Genetic Contribution to Yield Gains in the Florida Sugarcane Industry across 33 Years

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ABSTRACT

Sugarcane (Saccharum spp.) is a successful crop in the Florida Everglades Agricultural Area (EAA) that is characterized by high-N organic and low-fertility sandy soils, periodic freeze, and flood events. After 50 yr of breeding, the possibility of a yield plateau was investigated in the cooperative Florida sugarcane breeding program via an assessment of yield gains in the industry and an evaluation of the contribution attributed to breeding efforts. Long-term commercial and selection trial data, covering a 33-yr period (1968–2000), were used in single-degree-of-freedom regression analyses to determine rates of improvement in sucrose content (SC; kg Mg⁻¹), cane yield (CY; Mg ha⁻¹), and sugar yield (SY; Mg ha⁻¹). Analyses of commercial data reflected yearly increases of 0.80 ± 0.08 kg Mg⁻¹ of cane for SC, 0.31 ± 0.10 Mg ha⁻¹ for CY, and 0.10 ± 0.01 Mg ha⁻¹ for SY. Corresponding gains from selection trial data were 0.74 ± 0.15 kg Mg⁻¹, 1.06 ± 0.40 Mg ha⁻¹, and 0.16 ± 0.05 Mg ha⁻¹, respectively. Improvements were significant for all three traits across plant-cane, and first- and second-ratoon crops grown on organic soils but not on sandy soils. About 69% of the total gain in SY was attributed to the cooperative Canal Point public breeding program, via a greater allocation of assimilates toward sucrose accumulation, resulting in a contribution of $99 to 203 million as additional profits to the Florida economy across the 33 yr. The genetic potential of the working germplasm has not been exhausted (no evidence of a yield plateau for SC in this sugarcane breeding program. These gains and future advances are possible because of the use of a diverse gene pool and a breeding strategy that integrates growers’ participation into the program.

Commercial sugarcane cultivars are hybrids that originated from progeny of crosses between “noble” cane (S. officinarum L.) and its wild relatives (S. spontaneum L., S. sinense Roxb., or S. barberi Jesw.) that were backcrossed to S. officinarum in a process called “nobilization” (Brandes and Sartoris, 1936). Before 1911, the Florida sugarcane industry was dominated by noble cultivars. Starting in 1911, the industry relied on imported hybrid cultivars, such as POJ 2725 and Co 290, respectively, bred in Java, Indonesia and Coimbatore, India (James, 1970). The poor adaptation of these early cultivars to the high-N organic soils of the EAA, the industry expansion to areas not protected by the warming effect of Lake Okeechobee, and the susceptibility of some cultivars to diseases gave the incentive to develop cultivars adapted to Florida environments (James, 1970; Rice, 1970). The major participants in cultivar development included the University of Florida (the F-cultivars), the USDA Canal Point sugarcane breeding station (the CP-cultivars), and the Clewiston-based private program known as US Sugar Corporation or USSC (the CL-cultivars). Since 1966, the CP sugarcane cultivars have been released jointly by the USDA, the University of Florida, and the Florida Sugarcane League, Inc.

Successful maintenance of sugarcane within the portfolio of crops grown in the EAA has been made possible by two structured breeding programs (USDA, Canal Point and USSC, Clewiston) that share the same objective, namely the development of new cultivars with high and stable yields for South Florida. Improvements in cultural practices and milling efficiency have also contributed to the establishment of sugarcane as a viable and economic crop in the EAA.

Concerns exist that sugarcane yield may soon plateau or has already reached a plateau caused by exhaustion of genetic diversity (McCloud, 1977; Mariotti, 2002). Most of the sugarcane cultivars in the world can be traced back to a very limited number of parents used to synthesize the original interspecific hybrids bred in Indonesia and India (Berding and Roach, 1987; Deren, 1995). For most of the 20th century, sugarcane breeding worldwide thrived essentially on crossing progeny within this original population. The CP program tended to exploit a more diverse gene pool to transfer genes that conferred high yield and resistance to both biotic and abiotic stresses into the cultivated background (Tai and Miller, 1978). The CP breeding program has also adopted a “shuttle” breeding strategy (Young and Frey, 1994) that alternates clonal selection between optimum (organic soils in the initial three stages) and multilocation conditions (both organic and sandy soils in the final two stages) at representative farm sites. This philosophy also capitalizes on reentry of the best performing clones into the crossing program. The CP cultivars are currently grown on roughly 90% of the Florida sugarcane hectarage (Glaz et al., 2003) and are used extensively in many parts of the world, particularly the Caribbean and Central America (J.D. Miller, personal communication).

