	88	.00	0.90	88	.41

[a] *t*-statistics calculated in the *F*-test always follows distribution $F(k,N_1+N_2-2k)$, and k is the number of parameters in a single regression (2 in this case). We therefore only present the second degree of freedom in the table (N_1+N_2-2k).

Using data from 1911 to 2018, an analysis tested breakpoints to estimate the impact of hybrid cultivars and mechanization on Louisiana sugarcane and sugar yields. Corresponding with the end of the Noble variety era, as a result of mosaic and red-rot, and the adoption and introduction of POJ and CO cultivars in the 1920s, 1927 is chosen as a breakpoint. Given the adoption of whole-cane (soldier) harvesting during World War II and the beginning dominance of CP cultivars produced jointly through Louisiana and USDA research, 1946 is chosen as a breakpoint. With the ensuing importance of CP 65-357 and CP 70-321 cultivars, 1977 is tested as a breakpoint. Finally, given the adoption of LCP 85-384 and mechanized harvesting, we test to determine whether there was a change in yield trends with 1996 as a breakpoint.

3 | METHODS

To evaluate genetic gains for sugarcane and sugar yields, we follow the piecewise linear model used by Schmitz and Zhu (2017):

$$\gamma = \sum_{i=1}^{n} \alpha_i d_i + \sum_{i=1}^{n} \beta_i t d_i + \mu \tag{1}$$

where γ is the cane yield, t is the time variable, d_i is the dummy variable we use to divide the observations into different periods, and n is the number of periods. The variables α_i and β_i denote the constant and the annual sugarcane yield increase rate, respectively, for the ith period, and μ is the error term that follows a normal distribution with $E(\mu) = 0$.

Equation 1 is a piecewise linear regression with (n – 1) breakpoints (we choose n = 1, 2, 3 in this paper) and linear regression analysis within each subperiod. Breakpoints are observations that determine the occurrence of structural breaks within a series of data.

Compared with Edmé, Miller, Blaz, Tai, and Comstock (2005) and Schmitz and Zhu (2017), the data used in this study cover a longer period (1950–2018). We use yields based on Louisiana sugarcane and sugar statistics covering this period provided by the American Sugarcane League (American Sugarcane League, 2019) and the USDA National Agricultural Statistics Service (USDA–NASS, 2019).

Unlike previous studies, we test whether breakpoints are related to sugarcane genetics. We use the Chow test (Chow, 1960) to find breakpoints by determining whether the parameters are equal in two linear regressions of different but attached subperiods (e.g., β_1 and β_2 in Scenario 2, where we choose the breakpoint to be 1980 and n = 2). The Chow test is commonly used to test for structural breakpoints in some or all of the parameters of a scenario by testing whether one regression line or two separate regression lines best fit a split set of data. The Chow test is an application of the *F*-test, and it requires the sum of squared errors from three regressions: one for each sample period and one for the pooled data.

The test statistics can be calculated as follows:

$$\frac{\left(S_c - \left[S_1 + S_2\right]\right)/k}{\left(S_1 + S_2\right)/\left(N_1 + N_2 - 2k\right)} \sim F\left(k, N_1 + N_2 - 2k\right), \tag{2}$$

where S_1 and S_2 denote the sum of the squared residuals from both subperiods, one before the breakpoint and one after the breakpoint, and S_c represents the sum of squared residuals of the combined periods. In this Chow test, N_1 is the number of observations from the first subperiod and N_2 represents the number of observations from the second one, while k is the total number of parameters in the regression (k = 2 in this case).

3.1 | Regressions and the Chow Test

Using the Chow test (Table 1), half of the breakpoints used are significant (50% of the breakpoints are significant at the 10% level). It is important to note that the lack (or presence)

TABLE 2 Means (and standard errors) of regression: Louisiana raw sugar and gross sugarcane yields and sugar content, no breakpoints, 1911–2018

Estimated parameters	Raw sugar	Gross cane
α_1 (intercept, 1911–2018)	−50.160 ± 1.887***	−391.6 ± 1.837***
β_1 (slope, 1911–2018)	0.027 ± 0.001***	0.211 ± 0.01***

