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The impact of plant breeding on sugar-cane in Barbados

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The historical and agricultural background of Barbados sugar-cane agriculture is outlined. Since the late nineteen thirties, four cycles of varieties have been grown. Regression analysis of cane yields (based upon extensive commercial data) permits the separation of varietal effects on yield from an underlying curved trend due to changing weather and husbandry. The three sets of newer varieties varied in the yield advantage achieved over their predecessors and there were evident genotype-environment (GE) effects. Collectively, the grain was large and the new canes added about 6.7 Mt to total crop over a 36 year period; they also ratooned better, a further contribution to economy of production. There is no evidence of change in sugar content. In discussion, the biological and economic consequences of cane breeding, the importance of GE effects, implications for the interpretation of trials results and the need to widen the genetic base are topics touched upon.

INTRODUCTION

There is a widespread belief, among farmers, agricultural scientists and administrators alike, that plant breeding has been highly successful in promoting agricultural productivity either by enhancing yields per unit cost or by better matching the quality of the product to the needs of the consumer. This belief, however, has very rarely been tested by reference to actual agricultural data; it rests, rather, upon the expectation that results of trials truly reflect the agricultural reality. This belief, too, is untested and there exists at least one body of opinion to the effect that trials in agricultural research in general are but poor predictors (DAVIDSON, 1965; DAVIDSON and MARTIN, 1965). The principal obstacle to testing the effects of plant breeding in practice is, perhaps surprisingly, simply lack of usable data: very few crop yields are adequately recorded. Sugar-cane, however, provides an exception and a fine series of yield data from that crop in Barbados provides the subject matter of this paper.

BACKGROUND

Sugar-cane is a large perennial, stooling grass. It is clonally propagated by planting pieces of stem. At harvest, leaves and sheaths (`trash') are left behind and the stems are removed to the factory and crushed; the expelled juice yields sucrose and the fibrous remains (`bagasse') are used to fuel the factory. The first crop (`plant' crop, P) is taken in 12 to 15 months from planting and subsequent crops ('ratoons', R_1, R_2, R_3, etc) at yearly intervals. Ratoon yields decline at various rates in various places and replanting is ultimately necessary. The cause of decline in unknown, but the fact that it occurs and its rate are of great economic importance. Harvest is always in a dry (and preferably also cool) season; this checks growth, enhances sugar content of the juice, facilitates movement in the field and minimizes damage to soil structure.

The foregoing is a quite general summary of sugar-cane agriculture. Local practice varies very widely indeed, as might be expected of a crop that is widely adapted throughout the tropics and subtropics and is variously produced by industrial-style estates, farmers and peasants. Indeed, no two cane agricultures are quite alike, even within a small and relatively homogeneous area such as the West Indies. Barbados has several distinctive features. The early history was summarized by SAINT (1954) and STEVENSON (1960), later events by HUDSON (1973) and B.S.P.A. (1973) ; see also Sum (1976). Early history need not concern us here, beyond noting that the island has a continuous record of sugar production from 1640; for the present

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purpose, the interesting period is the last 37 years.

Barbados is a small Atlantic island (430 km^2, 13°N). Soils are sedimentary in origin and variable in character. Topography is undulating and generally low (maximum altitude 340 m). Rainfall is erratic, mostly in the range 1000 to 2000 mm/year and mostly falling in the period June to December; cane is harvested in the dry season February to May. Long-term rainfall cycles have long been suspected and recently established to occur on a 55 year cycle or thereabouts (BARR, personal communication, 1978; and see below). Within the island there is considerable variation and three rainfall areas are conventionally distinguished: low (L) (1000 mm, low-lying, coastal); medium (M) (1500 mm); high (H) (2000 mm, higher and generally more easterly-exposed topography). All students agree that rain is the major limiting factor for growth; HUDSON (1973) has developed an empirical `effective rainfall' equation which accounts rather well for seasonal variation in yield. The area cultivated in estate cane in the past 35 years has been in the range 10 to 14 kha distributed on average thus: L, 16 percent; M, 44 percent; H, 40 percent. The L area has fallen in the last decade in response to droughts and alienation of coastal land for other purposes. Estates are small, averaging 80 ha and are commonly family-owned; they would perhaps better be described as farms. There is also a substantial peasant cane production. The data used in this paper are based solely on the estates which render regular returns, accounting on average for about 70 percent of the cane area. Numerous small estates were, historically, matched by numerous small factories, but their number has shrunk in recent years to nine, making a total of about 120 kt of sugar (peak, mid-nineteen sixties, about 180 kt).

