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Research Article

Effect of Planting Material Type on Experimental Trial Quality and Performance Ranking of Sugarcane Genotypes

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In recent years, the use of presprouted setts (MPB, which stands for "mudas pre-brotadas" in Portuguese) to establish commercial sugarcane nurseries has grown in Brazil. MPB and single-bud setts (SBS) have the advantage of requiring less planting material and enabling a higher multiplication rate of the source material as compared with the conventional multibud sett (MBS) planting system. Sugarcane breeding programs could also potentially benefit from the precise spacing afforded by MPB or SBS planting materials, by reducing trial variability. However, the effect of planting material type on the performance ranking and consequent selection of sugarcane clones in a breeding program has not been previously investigated. We present results on possible interactions between genotype and the type of planting material (MPB, MBS, or SBS) on key performance parameters, like sugar content, cane yield, and sugar yield, in the context of the intermediate phase of a sugarcane breeding program. Our results indicate that trial quality does not necessarily improve with the use of MPB or SBS planting materials and that type of planting material has a significant effect on the ranking of sugarcane genotypes, and this needs to be taken into consideration when considering the use of new planting technologies in breeding trials of vegetatively propagated crops such as sugarcane.

1. Introduction

Sugarcane is a vegetatively propagated crop. Manual planting of multibud setts (MBS) is the traditional planting material used in the planting of commercial nurseries and production fields. To minimize the risk of gaps in the resultant stand, manual planting rates are high (15–21 buds/meter), corresponding to 11–14 tonnes (T) of planting material/hectare (ha). With mechanized planting, the amount of planting material used is even larger, reaching levels greater than 20 T/ha. Sugarcane production costs have increased due to increased labor and agricultural input costs, with the cost of planting material accounting for almost 25% of operational production costs [1]. The large quantity of planting material required in traditional planting systems also leads to problems with logistics, storage, and loss of bud viability.

New planting systems have been developed to overcome some of the disadvantages of traditional methods. The presprouted seedling (MPB) planting system allows for a reduction in the quantity of planting material and better control of seedling vigor [2–6]. Another planting system (Plene™) developed by Syngenta uses 5 cm, single-bud setts (SBS) treated with a pesticidal slurry [7]. Bud chips are also a promising alternative for reduction of sugarcane production costs, although improvement of survival rates and plant vigor under field conditions is needed [8].

Genetic improvement of sugarcane is based on the selection and cloning of superior genotypes of segregating populations obtained through sexual crosses between different individuals [9]. Different methodologies have been used in the selection of individuals in the early stages of sugarcane breeding: mass selection [9], Australian sequential selection [10], modified sequential selection [11], and individual simulated best linear unbiased prediction (BLUP) [12, 13], among them. After the initial seedling phase, selection is based on planting clonal setts, as MBS, in plots that are assessed for key agronomic attributes. As selection progresses, the size of the plot and the number of replicates per clone increase, which allows better assessment of the materials under selection.

Sugarcane breeding trials could benefit from using planting systems that increase efficiency and data quality. Higher trial data quality could result from more precise spacing in trial plots. Planting systems with the potential to do more replications in early breeding stages due to more efficient utilization of scarce planting material would provide an additional benefit. However, planting system modifications have the potential to affect the ranking and consequent selection of genotypes, since experimental results of important performance attributes such as yield and sugar content could differ depending on the planting system used. Studies on intrarow spacing and number of buds per sett in commercial varieties [14] and optimal planting rates using whole stalks for different varieties have been reported [15]. However, to date and to our knowledge, there have been no reports in the literature about the effect of presprouted seedling (MPB) or single-bud setts planting materials on clonal selection in sugarcane breeding programs.

In the present study, we evaluate potential interactions between genotypes and the type of planting system and whether the type of planting material has an effect on trial data quality.

2. Materials and Methods

2.1. Trial Design. Three types of planting material were tested: 3-4 bud setts (MBS—conventional method), presprouted seedlings (MPB), and 5 cm, single-bud setts (SBS). All planting materials were generated from selected healthy stalks harvested approximately 9 months after planting.

All three types of planting material were planted at a single location in three different adjacent trials. All trials were in a randomized complete block design with 3 replicates. Plots consisted of two 10 m rows spaced 1.5 m apart. Adjacent plots were spaced 3 m apart along their length.