***Significant at the .001 probability level.

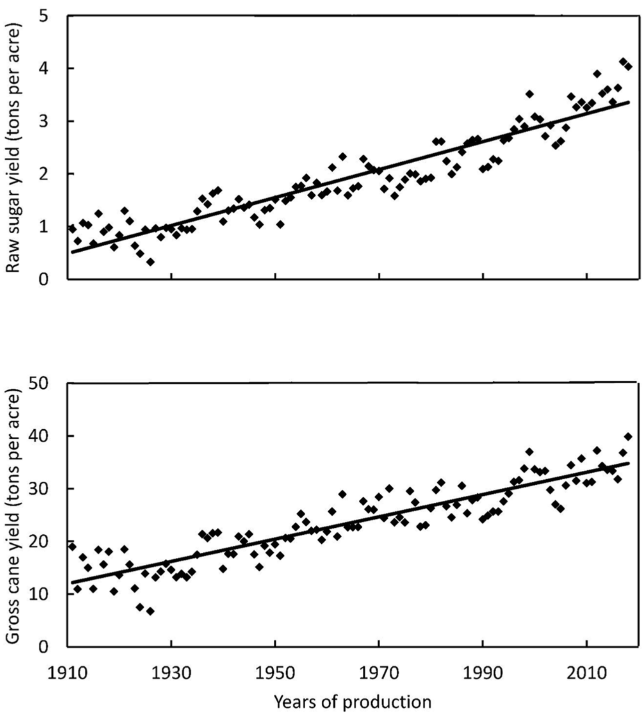

FIGURE 3 Louisiana raw sugar and gross sugarcane yields, no breakpoints, 1911–2018

of a significant breakpoint does not preclude (or guarantee) the significance of the yield coefficient in the corresponding regressions. New cultivars or the adoption of new production techniques may result in dramatic increases in yield. It must be remembered that research and development often simply allow the industry to maintain yield gains.

3.2 | Overall linear regressions (1911–2018)

Louisiana raw sugar and gross sugarcane yield changes from 1911 to 2018 are presented in Table 2 and Figure 3. The regression shows that raw sugar yield had an annual growth rate of 0.067 t ha^{-1} at the .1% significance level, while gross cane yield had an annual growth rate of 0.546 t ha^{-1} at the .1% significance level. Overall, these are positive yield growths for the Louisiana sugarcane industry during the period 1911–2018.

3.3 | Mechanization scenario (breakpoints 1945 and 1995)

We follow the same methodology used by Schmitz and Zhang (2019) and separate Louisiana raw sugar and gross sugarcane yields into three periods: 1911–1945, 1946–2000, and 2001–2018 (Table 3, Figure 4). For this scenario, the only significant breakpoint was the raw sugar breakpoint for 1995. Although the coefficients for all slopes were significant in this regression, the difference in the raw sugar slope coefficient for 1996–2018 relative to those of the first two periods is consistent with the results of the Chow test. With respect to the gross cane yields, while all three yield coefficients are significant, they are not overly dissimilar. This is once again consistent with the insignificant Chow test results for these gross cane breakpoints.

3.4 | Varietal era scenario (breakpoints 1926, 1945, 1976, and 1995)

Consider now the yield changes if the data are segmented into five periods to represent significant changes in both varietal development and harvesting technology: 1911–1926, 1927–1945, 1946–1976, 1977–1995, and 1996–2018 (Table 4, Figure 5). In the case of Scenario 3, only the breakpoint for 1926 was significant for raw sugar. The significance of this breakpoint is not surprising given the decreasing yields prior to 1927 and the dramatic growth afterwards. Conversely, all four gross cane breakpoints were significant at the 10% level. Although not all the periods exhibit a significant gross cane yield slope coefficient, there do appear to be five distinct periods with respect to gross sugarcane yields.