No attempt has been made to assess the impact of breeding on the improvement of sugarcane for Florida. Baver (1963) and Hogarth (1976) attributed 50 and 75% of the gains in sugarcane yields to genetics for Hawaii and Australia, respectively. Similar assessments have been made in other crops (Wych and Rasmussen, 1983; Duvick, 1992a; Lauer et al., 2001) to evaluate the genetic contribution to overall progress and to shed light on future strategies needed for advancement. Genetic improvements have contributed to about 50% of the yield gains attained in major U.S. crops (Fehr, 1984; Duvick, 1992b; Frisvold et al., 1999). Progress has been assessed with traditional yield trials or with long-term yield trials, by comparing performance of both old and new cultivars in common environments under current management.

Abbreviations: CP, Canal Point; CY, cane yield; EAA, Everglades Agricultural Area; SC, sucrose content; SY, sugar yield.
strategies (Wych and Rasmusson, 1983). Both of these methods have an upward bias resulting from the difficulty of not being able to remove the effects of cultural practices (Langer et al., 1978). However, yield trials across time, which include long-term reference cultivars, can enhance the reliability of the comparison (Langer et al., 1978; Peltonen-Sainio and Karjalainen, 1991). Other researchers have relied on historical records of yields from commercial production or cultivar trials conducted at several locations across several decades to estimate genetic gains and contribution to yield improvements (Langer et al., 1978; Peltonen-Sainio and Karjalainen, 1991; Specht et al., 1999). This study on sugarcane also used historical data from both commercial production and the last stage of experimental selection trials, which included long-term reference cultivars, to assess the genetic contribution to yield gains in the Florida sugarcane industry.

Quantifying genetic gains in sugarcane is an important step in the renewed efforts by the Florida sugar industry to maximize economic returns while protecting the environment and to improve end-product marketing (Shine, 2002). The objectives of this study were to estimate the overall rate of cultivar improvement achieved by the Florida sugarcane industry, to assess progress made for each of three crop ages (plant cane and first and second ratoons) grown on both organic and sandy soils, and to separate the genetic contribution from that of cultural practices.

MATERIALS AND METHODS

The Florida Sugarcane League, Inc. provided sugarcane production data spanning a 33-yr (1968–2000) period and these data were pooled across cultivars (CP and CL), crop ages (plant cane and first and second ratoons), and soil types (organic and sandy). This period included production for the first two major cultivars developed in Florida, namely CL 41-0223 released in 1956 and CP 63-0588 released in 1968, which makes 1968 an appropriate reference year from which to assess genetic gain. Long-term (1968–2000) farmer-managed cultivar yield trial data, collected in the last selection stage (Stage IV) of the Canal Point breeding program, were also used to determine the rates of improvement across crop age and soil type and to assess the magnitude of genetic contribution corrected for contribution of cultural practices. Stage IV trials were established with new genotypes every year, grown at the same locations and tested for three crop years (plant cane and first and second ratoons), with one to two reference cultivars common to all trials.

Three major yield variables were measured: sucrose content (SC; kg Mg⁻¹ of cane), cane yield (CY; Mg ha⁻¹), and sugar yield (SY; Mg ha⁻¹), by methods described by Arceneaux (1935) and Legendre (1992). Before 1993, whole plots were weighed in the field with a tractor-mounted device for calculation of cane and sugar yields (Glaz et al., 1993). Since 1993 and starting with the CP 89 series, cane and sugar yields were estimated from 10-stalk sample weights and stalk numbers, necessitated by labor shortage after the sugarcane industry shifted to mechanical harvesting (Glaz et al., 1994). To avoid any bias, mean yields of cultivars released before or after 1993 were regressed separately on years of release to calculate rates of increase due to genetic improvement.

The GLM procedure in SAS v. 8.2 (Littell et al., 2002) was used to regress performance data for SC, CY, and SY on years of production or of release as independent variables. Years were coded as 1 (1968) to 33 (2000) before carrying out single-degree-of-freedom regression analyses to determine the rate of genetic improvement in sugarcane across the 33-yr period. Commercial production data were regressed on years to obtain mean yield increase across time as realized gain and trends were also observed for each of the following three periods: 1968 to 1980 (Period 1), 1981 to 1990 (Period 2), and 1991 to 2000 (Period 3). Least-square means across clones, sites, and crop ages were used to assess the quality of the clones reaching Stage IV. Least-square means of released cultivars were also calculated to determine maximum genetic gain across time. The slopes or b values, significant at the 0.05 probability level, obtained from linear regression analyses, were considered as gains.