The same genotypes (cultivars and clones; see Table 1) were planted in each of the 3 different trials, adjacent to each other. Clones were part of the 3rd stage of the selection process of the Syngenta sugarcane breeding program. This stage is the first one in which replicates are used and plot weight is directly measured following mechanical harvesting.

The process for making and planting the different types of planting materials is described below and in the accompanying figures (Figures 1–3). In all cases, supplemental irrigation was applied until the crop stand was well established.

2.1.1. Presprouted Setts (MPB). Eight-month-old sugarcane stalks were harvested and 5 cm, single-bud setts were cut and planted in soil mix. The resultant sprouted seedlings were manually planted in the field trial after 50 days at an intrarow spacing of 0.5 m.

Table 1: Varieties and clones used in the study.

Varieties	Clones		
RB86-7515	S09-0001	S09-0040	S09-0114
RB96-6928	S09-0007	S09-0046	S09-0122
SP81-3250	S09-0011	S09-0048	S09-0140
	S09-0022	S09-0052	S09-0144
	S09-0023	S09-0055	S09-0146
	S09-0031	S09-0069	S09-0148
	S09-0036	S09-0080	S09-0153
	S09-0037	S09-0081	S09-0154
	S09-0038	S09-0098	

2.1.2. Single-Bud Setts (SBS). Ten-month-old sugarcane stalks were harvested, and 5-cm, single-bud setts were cut and treated with a slurry consisting of industrial proprietary treatment. Subsequently, these were planted manually in the field at a rate of 8 single-bud setts per meter.

2.1.3. Multibud Setts (MBS): Conventional Method. Ten-month-old sugarcane stalks were harvested manually and placed in row furrows. These were cut with a machete in the furrow into 30–40 cm pieces, as per conventional manual cane planting practice.

The 3 field trials were planted in a single week in April 2014. Fertilization and cultural practices followed conventional commercial practice and were the same for all trials. Evaluations of sugarcane agronomic parameters were made over two harvest cycles (plant cane and 1st ratoon). In August 2015, a sample of 10 stalks per plot was subjected to laboratory POL analysis (a measure of sugar content). Subsequently, in the same month, the trial was mechanically harvested and whole, individual plots were weighed to estimate TCH (tonnes cane per hectare). From the POL and TCH parameters, the TPH (tonnes POL per hectare) was calculated for the plant cane harvest. It was not possible to measure POL in the 1st ratoon harvest, but in May 2016, the Brix of 5 stalks per plot was taken and averaged. Mechanized harvesting and weighing of trial plots were conducted in June 2016. Thus, Brix, TCH, and TBH parameters (tonnes Brix per hectare) were estimated for the 1st ratoon harvest.

2.2. Statistical Analysis. Analysis of variance was done by planting material (MPB, SBS, and MBS) and harvest cycle (plant cane, 1st ratoon), considering the effects of genotype (26 clones and three varieties) and blocks (3 per planting material). For each of the three traits (POL or Brix; TCH; and TPH or TBH), the ratio between the largest and smallest mean residual squares was less than three. As a result, we performed joint analyses by traditional ANOVA and mixed model restricted maximum likelihood (REML)/best linear unbiased prediction (BLUP), in which planting material, harvest cycle, and blocks nested within planting material were fixed effects, and genotype, as well as genotypic