At its peak, in the nineteen fifties and early sixties, Barbados cane agriculture was outstandingly efficient, regularly producing 10 t/ha of sugar and, in many years, 11.3 t/ha. Indeed, it had something of the character of a horticulture. Cane was planted on the cane-hole pattern which is conservative of moisture; fertilizing was good; weeds were controlled by hoe; little heavy equipment was used; harvest was by hand and all trash was returned as mulch, to the joint benefit of soil and water conservation. The rising yields of the late nineteen forties (Figure 2) were mainly due to improved mineral fertilizing in addition to the traditional pen manure and mulch. The decline since the mid-nineteen sixties is related to recurrent droughts, labour shortage, probably to herbicide damage (WALKER, personal communication, 1978) and, above all, to burning. The last practice (now illegal) certainly made harvest easier and cheaper but destroyed potential mulch, damaged the soil, reduced ratoon yields, reduced sugar content (causing 'stale cane') and hampered sugar recovery in the factory.

The crop is generally planted about October and plants are reaped about 15 months later. Ratoons are thereafter taken at intervals of 12 months until declining yields enforce replanting. Survival is better the higher the rainfall and, as will appear below, has increased over the years. The planters' decision system for replanting is not known but must involve some sort of economic calculation, balancing declining returns against replanting costs (SIMMONDS, 1973).

It is against this complex background of changing husbandry and fluctuating environment that the effects of varietal change in Barbados must be viewed. The early history of varieties in Barbados has been reviewed by STEVENSON (1952, 1960, 1965) and need not concern us here but one might recall that Barbados was, with Java, one of the two pioneers in cane breeding. General breeding history of the crop has been summarized by SIMMONDS (1975). At the beginning of the period in question, the Barbados cultivation was dominated by three noble canes (N) (Table 1) and had been dominated by their parents and predecessors for the previous 140 years. Noble breeding produced successful new varieties from about 1900 onwards but there are no data by which their effects might be assessed.

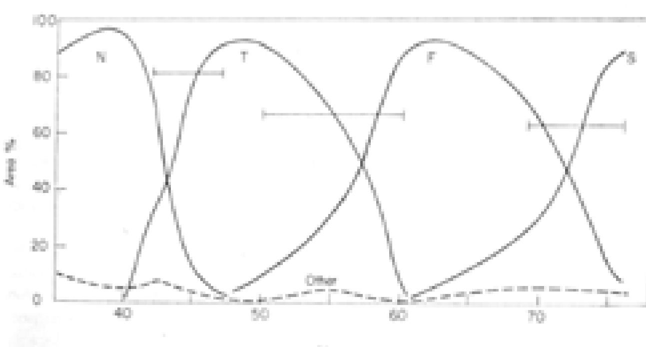

Figure 1. Four cycles of sugar-cane breeding in Barbados. Noble canes (N), Thirties (T), Forties (F) and Sixties (S). See Table 1 and text. The three horizontal lines show the periods over which contemporary yield comparisons were made (Table 2). The broken line represents the small residue of unidentified and minor varieties.

Table 1. History of leading sugar-cane varieties in Barbados*

Period	*Features*
Before 1942	Noble canes (*N*) dominant. *N1*: BH10/12; 1919–49; 30% in 1938; *H* *N2*: B726; 1930–47; 30% in 1938; *M* *N3*: B2935; 1933–45; 46% in 1941; *L* and *M*
1940–48	Transition, Noble (*N*) to Thirties (*T*). Sequence *M–L–H*; yield comparisons 1942–47
1945–55	Thirties (*T*) canes dominant. *T1*: 37161: 1942–63; peak 93% in 1949; *L*, *M* and *H*
1948–62	Transition, Thirties (*T*) to Forties (*F*). Sequence *H–M–L*; yield comparisons 1950–62
1958–69	Forties canes (*F*) dominant. *F1*: B41211; 1950–73; peak 26% in 1960; *L* and *M* *F2*: B45151; 1955–72; peak 22% in 1962; *M* and *H* *F3*: B4744; 1954–78; peak 33% in 1970–71; *M* and *H* *F4*: B49119; 1958–74; peak 30% in 1963–66; *L* and *M*
1962–76	Transition, Forties (*F*) to Sixties (*S*). Sequence *M–L–H*; yield comparisons 1969–76.
1974 onwards	Sixties canes (*S*) dominant. *S1*: B59162; 1971– ; peak 19% in 1975; *L* and *M* *S2*: B60267; 1970– ; peak 12% in 1974; *M* and *H* *S3*: B62163; 1972– ; peak 53% in 1976; *L*, *M* and *H*