3.5 | LCP 85-384 scenario (breakpoint 1995)

To consider the impact of the joint adoption of sugarcane LCP 85-384 along with a shift to the use of combine harvesters, we separate Louisiana raw sugar and gross sugarcane yields into two periods: 1911–1995 and 1996–2018 (Table 5, Figure 6). This 1995 breakpoint is based on the joint adoption of LCP 85-384 and the accompanying switch to combine harvesters in the 1990s. Raw sugar yield showed a significant increase for both periods with the growth rate in the period 1996–2018 being more than double that of the period 1911–1995. The Chow test for this break was extremely significant for raw sugar. However, in the case of gross cane yield, the Chow

TABLE 3 Means (and standard errors) of regression: Louisiana raw sugar and gross sugarcane yields and sugar content, 1945 and 1995 breakpoints, 1911–2018

Estimated parameters	Raw sugar	Gross cane
α_1 (intercept, 1911–1945)	$-35.021 \pm 8.554^{***}$	$-316.478 \pm 98.261^{**}$
β_1 (slope, 1911–1945)	$0.019 \pm 0.004^{***}$	$0.172 \pm 0.051^{**}$
α_2 (intercept, 1946–1995)	$-44.451 \pm 5.119^{***}$	$-337.370 \pm 58.805^{***}$
β_2 (slope, 1946–1995)	$0.024 \pm 0.003^{***}$	$0.184 \pm 0.030^{***}$
α_3 (intercept, 1996–2018)	$-90.900 \pm 16.724^{***}$	-290.772 ± 192.115
β_3 (slope, 1996–2018)	$0.047 \pm 0.008^{***}$	$0.161 \pm 0.096^{*}$

*Significant at the .05 probability level.
**Significant at the .01 probability level.
***Significant at the .001 probability level.

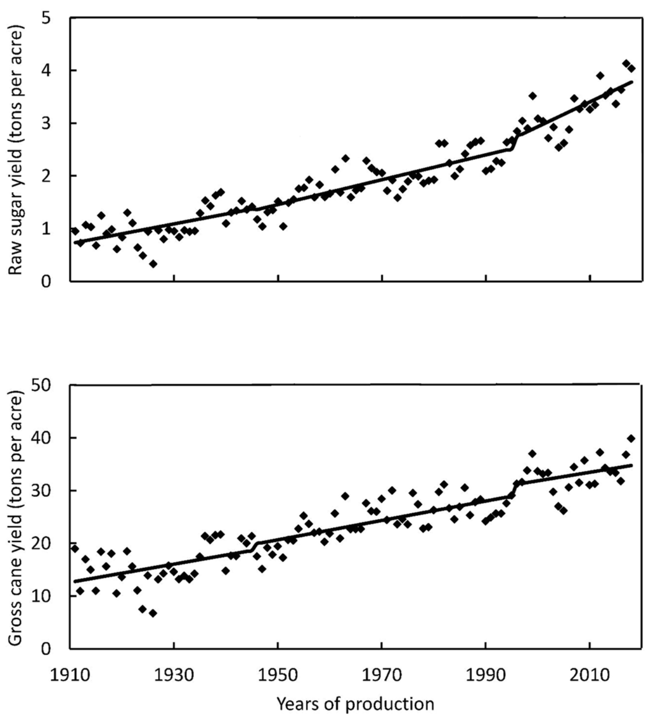

FIGURE 4 Louisiana raw sugar and gross sugarcane yields, 1945 and 1995 breakpoints, 1911–2018

test did not indicate a significant break. This is consistent with the regression results for gross cane yields. While the slope of both periods is significant, they do not appear to be dissimilar.

3.6 | End of Noble era and adoption of LCP 85-384 (Breakpoints 1926 and 1995)

In the final scenario considered, the data are separated into three periods (Table 6, Figure 7). The 1926 breakpoint is based on the introduction of the POJ and CO cultivars combined with the development of a Louisiana-specific breeding program in the 1920s. The 1995 breakpoint is based on the adoption of LCP 85-384 and combine harvesting in the 1990s. The data are segmented into the periods 1911–1926, 1927–1995, and 1996–2018. The Chow test showed significant breaks for raw sugar between all periods, while only the break in 1926 was significant for gross sugarcane yields (Table 1). The information in Table 6 is useful in showing the differences in yield gains between eras. While yield growth prior to 1927 was either negative or highly variable, growth in both raw sugar and gross sugarcane yields since then has been positive and significant, with greater gains in raw sugar yield in the more recent period.

4 | DISCUSSION AND CONCLUSION

The primary challenge of the Louisiana sugarcane industry is to grow a tropical crop in a temperate climate (Gravois, 2001). While many modern sugarcane cultivars can thrive in any number of tropical locales, the Louisiana industry requires sugarcane cultivars that are tailored to succeed in its temperate climate (Martin & Hoy, 2001).