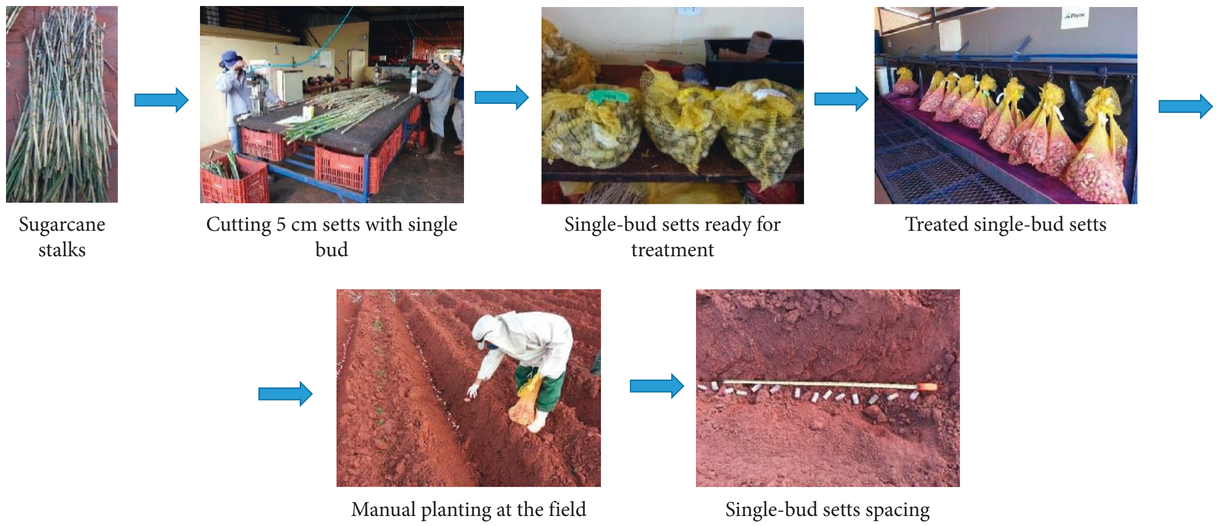

Figure 1: Process for SBS (single-bud sett) production and planting.

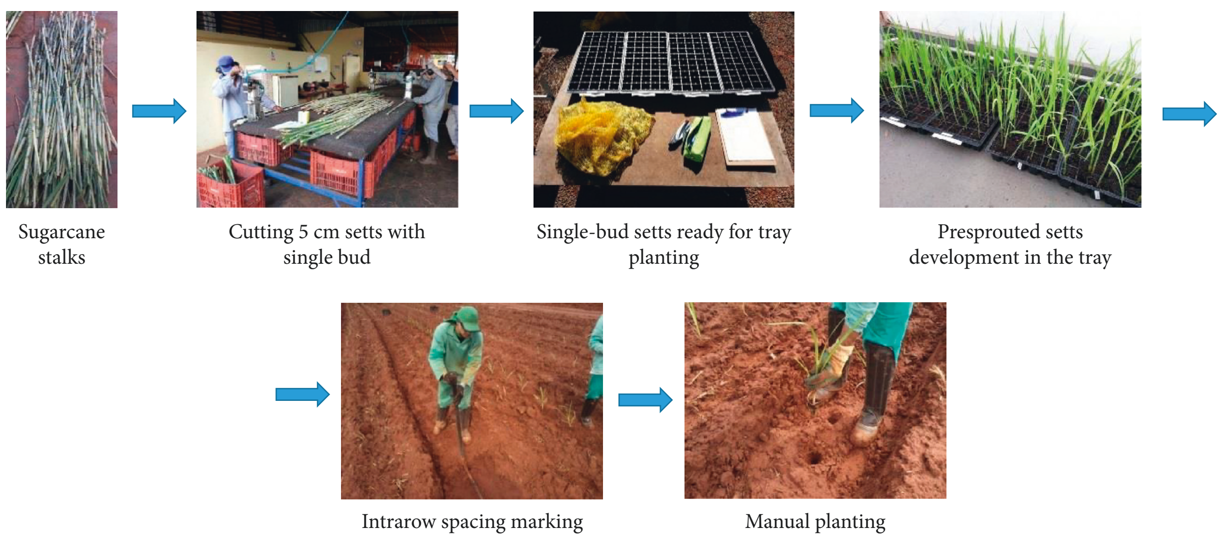

Figure 2: Process for MPB (presprouted seedling) production and planting.