* See also Figure 1

Table 2. Three cycles of sugar-cane varietal change in Barbados. Survival, yield and yield regressions during the transitional periods

		Rainfall area									
		Low		*Medium*		*High*		*Regression*			
		X	*Y*	*X*	*Y*	*X*	*Y*	*N*	*r*	*a*	*b*
(1) *N* and *T*											
Survival	(year)	1·4	1·7	1·8	2·2	2·0	2·7	—	—	—	—
Yield (t/ha)	*P*	**65·5**	**72·8**	**75·1**	**87·6**	**87·6**	**91·4**	15	0·871	17·1	0·873
	R_1	49·7	56·7	55·0	69·5	72·1	**76·1**	13	0·768	22·1	0·754
	R_2	—	—	—	—	65·0	65·5	8	0·474	50·2	0·221
(2) *T* and *F*											
Survival	(year)	2·5	3·1	2·9	3·4	3·6	3·6	—	—	—	—
Yield (t/ha)	*P*	**80·6**	**91·1**	**93·9**	**102·4**	**105·2**	**114·5**	31	0·952	2·0	1·082
	R_1	67·3	**78·3**	**75·8**	**87·9**	**90·4**	**104·2**	31	0·963	6·3	1·077
	R_2	62·8	70·8	72·8	83·9	**80·1**	**99·2**	30	0·938	−4·8	1·239
	R_3	62·3	69·8	67·8	76·6	67·5	84·6	24	0·887	4·0	1·114
(3) *F* and *S*											
Survival	(year)	3·3	3·7	4·0	4·2	4·3	5·0	—	—	—	—
Yield (t/ha)	*P*	**55·5**	**66·5**	**75·6**	**80·8**	**94·7**	**88·6**	16	0·853	40·7	0·517
	R_1	**39·2**	**44·2**	**62·0**	**68·0**	**90·6**	**85·4**	15	0·967	14·3	0·823
	R_2	39·4	47·0	51·7	**59·5**	**78·1**	**76·3**	15	0·919	21·8	0·688
	R_3	—	—	47·5	54·2	69·8	**66·3**	10	0·897	29·9	0·530
	$R_{4,5}$	40·4	44·2	50·7	53·0	64·8	63·5	—	—	—	—

Notes:

1. For each cycle, T, the independent variate in the regression columns, is the new variety or varieties that displaced the old, thus: (1) $\mathcal{T}$ on $\mathcal{N}$; (2) F on $\mathcal{T}$; (3) *S* on $\mathcal{F}$.
2. In the columns headed Regression, N is the number of data-pairs in each entry, r the correlation coefficient, a the intercept and b the regression coefficient
3. Mean yields unbiased by ratoon selection (>90 percent survival) shown in **bold face**

It was the last of these nobles that were displaced by the new interspecific hybrid-derived canes in the period now being reviewed. Three clear cycles of replacement may be distinguished (Figure 1, Table 1). The first cycle, the canes bred in the nineteen thirties (T), was effectively represented in Barbados by one clone, B37161; other representatives of these early `nobilizations' were successful elsewhere in the West Indies (e.g. B34104) but not in Barbados. The second and third cycles [Forties (F) and Sixties (S) in Table 1] were, broadly speaking, the products of two rounds of generationwise assortative mating of the T canes.

These cycles were represented in Barbados by three or four varieties each (Table 1); again, different clones succeeded elsewhere in the West Indies (McCoLL, 1971). All the varieties included in the present study attained at least ten percent of the Barbados area and persisted for a decade; collectively they account for over 90 percent of the total area reported upon (Figure 1).

The data upon which this paper is based were all published in a series of annual reports that started in 1936 under the general title 'The yields of sugar cane in Barbados' (VARIOUS AUTHORS, 1936-76) ; earlier issues were printed for the Department of Agriculture Barbados, later ones mimeographed. These reports summarize cane yields by variety, crop and locality and are based on estate returns. Factory returns are also recorded and published but on an island basis and cannot, unfortunately, be related to variety. We therefore have very good information on cane yields by variety but none on sugar content.