Long-term reference cultivars were used to calculate the relative contribution attributed to plant breeding. Commercial sugar yields for the Florida industry were averaged for each of the three periods, corresponding to the time when a released cultivar dominated, and compared with mean yields of these cultivars obtained in Stage IV trials for the same time periods, according to Wych and Rasmusson (1983). Reference cultivars were CP 63-0588 for Period 1; CP 70-1133, CP 72-1210, CP 72-2086, CP 73-1547, and CP 80-1827 for Period 2; and CP 78-1628, CP 80-1743, CP 88-1762, and CP 89-2143 for Period 3. Percent increases within periods, obtained from Stage IV trials, were averaged and divided by increases realized in commercial fields to obtain an estimate of the overall contribution attributable to the Canal Point sugarcane improvement program, in accordance with Wych and Rasmusson (1983).

Annual values of the additional producer benefits were estimated from mean commercial sugar yields for the 1968 to 2000 period and converted to year 2000 dollar values, based on the annual hectarage harvested for sugar, the portion of the rate of progress for sugar yield attributable to breeding, and a base price of $440.00 Mg⁻¹ of raw sugar. This was accomplished by compounding past dollar amounts to the year 2000, using a compound interest formula, with interest rates of 0% and 5% (Frisvold et al., 1999; Yu et al., 2002). Cumulative gross benefits were calculated after summing present values across the 33-yr period considered. The present value (PV) in year 2000 dollars was calculated with the following formula:

\[ PV = B \times \left(1 + \frac{r}{n}\right)^{-n} \times a \]

where \(B\) = starting value as benefit (based on a price of $440.00 Mg⁻¹ raw sugar), \(r\) = interest rate, \(Y\) = number of years of production, and \(n\) = number of times the interest is compounded (\(n\) was taken as 1 in this study).

RESULTS AND DISCUSSION

Realized Gains

Linear regression analyses indicated that SC increased significantly (\(P < 0.01\)) and similarly under Stage IV trials and commercial field conditions at annual rates of 0.74 and 0.80 kg Mg⁻¹ of cane (Fig. 1a), respectively. The overall improvement over 1968 was 24.0% (Stage IV) and 26.0% (commercial fields). SC seemed to have leveled off during Period 1 since no significant improvement (\(P > 0.05\)) was achieved (Table 1), because CY, not SC, was then the primary breeding and selection objective. The fastest rate of improvement was realized during Period 2 (1.84 kg Mg⁻¹ yr⁻¹), followed by a slower but significant (\(P < 0.05\)) improvement gain (0.49 kg
Cane yield (CY) increased significantly ($P < 0.01$) at linear rates of 0.31 and 1.06 Mg ha$^{-1}$ yr$^{-1}$ under commercial field and Stage IV trials conditions, respectively, representing total improvements of 15.5 and 35% across 33 yr (Fig. 1b). The faster rate of increase (3.4 times) obtained in Stage IV trials can be explained mostly by the fact that some Florida sugarcane growers grow more crop-years (plant cane and ratoons) than the three tested in the breeding program with CY normally decreasing with an increase in ratoon crops. An analysis by period of commercial production data reflected no significant CY gain during Period 1 or Period 2, with most of the gain (1.12 Mg ha$^{-1}$ yr$^{-1}$) occurring during Period 3 (Table 1). Improved cultivars were released to the industry during Period 1 and Period 2. More specifically, CY increased from 66.0 Mg ha$^{-1}$ in 1968 to 85.0 Mg ha$^{-1}$ in 1973, then declined, leveled off throughout Period 2, and increased to the level of 1973 during Period 3. In Stage IV trials, CY did not change during Period 1 but rose at linear rates of 2.10 and 4.10 Mg ha$^{-1}$ yr$^{-1}$ during Period 2 and Period 3, respectively. These gains in CY were not apparent across the sugarcane industry during Period 1 and Period 2 as a result of an 81% expansion of the planted hectarage to environments that the improved cultivars were not fully tested for.