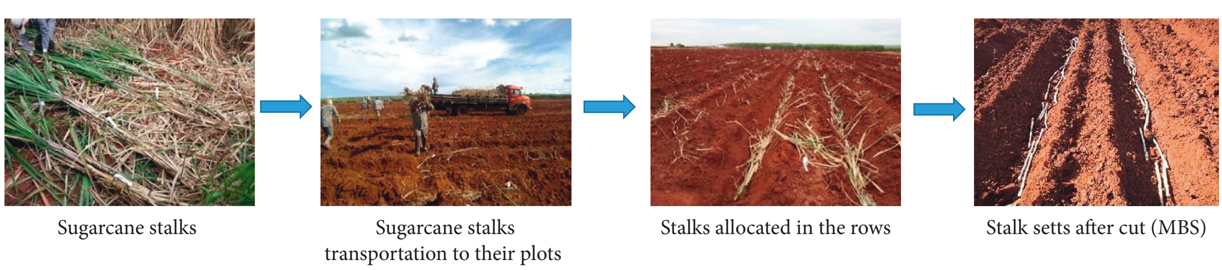

Figure 3: Process for MBS (multibud sett) production and planting.

interactions with planting material and harvest cycle, were random effects. A split-plot design was not used due to possible plot border effects resulting from different growth rates of different adjacent plant material types. As stated above, mean residual squares within each trial were similar; consequently, we performed a joint analysis by ANOVA (despite the absence of randomization), much as experiments across locations are analyzed.

Within each cycle (plant and ratoon cane), statistical modeling was done as for a split-plot design in time.

Table 2: Average performance parameters and coefficients of variation (CV) in trials with 3 types of planting materials, 29 genotypes, and 3 blocks (replicates) per planting material.

Performance parameter	MBS average	SBS average	MPB average
POL-Brix			
Plant cane POL	12.42	13.55	13.05
1st ratoon Brix	13.59	14.71	14.71
%CV, plant cane POL	7.47	5.89	7.34
%CV, 1st ratoon Brix	8.25	7.23	7.46
TCH			
Plant cane TCH	136.11	134.78	139.10
1st ratoon TCH	104.79	97.35	106.95
%CV, plant cane TCH	12.54	15.15	13.95
%CV, 1st ratoon TCH	12.19	16.69	14.29
TPH_TBH			
Plant cane TPH	16.85	18.10	17.94
1st ratoon TBH	14.29	14.21	14.84
%CV, plant cane TPH	14.44	17.01	16.85
%CV, 1st ratoon TBH	15.81	15.53	16.81

Table 3: Mean squares (MS) and p values pooled joint analysis of variance. Conventional fixed model, with planting material type as test and harvest cycle (plant cane, 1st ratoon) as split-plot, was used.

Source of variation	POL_BRIX	TCH	TPH_TBH
Planting material (PM)	59.60 ($p < 0.0001$)	1484.92 ($p = 0.02$)	24.17($p = 0.06$)
Genotype	19.83 ($p < 0.0001$)	4855.15 ($p < 0.0001$)	104.95 ($p < 0.0001$)
Genotype × PM	1.48 ($p = 0.01$)	494.80 ($p = 0.07$)	12.48 ($p = 0.03$)
Harvest cycle	141.37 ($p < 0.0001$)	12,2717.39 ($p < 0.0001$)	1085.90 ($p < 0.0001$)
Harvest cycle × PM	1.88 ($p = 0.22$)	364.55 ($p = 0.17$)	13.61 ($p = 0.08$)
Harvest cycle × genotype	3.87 ($p < 0.0001$)	1002.86 ($p < 0.0001$)	16.51 ($p < 0.0001$)

3. Results

Mean values of TPH_TBH were similar for the three planting material types tested (Table 2). Average POL and Brix were higher for SBS and MPB than for conventional MBS planting material, whereas average TCH for SBS was lower than that of the other two types of planting material. Average TCH for MPB and the conventional MBS planting material was quite similar, as previously observed by [16], who noted that MPB required less planting material. Regarding trial coefficients of variation (CVs), these were similar across trials, planting material type, and harvest cycles, being in general lower for POL_Brix. TCH CVs for MPB and SBS were slightly higher than for the conventional MBS planting type. For TPH_TBH, the plant cane average was higher for MPB, but no differences between the 3 planting material types were observed in the 1st ratoon. The CV for TBH was slightly lower in the conventional MBS planting type than for the other two.

Conventional analysis of variance (Table 3) points to highly significant effects of genotype ($p < 0.0001$) and of the interaction of genotype with planting material type ($p \leq 0.1$) across the different parameters evaluated, indicating that rank ordering of genotypes could be affected depending on the planting material type used in the trial. However, harvest cycle and the interaction of harvest cycle with genotype also had a highly significant effect ($p < 0.0001$) on the parameters tested.