Abbreviations adopted in this paper have been given above and may conveniently be summarized as follows:

Crops:	P (plant), R_1, R_2, R_3 etc (ratoons)
Areas, rainfall:	L (low), M (medium), H (high)
Varietal cycles:	N (Noble), T (Thirties), F (Forties), S (Sixties).

RESULTS

Cane yields and longevity

The results to be described mostly relate to cane yield and attention will be given first to the periods in which varietal comparisons can be made unconfounded by seasonal effects, namely the three transitional periods detailed in Table 1. As this table and Figure 1 show, the first transition was remarkably rapid, the second much slower and the third intermediate in rate. All three resulted in about 90 percent of the area (after the transition had been effected) being occupied by the leading varieties specified in Table 1. Survival and yields are summarized in Table 2. Survival is defined as the mean age at replacement and it was estimated by constructing, in effect, life tables. Yield comparisons were based on pairs of values, for new and old varieties, in the same rainfall area, in the same year and in the same stage of the crop cycle. Except that very small areas were discarded, all the data were used, so the results are founded on enumeration of a substantial part of the island's crops in those years.

Conclusions are that: (1) all three cycles of replacement resulted in longer ratooning in all areas (but see also below) and that this was superimposed on the expected differences between areas (H> M> L) and upon an underlying upward trend of survival with time; (2) the first two cycles also resulted in substantial increases in cane yield, superimposed, like survival, on expected differences between rainfall areas and an upward trend with time; (3) the third cycle took place against a background of recurrent drought and declining husbandry (see above); the new varieties (the Sixties canes) showed a clear yield advantage only in the harder conditions and were actually lower-yielding than the Forties in the better areas.

The regressions in the last two columns of Table 2 are based on all available data across rainfall areas, since these were found to be (with one exception) homogeneous. Regressions between crops, especially in the later ratoons, were probably somewhat heterogeneous; since many ratoon crops had been fairly severely selected in preceding years, complete homogeneity would perhaps be surprising but no evident pattern emerges. For the first cycle, despite ratoon selection, P and R were homogeneous. For the second and third cycles first ratoon survival was high, P and R1 were homogeneous and the joint regressions were (t/ha) :

$$\mathcal{Y}_T = 16.5 + 0.864\, \mathcal{Y}_N \qquad (r=0.865,\ \mathcal{N}=28) \quad (1)$$

$$\mathcal{Y}_F = 8\text{-}8 + 1.024\, \mathcal{Y}_T \qquad (r=0.959,\ \mathcal{N}=62) \quad (2)$$

$$\mathcal{Y}_S = 24.9 + 0.696\, \mathcal{Y}_F \qquad (r=0.912,\ \mathcal{N}=31) \quad (3)$$

Correlations are generally high, sometimes very high. There was no evidence of non-linearity. The regression coefficients just given are, as `functional relationships', somewhat underestimated because of 'attenuation' due to `departures' in the independent variate (SPRENT, 1969). Several alternative estimates are available (see RICKER, 1973, for general discussion) of which the one used here is that which minimizes sums of squares of deviations perpendicular to the line. So adjusted, the equations become:

$$Y_T = 9.8 + 0.999\ Y_N \quad (4)$$

$$Y_F = 6.4 + 1.071\ Y_T \quad (5)$$

$$Y_S = 22.4 + 0.744\ Y_F \quad (6)$$

These equations imply widely varying differences in adaptability. T (with b =1) was constantly superior to N by about 10 t/ha at all levels of performance; F (with b > 1) was slightly more responsive than T to good conditions but superior everywhere; S (with b < 1) is superior to F only under poor conditions (as is also evident from mean yields over areas in Table 2).

In Figure 2, yields in the three rainfall areas were combined as means, weighted by areas, to give estimates of island plant crop yields had N, T, F and S been grown alone for the whole period. The unbroken parts of the lines represent actual yield data; the broken parts were constructed from the regressions given above.