Following Edmé et al. (2005), Schmitz and Zhu (2017), and Schmitz and Zhang (2019) for Florida sugarcane, we review and highlight the major sugarcane developments in the Louisiana sugarcane industry. The decreasing yields from 1911 to 1926 served as an impetus for the development of an impressive system of research capacity for the Louisiana sugarcane industry through the development of its three-way partnership. The inflow of genetics, combined with advances in breeding techniques and research capacity, have served the industry well. Our results show impressive increases in sugarcane and sugar yields, especially during the periods 1927–1945, 1946–1976, and 1996–2018. Although the period 1977–1995 did exhibit significant gains for raw sugar yields, those gains were not as impressive as those seen in the prior and following periods. Although raw sugar and gross sugarcane yields exhibited impressive gains throughout the period 1911–2018, our analysis of breakpoints using the Chow test

TABLE 4 Means (and standard errors) of regression: Louisiana raw sugar and gross sugarcane yields and sugar content, 1926, 1945, 1976, and 1995 breakpoints, 1911–2018

Estimated parameters	Raw sugar	Gross cane
α_1 (intercept, 1911–1926)	39.407 ± 26.687	764.331 ± 284.805**
β_1 (slope, 1911–1926)	−0.020 ± 0.014	−0.391 ± 0.148**
α_2 (intercept, 1927–1945)	−70.963 ± 20.799***	−806.951 ± 221.970***
β_2 (slope, 1927–1945)	0.037 ± 0.011***	0.426 ± 0.115***
α_3 (intercept, 1946–1976)	−45.461 ± 10.100***	−604.178 ± 107.790***
β_3 (slope, 1946–1976)	0.024 ± 0.005***	0.320 ± 0.055***
α_4 (intercept, 1977–1995)	−51.532 ± 21.336*	−61.839 ± 227.702
β_4 (slope, 1977–1995)	0.027 ± 0.011*	0.045 ± 0.114
α_5 (intercept, 1996–2018)	−90.900 ± 16.182***	−290.772 ± 172.696*
β_5 (slope, 1996–2018)	0.047 ± 0.008***	0.161 ± 0.086*

*Significant at the .05 probability level.
**Significant at the .01 probability level.
***Significant at the .001 probability level.

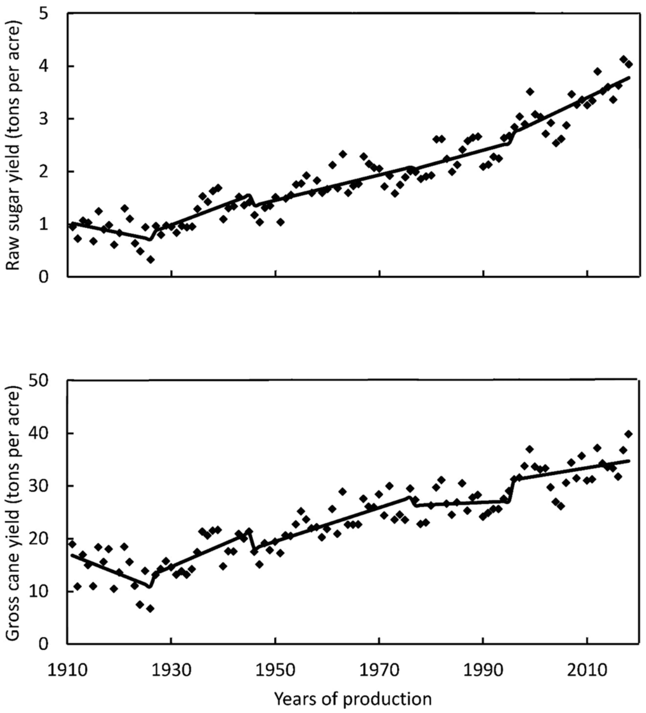

FIGURE 5 Louisiana raw sugar and gross sugarcane yields, 1926, 1945, 1976, and 1995 breakpoints, 1911–2018

and piecewise regression allows for the decomposition of those gains according to the relevant periods.