Random effect variances obtained using a mixed model (Table 4) show that genotype accounts for approximately 36–37% of the variability, which allows for selection of the best clones in a breeding program. Interactions of genotype with planting material type ranged from 2.7% to 7.1%: lower but significant ($p < 0.05$) for POL_Brix and higher for TCH and TPH_TBH, indicating that planting material type has the potential to affect the rank order of clones in the selection process. Interaction of genotype with harvest cycle was significant ($p < 0.05$), as expected, since varieties in commercial sugarcane fields will also differ in their performance depending on harvest cycle that includes the environmental effects of growing season. There is also a weak interaction of harvest cycle with planting material type ($p < 0.25$; data not shown).

Predicted genotypic differences (PGDs) obtained in the mixed model (Tables 5 to 7) are presented to show differences in genotype ranking for each performance parameter, by planting material type. For each genotype, the expected genotypic value is the mean + PGD.

For TPH_TBH (Table 5), the MPB and SBS planting materials produced similar means ($p < 0.05$) that were higher than those obtained with the MBS conventional planting material. Results with the 10 best genotypes show differences in rank ordering. For example, using conventional MBS planting material, the best clone was S09-0146, yielding 4.74 tonnes above the 15.57 TPH_TBH general average, and slightly surpassing the two RB variety checks.

Table 4: Components and percentage of variance as obtained in a pooled joint analysis with a mixed REML/BLUP model, considering genotype, genotype × planting material, genotype × harvest cycle, and residual as random effects.

Variable	POL_BRIX	TCH	TPH_TBH
Genotypes	0.8658 (37.08%)	232.02 (36.41%)	5.1067 (36.16%)
Genotypes × PM	0.0632 (2.71%)	37.75 (5.92%)	1.0028 (7.10%)
Genotypes × harvest cycle	0.3081 (13.20%)	93.47 (14.67%)	1.3193 (9.34%)
Residual	1.0978 (47.02%)	274.07 (43.00%)	6.6918 (47.39%)

Table 5: Predicted genotypic differences (PGD) for TPH_TBH across 29 genotypes (mean plant cane TPH and 1st ratoon TBH) and three planting material types (MBS, SBS, or MPB).

Rank	Genotype	MBS	p value	Genotype	SBS	p value	Genotype	MPB	p value
1	S09-0146	4.7444	**<0.001**	RB966928	4.4965	**<0.001**	RB966928	4.592	**0.0002**
2	RB867515	4.4646	**<0.001**	S09-0144	4.1737	**0.0002**	RB867515	4.5099	**0.0003**
3	RB966928	3.702	**0.001**	S09-0146	4.1348	**0.0003**	S09-0122	3.0073	**0.0095**
4	S09-0031	3.0899	**0.006**	S09-0114	3.4487	**0.0021**	S09-0114	2.614	**0.033**
5	S09-0114	2.4153	**0.031**	S09-0038	3.2957	**0.0384**	S09-0140	2.5809	**0.0254**
6	S09-0038	2.0233	0.07	S09-0052	2.7208	**0.0325**	S09-0144	2.304	0.0597
7	S09-0052	1.887	0.09	S09-0153	2.1413	0.0919	S09-0031	1.773	0.1228
8	S09-0140	1.6314	0.143	S09-0140	2.0738	0.0607	S09-0069	1.5078	0.1889
9	S09-0144	1.2664	0.254	S09-0148	1.6054	0.1454	S09-0023	1.3682	0.2614
10	S09-0148	1.2593	0.257	RB867515	0.8213	0.4548	S09-0052	1.0307	0.3682
11	S09-0037	0.7224	0.515	S09-0037	0.7444	0.555	S09-0146	0.9092	0.4548
12	S09-0122	0.3986	0.719	S09-0031	0.3428	0.7548	S09-0007	0.5837	0.6099
13	SP813250	0.3901	0.725	S09-0069	0.1064	0.9227	S09-0153	0.0999	0.9345
14	S09-0046	0.2438	0.826	S09-0055	−0.045	0.9713	S09-0046	−0.209	0.8549
15	S09-0023	0.1558	0.888	S09-0122	−0.09	0.9431	S09-0148	−0.643	0.6231
16	S09-0055	−0.394	0.722	SP813250	−0.183	0.8674	S09-0055	−0.699	0.5416
17	S09-0069	−0.435	0.695	S09-0154	−1.439	0.1916	S09-0038	−0.912	0.4259
18	S09-0153	−0.659	0.552	S09-0080	−1.678	0.1282	S09-0040	−0.943	0.4101
19	S09-0007	−0.694	0.532	S09-0022	−1.793	0.1565	S09-0001	−1.12	0.3576
20	S09-0036	−0.708	0.524	S09-0081	−1.854	0.0932	S09-0048	−1.192	0.2983
21	S09-0022	−1.703	0.126	S09-0040	−2.074	0.0607	S09-0037	−1.501	0.218
22	S09-0001	−2.118	0.058	S09-0023	−2.299	0.0379	S09-0081	−1.512	0.2148
23	S09-0154	−2.368	0.034	S09-0046	−2.327	0.1421	S09-0036	−1.605	0.1621
24	S09-0048	−2.389	0.033	S09-0007	−2.401	0.0303	S09-0022	−1.733	0.1313
25	S09-0081	−2.808	0.012	S09-0036	−2.527	0.0228	SP813250	−2.164	0.0767
26	S09-0098	−2.91	0.01	S09-0011	−2.685	0.0157	S09-0154	−2.295	0.0464
27	S09-0011	−3.422	0.002	S09-0048	−2.789	0.0285	S09-0098	−2.682	0.0203
28	S09-0080	−3.856	0.0007	S09-0001	−2.907	0.0226	S09-0080	−3.669	0.0017
29	S09-0040	−3.93	0.0005	S09−0098	−3.015	0.0068	S09-0011	−4.001	0.0013
TM[1]	—	15.57 **B**	—	—	16.16 **A**	—	—	16.26 **A**	—