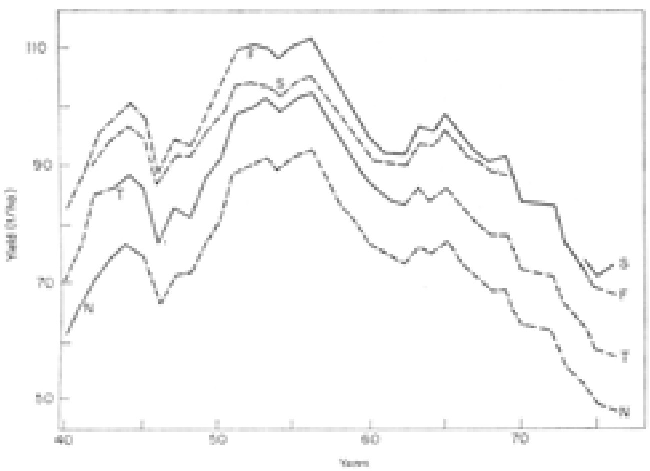

Figure 2. Plant crop cane yields in Barbados by the four groups of varieties. Means, weighted by areas over the three rainfall zones, plotted as five year moving averages. Unbroken lines are actual yields, as observed, broken lines are calculated from regressions (see text)

Trial calculations show that the exact form of regression chosen is not very critical and would not affect the main conclusions that: the two earlier cycles were roughly equal in effect and jointly added about 20 t/ha to plant crop yields; and the superiority of the S clones to F in the drier parts is so closely compensated by lower yields elsewhere (Table 2) that mean performance has differed but little.

There is no doubt therefore that the new canes contributed greatly to yield in the plant crop. What, then, of survival and yield in the ratoons? Table 2 shows, remarkably consistently over rainfall areas, that each cycle was accompanied by prolonged survival; on an all-island basis the average life of a field increased from 1.8 to 4.5 year over the 35 year period and it looks as though about 1.2 year of this 2.7 year increase could have been due to the new varieties. This is an upper estimate because any underlying trend is confounded with varietal change during the transition period. The local tradition, however, is strong that the newer varieties have ratooned better than the old ones but the effect does not seem to be as big as might have been expected; certainly there has been an underlying upward trend of longevity, the product of economic pressures and independent of variety.

Data on ratoon yields unbiased by selection are sparse. Table 2 shows that, virtually everywhere, the decline from P to R is greater than from R_1 to R_2. This, as noted above, is expected, because of the longer

Table 3. Yields (t/ha) of plant and ratoon crops, orthogonal with respect to season and unbiased by ratoon selection

Cycle	No. of observations	Crop			Difference	
		P	R_1	R_2	$P-R_1$	R_1-R_2
N	5	87·7	72·6	—	15·1	—
T		91·3	76·2	—	15·1	—
Difference					0·0	
T	8	106·0	90·8	80·5	15·2	10·3
F		116·9	106·3	98·8	10·6	7·5
Difference					4·59†	2·81‡
F	12	84·1	75·3	67·2	8·9	8·0
S		83·8	75·1	71·8	8·7	3·3
Difference					0·20	4·67§

Tests of differences were all positive but none significant:
† t [7 *d.f.*] = 4·59/2·10 = 2·18
‡ t [11 *d.f.*] = 2·81/1·48 = 1·91
§ t [11 *d.f.*] = 4·67/2·76 = 1·70

growth of the plant crop. The data of Table 2, however, are non-orthogonal with respect to seasons; extraction of orthogonal data yielded Table 3.

Regressions of P on R_1 and R_1 on R_2 showed that B1, so constant decline at all yield levels is indicated. Table 3 suggests that ratoon yields have been better sustained in recent years and that the two latest cycles of new varieties were superior to their predecessors in this respect. None of the relevant t, however, is significant though all are suggestive. On balance it looks as though the advantage might be 2 to 5 t/ha in two successive crops but the amount is not well estimated and it is clear that any gain in this respect is smaller than the plant crop effect (Figure 2) sustained over crops. In summary, therefore, it seems certain that new varieties survived longer than their predecessors and at least likely that their ratoon yields declined a little more slowly.

Sugar content

The results so far have all referred to cane yields and longevity. Turning now to sugar content (Q, sucrose percent cane), there are, as noted above, no data by varieties and any analysis must depend on examination of trends of Q with time. In the event, no clear conclusions are possible (Table 4); any apparent regression of means of Q, on time is non-significant. Reporting in the early years was incomplete; there was a rising trend of factory efficiency in the nineteen forties; there is some negative relationship between cane yield and Q because rainfall that favours one disfavours the other; and the potentially favourable effect of recent droughts

Table 4. Out-turn of sugar (Q) from Barbados factories for various periods characterized by varieties grown, 1936-76. Q as 96° sucrose percent off fresh cane

	Period					
	1936–42 N	*1943–46* N–T	*1947–51* T	*1952–61* T–F	*1962–69* F	*1970–76* F–S
No. of years	7	4	5	9†	8	7
Q‡	11·56	11·75	11·68	11·53	11·49	11·41