The broad-based composition of the Louisiana industry is a factor that lends itself to a greater degree of cooperation between the industry and public sugar research programs. The American Sugar Cane League (League) is a broad-based coalition of Louisiana sugarcane producers and processors that are dedicated to supporting the Louisiana sugar industry through a variety of means, including research (American Sugar Cane League, 2019). The League has a long history of cooperating with the Louisiana Agricultural Experiment Station and USDA through public–private partnerships to develop high-yielding, disease and pest resistant sugarcane cultivars tailored to Louisiana's temperate climate (Gravois & Bischoff, 2001). Through their efforts, the League was responsible for the establishment of the Louisiana Agricultural Experiment Station and USDA–ARS facilities in Canal Point (Florida) and Houma (Louisiana). With the discovery that sugarcane flowered according to a photoperiod response, sugarcane crossing was conducted in Baton Rouge starting in 1954 and later in St. Gabriel. These events lay the groundwork for the establishment of a Louisiana-specific breeding program that would yield such cultivars as LCP 85-384 (Gravois & Bischoff, 2001).

TABLE 5 Means (and standard errors) of regression: Louisiana raw sugar and gross sugarcane yields and sugar content, 1995 breakpoint, 1911–2018

Estimated parameters	Raw sugar	Gross cane
α_1 (intercept, 1911–1995)	−39.933 ± 2.280***	−366.367 ± 26.124***
β_1 (slope, 1911–1995)	0.021 ± 0.001***	0.198 ± 0.013***
α_2 (intercept, 1996–2018)	−90.900 ± 16.659***	−290.772 ± 190.887
β_2 (slope, 1996–2018)	0.047 ± 0.008***	0.161 ± 0.095*

*Significant at the .05 probability level.
***Significant at the .001 probability level.

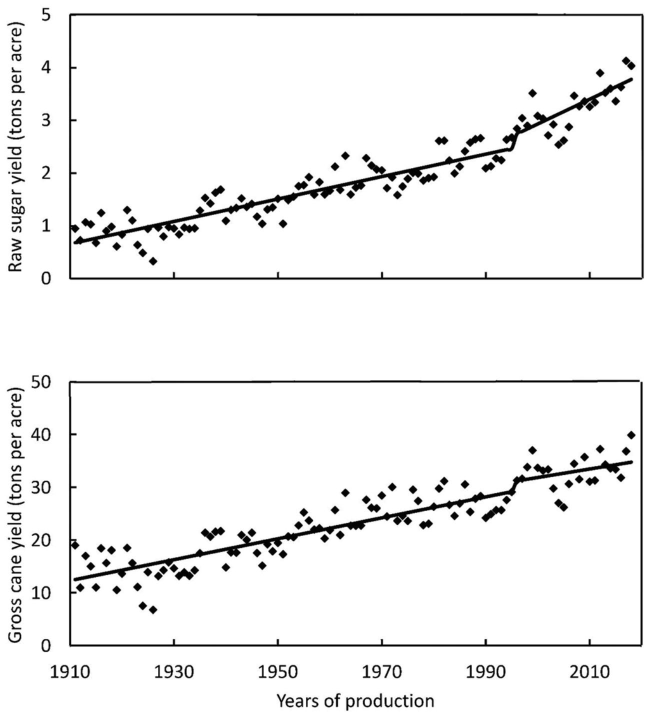

FIGURE 6 Louisiana raw sugar and gross sugarcane yields, 1995 breakpoint, 1911–2018

The Louisiana sugarcane breeding program has been developing sugarcane cultivars for nearly a century. Recent gains through LCP 85-384 have highlighted the success of the program (Gravois & Bischoff, 2001) that has achieved progress through a combination of both introgressive breeding [crosses with other sugarcane and wild sugarcane (*S. spontaneum* L.) clones] as well as recurrent selection (backcrossing with successful hybrid cultivars). While many modern sugarcane cultivars draw on a limited number of progenitor clones relative to the vast number of basic clones available in the *Saccharum* genus, the use of additional basic clones expands the genetic base of modern sugarcane cultivars and offers potential for breakthroughs with respect to desirable characteristics. However, these gains come with greater risk than those derived from recurrent selection.

Examples of successful breeding programs that have found success through the use of basic germplasm include the Australian use of the parent clone 66N2008, derived from the Burmese wild sugarcane clone Mandalay, and development of LCP 85-384 in Louisiana derived from the Thai wild sugarcane clone US56-15-8 (Jackson, 2005). Even with these examples of successful introgressive breeding, the uncertainty associated with the use of additional basic clones may deter its use in favor of the recurrent selection of successful progeny.