[1]TM with different letters indicate significant (p value < 0.05) by T-test (LSD). TM = trial mean; p value testing PGD as null.

S09-0146 is ranked 3rd for TPH_TBH when planted as SBS, but is not among the top 10 genotypes when MPB is used as the planting material. Clone S09-0031 is ranked 4th just below the two RB checks when planted as MBS and is in the top 10 when MPB planting material is used, but not when planted as SBS. Similarly, S09-0122 is the top ranked clone when MPB planting material is used, suggesting good adaptation to this planting methodology, but is not in the top 10 when using the other planting methodologies. Among the checks, RB966928 was ranked 3rd when conventional MBS planting material is used, but 1st when MPB or SBS planting materials are used, whereas RB867515 did not perform well when SBS planting material was used.

For TCH (Table 6), the highest average yields were obtained from conventional MBS and MPB planting materials, with SBS planting material having a significantly lower ($p < 0.05$) mean. In terms of rank, MPB and SBS methods improved the performance of check variety RB966928 while SBS leads to deterioration in performance of the RB867515 check. Among the clones, S09-0146 is again at the 1st place when conventional MBS and SBS planting materials are used, but at the 4th place using MPB, whereas clone S09-114 ranks 3rd with all 3 planting material types. The clone S09-0038, at the 4th and 5th place when planted as MBS or SBS, respectively, drops to the 9th place when MPB is used, whereas the clone S0-007, at the 4th place when the MPB planting material is used, drops to 11th with MBS and 22nd with SBS.

For POL and Brix (Table 7), means were significantly different ($p < 0.05$) depending on the type of planting material, being higher (14.13) when SBS planting material was used; intermediate for MPB (13.45); and lowest for

Table 6: Predicted genotypic differences (PGD) for TCH across 29 genotypes (mean plant cane and 1st ratoon TCH) and three planting material types (MBS, SBS, or MPB).