† One freakishly low year (1958, 10·1 per cent) excluded
‡ *GM* = 11·55; *VR* [*d.f.* = 5 and 34] = 0·0802/0·1323 = 0·61

on Q have been substantially offset by the deleterious effects of burning. Any possible varietal effects are hopelessly confounded with these other changes. Local tradition is strong that new varieties have been at least no worse than their predecessors but, while no doubt true, this belief is strictly untestable. Trials in Guyana of materials comparable with the N—T—F cycles treated here suggested considerable improvement in Q (Simmonds, 1976) but the result obviously cannot be extrapolated to different varieties at a different time in a different place.

Effect of new varieties on total crop

An attempt is now made to estimate the overall effect of new varieties on the crop, basing the calculations essentially on the plant crop yields summarized in Figure 2. Study of aggregate yield data for the island and of more detailed figures for transitional periods suggested the rule that yield over all crops could be well approximated by plant yield minus x, where x was about 6.3 t/ha up to 1955 and 12.5 t/ha thereafter. Then, knowing areas under cane and patterns of varietal replacement, and using the plant crop yields (actual and constructed) of Figure 2, the varietal component of increasing yield can be estimated (Figure 3). Taking the nobles (N) as base, the additional crop annually attributable to new varieties rose from about 0.1 Mt due to the T canes to about 0.25 Mt when the F canes were fully established.

The gains due to new varieties may be thought of in relation to their immediate predecessors or to a more remote base (Table 5). The former view attributes a permanent gain to a new variety even though it may have disappeared from cultivation; old varieties long outclassed are thus heavily weighted (e.g. T in Table 5); the latter view sets new varieties against standards with which they never actually competed and is to this extent unrealistic. There appears to be no simple answer to this, the problem of assessing the relative success of non-contemporary varieties. There is no doubt, however, of the collective success of the three cycles of Barbados canes; they added about 23 percent to crop over the whole period. Current gains, due to the S canes, are as great as ever in absolute terms and (because average yields are low) relatively larger than before; but they show up best in poor conditions and their average advantage over their immediate predecessors (F) is

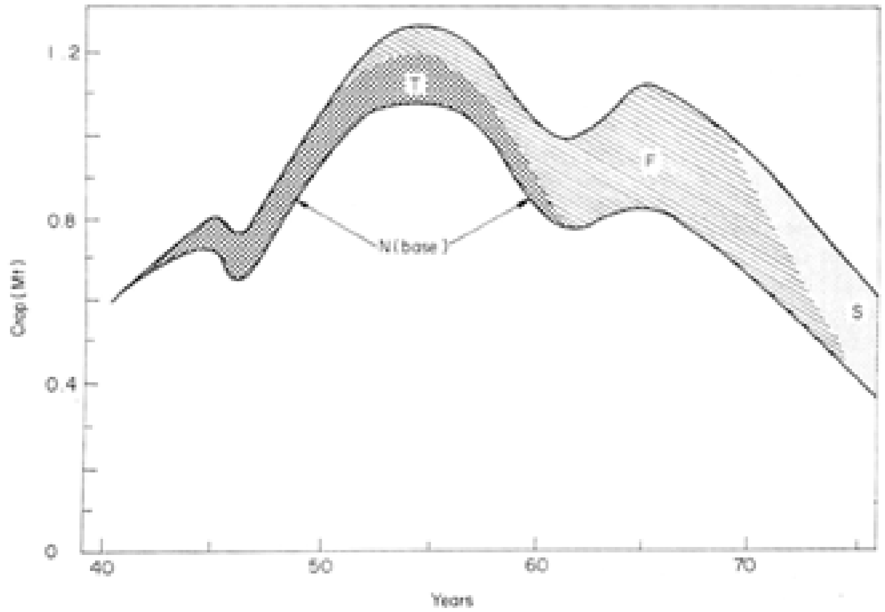

Figure 3. The contribution of breeding to the Barbados sugar-cane crop. Shaded areas are increments of crop over the calculated Noble (N) base attributable to three cycles of new varieties. See text and Table 5

Table 5. Estimated total gains (Mt) to the Barbados sugar-cane crop due to plant breeding, 1940-76

Gain	*Cycle* *T*	*F*	*S*
Over predecessor	4·00	2·63	0·05
Over base	1·82	3·65	1·21
Base (Noble) total for 37 years	= 28·80 Mt		
Gains due to plant breeding	= 6·67 Mt		
Total crop	= 35·47 Mt		
Gain over base, per cent	= 23·2		
Gain, per cent per annum (36 years)	= 0·64		

small. In practice, their longer ratooning (Table 2) may be more important economically than a comparatively modest yield advantage.