The League touted the success of Dr. E. W. Brandes in his excursion to bring back from the South Pacific Islands 143 cultivars of sugarcane and safely establish 80 of these cultivars, including eight wild forms, in the USDA Quarantine facilities (American Sugar Cane League 1936). Cultivars were collected from the South Pacific region. The early U.S. breeding programs benefited from this influx of germplasm. This introgressive approach highlights the importance of cooperation between experiment stations from around the world and the sustained identification and incorporation of appropriate untapped basic *Saccharum* clones into sugarcane breeding programs. The Louisiana sugarcane breeding program continues to use introgression along with recurrent selection.

We have drawn on the work by Schmitz and Moss (2015) to consider not only the impact of new genetics, but also mechanization (future work should consider additional factors such as the control of plant diseases and pests). This analysis highlights the differences in impact between the adoption of alternative harvesting techniques (mechanization) using the 1945 and 1995 breakpoints. The movement from harvesting by hand to mechanized harvesting in the 1940s was a significant labor-changing event in the history of the Louisiana sugarcane industry. This adoption of mechanized whole-stalk harvesting provided benefits to the industry through the minimization of labor inputs at a time when labor was in short supply as a result of World War II. However, our analysis shows that this event was not responsible for increased yields. In contrast, the shift from whole-stalk to combine harvesting in 1995 shows a significant breakpoint for raw sugar yields but not gross

TABLE 6 Means (and standard errors) of regression: Louisiana raw sugar and gross sugarcane yields and sugar content, 1926 and 1995 breakpoints, 1911–2018

Estimated parameters	Raw sugar per acre	Gross cane per acre
α_1 (intercept, 1911–1926)	39.407 ± 26.513	764.332 ± 297.347*
β_1 (slope, 1911–1926)	−0.020 ± 0.014	−0.391 ± 0.155*
α_2 (intercept, 1927–1995)	−42.152 ± 3.021***	−376.487 ± 33.877***
β_2 (slope, 1927–1995)	0.022 ± 0.002***	0.203 ± 0.017***
α_3 (intercept, 1996–2018)	−90.900 ± 16.076***	−290.772 ± 180.302
β_3 (slope, 1996–2018)	0.047 ± 0.008***	0.161 ± 0.090*

*Significant at the .05 probability level.

***Significant at the .001 probability level.

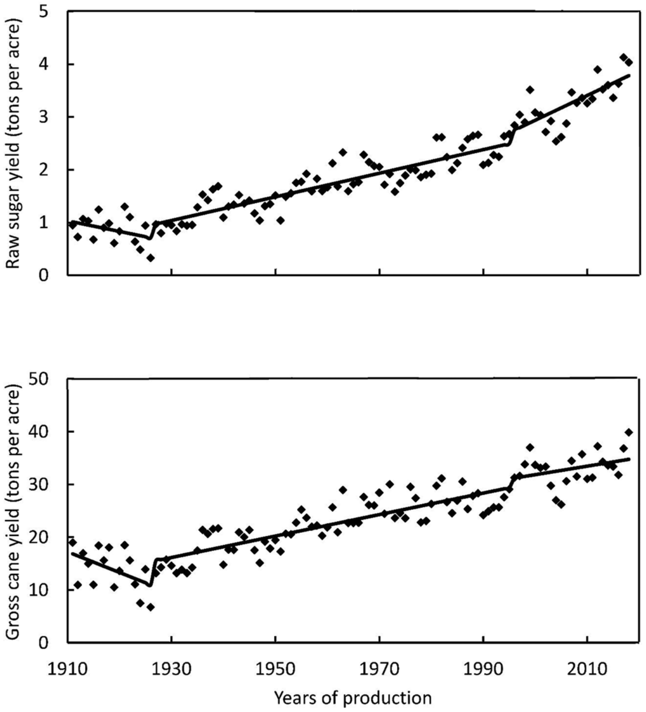

FIGURE 7 Louisiana raw sugar and gross sugarcane yields, 1926 and 1995 breakpoints, 1911–2018

sugarcane. The use of combine harvesters allowed for the adoption of high-sucrose cultivars, such as LCP 85-384, despite their tendency toward lodging. This codependence between sugarcane cultivar and harvesting technology is often overlooked in quantitative analysis.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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