Rank	Genotype	MBS	p value	Genotype	SBS	p value	Genotype	MPB	p value
1	S09-0146	39.089	**<0.001**	S09-0146	26.489	**0.0008**	RB867515	28.893	**0.0003**
2	RB867515	29.224	**<0.001**	RB966928	24.382	**0.0019**	RB966928	22.466	**0.0046**
3	S09-0114	20.817	**0.006**	S09-0114	23.463	**0.0028**	S09-0114	16.734	**0.0337**
4	S09-0038	20.557	**0.006**	S09-0153	22.079	**0.0138**	S09-0146	15.104	0.0548
5	RB966928	19.358	**0.01**	S09-0038	21.821	**0.049**	S09-0007	14.768	0.0461
6	S09-0031	14.071	0.06	S09-0144	21.342	**0.0063**	S09-0069	13.874	0.0608
7	S09-0144	12.829	0.086	S09-0052	16.24	0.0677	S09-0154	10.657	0.1486
8	S09-0052	8.2784	0.266	S09-0154	12.845	0.097	S09-0140	9.5021	0.1974
9	S09-0154	5.8661	0.43	RB867515	8.122	0.2923	S09-0038	9.2683	0.2086
10	S09-0153	5.3894	0.469	S09-0140	6.2557	0.4168	S09-0023	8.135	0.2985
11	S09-0007	4.4072	0.553	S09-0148	5.5204	0.4735	S09-0040	7.6597	0.2982
12	S09-0140	3.4683	0.641	S09-0069	3.8803	0.6142	S09-0153	6.2699	0.4226
13	S09-0148	3.4538	0.642	S09-0037	1.7567	0.8423	S09-0144	6.254	0.4238
14	SP813250	2.9916	0.687	S09-0040	0.8263	0.9145	S09-0122	4.4561	0.5445
15	S09-0069	0.5793	0.938	S09-0055	−0.536	0.9516	S09-0031	4.0024	0.5862
16	S09-0037	0.0882	0.991	SP813250	−2.002	0.7948	S09-0052	−0.356	0.9613
17	S09-0023	−2.079	0.7800	S09-0031	−2.242	0.7708	S09-0148	−1.780	0.8324
18	S09-0040	−2.310	0.756	S09-0122	−4.794	0.5873	S09-0001	−5.042	0.5189
19	S09-0036	−4.000	0.591	S09-0022	−6.746	0.4453	S09-0036	−7.231	0.326
20	S09-0122	−7.842	0.292	S09-0080	−8.124	0.2922	SP813250	−8.281	0.29
21	S09-0055	−9.301	0.212	S09-0001	−11.39	0.1986	S09-0055	−10.43	0.1572
22	S09-0022	−11.24	0.132	S09-0007	−12.61	0.1033	S09-0046	−11.11	0.1323
23	S09-0046	−11.71	0.117	S09-0081	−14.50	0.0614	S09-0037	−11.96	0.1274
24	S09-0001	−12.44	0.096	S09-0023	−20.16	0.0098	S09-0048	−14.78	0.046
25	S09-0098	−20.84	0.006	S09-0011	−21.57	0.0058	S09-0022	−15.45	0.0371
26	S09-0081	−23.99	0.002	S09-0036	−21.81	0.0053	S09-0098	−17.09	0.0214
27	S09-0048	−24.47	0.001	S09-0098	−22.26	0.0045	S09-0081	−18.45	0.0194
28	S09-0011	−28.56	2E−04	S09-0048	−22.57	0.0117	S09−0080	−25.76	0.0006
29	S09-0080	−31.69	<0.001	S09-0046	−23.71	0.0327	S09-0011	−30.31	0.0002
TM[1]	—	120.45 **A**	—	—	116.07 **B**	—	—	121.62 **A**	—

[1]TM with different letters indicate significant (p value<0.05) by T-test (LSD). TM = trial mean; p value testing PGD as null.

conventional MBS (13.00). Four clones showed higher POL_Brix than the RB966928 check: clones S09-0046 and S9-0122 ranked highest in POL_Brix but were not among the top 10 for TCH. On the other hand, clone S09-0146 which ranked high for TCH was not among the best clones for POL_Brix.

Results of the correlations between predicted genotypic differences (PDG; Tables 5 to 7) were used to evaluate correlations between the 3 different planting material types for the three performance parameters (Table 8). Correlations of 0.82–0.85 were observed when comparing conventional MBS and the MPB and SBS planting materials for POL_Brix, and when comparing conventional MBS with MPB for TCH. Slightly lower correlations (0.75–0.79) were observed when comparing conventional MBS with MPB and SBS for TPH_TBH, and for conventional MBS and SBS for TCH. Hence, there are relatively good but not perfect correlations between the conventional MBS and the SBS and MPB planting materials, possibly due to interactions between some genotypes and planting material type. Correlations between MPB and SBS were generally lower, ranging from 0.61 for TPH_TBH, 0.65 for TCH, and 0.76 for POL_Brix, possibly due to higher risks to stand establishment when using SBS planting materials.