From 1968 to 2000, SY improved significantly ($P < 0.05$) at linear rates of 0.10 and 0.16 Mg ha$^{-1}$ yr$^{-1}$ under commercial fields and Stage IV trials, respectively (Fig. 1c). This corresponded to respective gains of about 47 and 53% across 33 yr. Sugar yield did not change significantly ($P > 0.05$) during Period 1, but it improved at rates of 0.17 and 0.18 Mg ha$^{-1}$ yr$^{-1}$ during Period 2 and Period 3, respectively, under commercial field production (Table 1). In Stage IV trials, SY improved at a faster linear rate during Period 3 (0.62 Mg ha$^{-1}$ yr$^{-1}$) than during Period 2 (0.13 Mg ha$^{-1}$ yr$^{-1}$). SY is the product of CY and SC. Since there was no increase in CY or SC during Period 1, no accompanying gains were observed in SY, as expected. Gains in SY during Period 2 resulted from an improvement in SC, whereas during Period 3, improvements in both CY and SC contributed to increases in SY. Many sugarcane breeding programs in the world have relied on improving cane yield to increase sugar yield per hectare (Mariotti, 2002). However, there is an added incentive to increase sugar yield by improving sucrose content, because milling efficiency tends to decline with high sugarcane biomass and some sugarcane payment systems impose a penalty for high-tonnage low-sucrose cultivars (Legendre, 1992).

The 1968-1980 period was dominated by cultivars such as CL 41-0223 and CP 63-0588. This period was characterized by steady expansions of the industry onto cold-prone fields away from Lake Okeechobee and also by efforts to increase sugarcane production on shallower organic soils and on sandy soils (James, 1970; Aleman,
1984). A two-fold increase in planted hectarage (6140 ha yr⁻¹) was recorded during Period 1 from 75,000 ha in 1968, as compared with 3868 ha yr⁻¹ during Period 2 and Period 3, respectively (data not shown). Moreover, during Period 1, the primary selection emphasis was on CY and better adapted cultivars, with a minimum standard imposed on SC. This period also coincided with the appearance of new diseases and an increased incidence of smut [caused by *Sporisorium scitaminea* (formerly *Ustilago scitaminea* H. Syd. and P. Syd.)], leaf scald (caused by *Xanthomonas albilineans* Asby), and rust (caused by *Puccinia melanocephala* H. Syd. and P. Syd.). Under these disease pressures, Florida sugarcane breeders adjusted their strategies in response to industry needs, which likely contributed to absence or non-evidence of yield gains during Period 1. As selection pressure was applied on both SC and CY, all three traits improved simultaneously as reflected by the release of high sucrose and/or tonnage cultivars (CP 70-1133, CP 72-1210, CP 72-2086, and CP 80-1827) and better sand-adapted cultivars (CP 70-1133 and CP 73-1547) during the 1981-to-1990 period. Contrary to belief, gains in SY may be more associated with gains in SC than with gains in CY as Fig. 1 seems to indicate that new cultivars may allocate assimilates more efficiently toward accumulation of sucrose. A good sampling and pyramiding of the desirable genes (for disease resistance, cold tolerance, and yield) available in the working germplasm might have also contributed to the yield changes observed under both commercial fields and the last stage of selection.

### Gains across Soil Types and Crop Ages

There were substantial differences in progress on organic soils versus that on sandy soils (Table 2). Florida sugarcane breeders improved SC (*P < 0.01*) on organic soils at a rate of 0.81 kg Mg⁻¹ of cane yr⁻¹. This overall gain was sustained by performance improvements in plant-cane (0.79 kg Mg⁻¹ of cane yr⁻¹), first-ratoon (0.82 kg Mg⁻¹ of cane yr⁻¹), and second-ratoon (0.79 kg Mg⁻¹ of cane yr⁻¹) crops. Improvements for SC were not recorded on sandy soils, regardless of crop age.

Cane yield of released cultivars on organic soils increased (*P < 0.01*) at an overall rate of 1.61 Mg ha⁻¹ yr⁻¹, reflecting improved performance in plant-cane (1.89 Mg ha⁻¹ yr⁻¹), first-ratoon (2.03 Mg ha⁻¹ yr⁻¹), and second-ratoon (0.90 Mg ha⁻¹ yr⁻¹) crops (Table 2). A slightly greater gain was realized in the first-ratoon than in the plant-cane crop. Greater variability exists with first-ratoon crops as compared with plant-cane crops, which are usually heavier on organic soils, making it easier to combine, in the cultivars, good ratooning ability with good plant-cane crop performance. The performance of released cultivars on sandy soils did not change across time in plant-cane and first-ratoon crops, but it improved (*P < 0.01*) at a rate of 1.45 Mg ha⁻¹ yr⁻¹ for the second-ratoon crop. Greater variability exists usually in second-ratoon crops as first-ratoon crops are usually better or similar to plant-cane crops on organic soils.