DISCUSSION

There are four points to make. They concern: the biological advantages of the new canes, their economic effects, the importance of genotype—environment (GE) interactions and longer-term implications for cane breeding.

The principal advance has clearly been in cane yield sustained over crops; there may have been a slight reduction in the rate of yield decline over crops but this is unproved and there is no evidence, either way, for any change in quality (i.e. sugar percent cane). Breeding has therefore primarily affected crop biomass, there being no evidence for enhanced partition. In many other crops, changed partition (towards product, away from crop waste) appears to have been a more important component of rising yields than biomass per se (SIMMONDS, 1979, Chapter 3).

This study provides a basis for an economic analysis, in cost-benefit terms, of the effects of cane breeding, freed by the form the calculations take, of the confusing effects of changing husbandry and weather. Such an analysis, however, would not be easy because it would have to take account, not only of enhanced sugar production per unit area, but also of altered costs of production (including ratooning capacity and the lengthened replanting cycle). There is a growing interest in analysing the economic consequences of applied research and several plant breeding programmes have been shown to be highly successful [short review and references in Simmonds (1979), Chapter 10]. Barbados cane breeding is certainly in this category and it is to be hoped that some interested economist will take the matter up. The impact of canes bred in Barbados certainly goes far beyond Barbados and any serious analysis would have to take a wide view of the matter.

At an admittedly rough computation, the total increment of sugar due to Barbados breeding is probably about 4 Mt over a 30 to 40 year period. EVENSON (1977) (see also EVENSON and KISLEV, 1975) has concluded, by means of production—function analysis, that cane research has indeed been highly productive but the work does not separate breeding from other research components.

The idea of using regressions of individual varieties on trials means, as a measure of adaptation in plant breeding programmes, was advanced by FINLAY and WILKINSON (1963), was later elaborated by EBERHART and RUSSELL (1966) and has since gained fairly wide currency. Briefly, low slopes ($b < 1$) indicate the widely adapted, 'stable' variety, unit slopes ($b = 1$) the average variety and steep slopes ($b > 1$) the narrowly adapted variety responsive to good conditions. A slope other than unity indicates the variety that shows a pronounced GE interaction (see HILL, 1975 for review). It has often been suggested that breeders should prefer one type or the other (usually the stable kind with $b < 1$). In practice, serious selection is hardly feasible and it is left to farmers to find the appropriate niche for a new variety. The idea of using regressions to compare individual varieties (or, as here, small groups of related varieties) is less familiar (discussion and sugar cane example in SIMMONDS, 1979, Chapter 6). There are two aspects, namely comparisons of stability of yield and of yield itself. From the adjusted regressions given above we have the following mean regressions as measures of stability:

$F(1.16) > T(1.06) = N(1.06) > S(0.78)$

There is no simple historical sequence but we might speculate that the responsive F and T canes were adapted to the improving environments of their times, the 'stable' S canes to the declining conditions of recent years (Figure 3). As to yields per se, it will be obvious that only when $b = 1$ can a difference be described by a simple mean and only when $a = 0$ by a single percentage figure. Here we touch upon the trials problem mentioned in the introduction: the only evident method of testing the indeed universal (but so far untested) assumption to the effect that trials predict agricultural performance is by examining the colinearity of trials and agricultural regressions. These Barbados data provide (so far as can be ascertained) the first occasion on which such a test has become possible and results will be reported in due course.

Finally, there is the question of long-term progress in cane breeding. For the past 15 years, cane breeders all over the world have been conscious that the genetic base of the crop was narrow (as evidenced by pedigree studies), that the marvellous achievements of the thirties and forties would not readily be repeated and that there was a fairly urgent need to widen the genetic base.

This is in hand in many programmes but decisive results have yet to emerge. On the basis of informed guesswork, one might suspect that future advances will resemble those of the recent past, though maybe individually of lesser magnitude. That is, biomass and maintenance of biomass over crops (including, of course, disease resistance as a component) will be the principal elements; sucrose content must be maintained but is probably now so near a physiological limit that substantial improvement can hardly be expected.

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