**Table 1. Rates of changes (slopes of linear regression) in sucrose content, cane yield, and sugar yield during the 1968-to-2000 period for the Florida sugarcane industry (using commercial field production data).**

<table>
<thead>
<tr>
<th>Period</th>
<th>Sucrose content</th>
<th>Cane yield</th>
<th>Sugar yield</th>
</tr>
</thead>
<tbody>
<tr>
<td>1968–1980</td>
<td>0.16 ± 0.32**</td>
<td>−0.29 ± 0.43ns</td>
<td>−0.17 ± 0.15ns</td>
</tr>
<tr>
<td>1981–1990</td>
<td>1.84 ± 0.51**</td>
<td>0.38 ± 0.50ns</td>
<td>0.17 ± 0.08**</td>
</tr>
<tr>
<td>1991–2000</td>
<td>0.49 ± 0.13**</td>
<td>1.12 ± 0.46a</td>
<td>0.18 ± 0.06**</td>
</tr>
</tbody>
</table>

* Significant at the 0.05 probability level.
** Significant at the 0.01 probability level.
† ns, Not significant.
‡ b values = standard errors obtained from linear regression analyses.

**Table 2. Rates of changes (slopes of linear regression) in sucrose content, cane and sugar yields based on released sugarcane cultivars tested under organic and sandy soils during the period 1968 to 2000 in the Canal Point breeding program, FL.**

<table>
<thead>
<tr>
<th>Crop age</th>
<th>Organic soils</th>
<th>Sandy soils</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant cane</td>
<td>0.79 ± 0.19**</td>
<td>0.44 ± 0.20ns</td>
</tr>
<tr>
<td>First ratoon</td>
<td>0.82 ± 0.29**</td>
<td>0.76 ± 0.43ns</td>
</tr>
<tr>
<td>Second ratoon</td>
<td>0.79 ± 0.21**</td>
<td>0.22 ± 0.42ns</td>
</tr>
<tr>
<td>Overall</td>
<td>0.81 ± 0.17**</td>
<td>0.32 ± 0.34ns</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cane yield</th>
<th>Organic soils</th>
<th>Sandy soils</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant cane</td>
<td>1.89 ± 0.41**</td>
<td>−0.15 ± 0.75ns</td>
</tr>
<tr>
<td>First ratoon</td>
<td>2.03 ± 0.39**</td>
<td>−0.45 ± 0.50ns</td>
</tr>
<tr>
<td>Second ratoon</td>
<td>0.90 ± 0.43*</td>
<td>1.45 ± 0.49**</td>
</tr>
<tr>
<td>Overall</td>
<td>1.61 ± 0.38**</td>
<td>0.31 ± 0.50ns</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sugar yield</th>
<th>Organic soils</th>
<th>Sandy soils</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant cane</td>
<td>0.25 ± 0.06**</td>
<td>−0.02 ± 0.10ns</td>
</tr>
<tr>
<td>First ratoon</td>
<td>0.26 ± 0.05**</td>
<td>−0.05 ± 0.08**</td>
</tr>
<tr>
<td>Second ratoon</td>
<td>0.12 ± 0.05*</td>
<td>0.12 ± 0.05*</td>
</tr>
<tr>
<td>Overall</td>
<td>0.21 ± 0.05**</td>
<td>0.02 ± 0.06ns</td>
</tr>
</tbody>
</table>

* Significant at the 0.05 probability level.
** Significant at the 0.01 probability level.
† ns, Not significant.
‡ b values = standard errors obtained from linear regression analyses.
will be necessary to minimize the difference between represented an annual increase of 1.09%. This increase
gains in SY for the corresponding periods and CP 84-1591), adapted to sandy soils, have been showed an increase of 0.085 Mg ha

contributed to a significant ($P < 0.01$) overall increase in SY of 0.21 Mg ha$^{-1}$ yr$^{-1}$ (Table 2). Overall, SY on sandy soils did not change because of the absence of gains for plant-cane and first-ratoon crops. There was, however, a gain of 0.12 Mg ha$^{-1}$ yr$^{-1}$ for the second-ratoon crop.

There were significant improvements in performance in all three crop ages for SC, CY, and SY across soil types (Table 3), contributed mostly by improvements on organic soils (Table 2). Ratooning ability is an important selection criterion in sugarcane breeding programs. Overall gains achieved with the release of improved sugarcane cultivars in the 33-yr period largely reflected favorable progress on organic soils. Greater stress tolerance will be necessary to minimize the difference between gains in performance on organic and sandy soils. Most of the improved cultivars were better adapted to the organic soils of the EAA than to the sandy soils. High-yielding cultivars (CP 70-1133, CP 75-1547, CP 78-1628, and CP 84-1591), adapted to sandy soils, have been released also to the industry across the years and sucrose content of these cultivars grown on sandy soils still ranged from 100 to 150 kg Mg$^{-1}$ of cane. Even though the breeding strategy, espoused by the cooperative Canal Point sugarcane breeding program, is able to advance clones with potential release for sandy soils to Stage IV, the frequency is not as high as that obtained on organic soils. To upgrade and increase the frequency of advanced materials for sandy soils would require specific crosses to be made for the sand-soil environment and to begin testing clones in the early stages directly on sandy soils. However, plant breeding programs usually have to make compromises and establish priorities because of availability of limited resources to breed for the different target environments (Brown and Glaz, 2001).

### Genetic Contribution and Benefits

On the basis of production data from commercial fields, gains in SY averaged 0.0962 Mg ha$^{-1}$ yr$^{-1}$, which represented an annual increase of 1.09%. This increase represented a combined contribution from genetic, agronomic, and technological advances at the farm and mill levels. Averaging the means of the dominant cultivars from Stage IV for the corresponding periods showed an increase of 0.085 Mg ha$^{-1}$ yr$^{-1}$ in SY or 0.75% yr$^{-1}$. This increase obtained in Stage IV trials reflected genetic improvement based on yield differences among the released cultivars. Dividing 0.75 by 1.09 indicates that about 69% of SY gain obtained by Florida sugarcane growers was attributable to genetic improvement. The remaining 31% yield gain can be associated with improved management practices and milling efficiency. The 69% contribution from improved sugarcane cultivars in Florida falls within the 50 (Ho-garth, 1976) to 75% (Baver, 1963) range of contributions from genetic improvement previously reported for sugarcane (Heinz, 1987). About 50% of yield gains obtained in major U.S. crops have been attributed to genetic improvements for about the same period (1960–1999) (Fehr, 1984; Frisvold et al., 1999).

Some scientists believe that gains in sugarcane for Florida could be higher on commercial fields, were it not for successive plantings (sugarcane–sugarcane rotation system without fallow) and certain restrictions for environmental protection. A review of annual census reports
on Florida sugarcane hectarage generally documents a greater area devoted to successive than to fallow plantings (Glaz and Coale, 1987; Glaz, 1994, 1995; Glaz and Ulloa, 1995). Successive planting is part of the rotation system and is being accounted for in the breeding program in the last stage (Stage IV) of selection. Moreover, efforts are being made to address the sustainability of sugarcane to potential changes in agricultural practices (mechanical harvesting, higher water tables, efficiency in phosphorus uptake, etc.) associated with ongoing Everglades restoration and protection efforts (Shine, 2002).

The cumulative benefits to the Florida economy in Year 2000 dollar values, attributed to sugarcane breeding efforts by the cooperative USDA-ARS Canal Point program, were estimated to range between $99 million (0% interest) and $203 million (5% interest) (Table 4). In an assessment of benefits contributed by the University of Nebraska-Lincoln wheat breeding program (associated with a considerably larger hectarage), Yu et al. (2002) reported benefits that ranged from $200 million (0% interest) to $485 million (5% interest) across a period of 30 yr.

CONCLUSIONS

Analyses of both commercial and Stage IV data indicated that there was no evidence of a yield plateau for SC and SY in the Canal Point sugarcane breeding program. A plateau for CY was detected since the early 1970s, indicating that gains in SY were more associated with a greater allocation of assimilates toward sucrose accumulation. Greater progress was observed on organic than on sandy soils (where yield-limiting factors are more critical), more likely as a result of not selecting on sandy soils until the final two stages of the breeding program. Given adequate resources, planned crosses and/or selection on sand in the early stages of the breeding program may be required to upgrade cultivars for sandy soils at a faster rate.

The potential for selecting higher yielding clones has increased across the years and helps explain the advances documented in the Florida sugarcane industry. Effective sampling and pyramiding of the desirable genes available within the working germplasm led to the improvements in SC, CY, and SY. With the polyploid nature of sugarcane and keeping in mind that only about 12 generations have passed since inception of sugarcane breeding, more yield progress is to be expected. Continued use of a widened gene pool will still be necessary to maintain future increases in yield potential.

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