4. Discussion

The observed CVs for the parameters analyzed (Table 2) were in line with those previously observed in the scientific literature. Couto et al. [17] evaluated the range of CVs observed in sugarcane experiments and concluded that the TCH and TPH parameters presented the highest CV ranges, whereas % sucrose presented the lowest. These authors also indicated that upper CV limits for good to high precision as being 10%, 15%, and 19% for % sucrose, TCH, and TPH, respectively. Using these numbers as a guide, in the present study, only the TCH in the SBS trial is higher than these limits, which indicates that trial quality was high enough to draw conclusions from this study. Although we observe lower POL and Brix CVs with the SBS and MPB planting material (Table 2), in general our data do not provide evidence that MPB or SBS planting materials decrease variability, and thus improve trial quality, in sugarcane breeding selection trials.

Conventional analysis of variance (Table 3) points to highly significant effects of genotype and harvest cycle, and also of the interaction of harvest cycle with planting material. Milligan et al. [18] also found that genotype by harvest cycle interaction was important for sugar yield and its component

Table 7: Predicted genotypic differences (PGD) for POL_Brix across 29 genotypes (mean plant cane POL and 1st ratoon Brix) and three planting material types (MBS, SBS, or MPB). TM = trial mean; p value testing PGD as null.

Rank	Genotype	MBS	p value	Genotype	SBS	p value	Genotype	MPB	p value
1	S09-0046	1.4759	**0.0021**	S09-0046	1.7214	**<0.001**	S09-0122	1.8558	**0.0002**
2	S09-0122	1.2755	**0.0076**	S09-0140	0.9188	**0.0279**	S09-0144	1.1144	**0.0211**
3	S09-0140	0.8705	0.0667	S09-0144	0.7226	0.0828	S09-0046	1.1046	**0.0222**
4	S09-0031	0.8431	0.0757	S09-0052	0.7143	0.0864	S09-0140	0.9496	**0.0488**
5	RB966928	0.8321	0.0795	S09-0122	0.6489	0.119	S09-0081	0.9468	**0.0495**
6	S09-0055	0.7827	0.0989	S09-0036	0.6434	0.1222	RB966928	0.9301	0.0536
7	S09-0148	0.7676	0.1055	S09-0023	0.6406	0.1238	S09-0031	0.9022	0.0611
8	S09-0048	0.7429	0.1171	S09-0148	0.5182	0.2125	S09-0052	0.8589	0.0744
9	S09-0052	0.7291	0.124	RB966928	0.489	0.2392	S09-0048	0.6453	0.179
10	S09-0037	0.6221	0.1889	S09-0031	0.4834	0.2446	S09-0055	0.6145	0.2005
11	RB867515	0.3585	0.448	S09-0011	0.3832	0.3558	RB867515	0.44	0.3587
12	S09-0023	0.3516	0.4567	S09-0048	0.3053	0.4617	S09-0011	0.3297	0.4913
13	S09-0081	0.202	0.6687	S09-0037	0.2511	0.5449	S09-0037	0.2697	0.5734
14	S09-0080	0.154	0.7443	S09-0055	0.2191	0.5972	S09-0148	0.1943	0.6849
15	S09-0011	0.1306	0.782	S09-0114	0.2038	0.623	S09-0022	0.1859	0.6978
16	S09-0114	-0.1494	0.7517	SP813250	0.1482	0.7208	S09-0023	0.1105	0.8175
17	S09-0146	−0.1549	0.7429	S09-0081	0.1384	0.7384	S09-0114	0.01136	0.9811
18	SP813250	−0.1549	0.7429	S09-0146	0.137	0.741	S09-0069	−0.2428	0.6122
19	S09-0036	−0.1919	0.6843	S09-0098	−0.1356	0.7436	S09-0001	−0.3237	0.4992
20	S09-0022	−0.2455	0.6032	S09-0038	−0.1982	0.6326	S09-0080	−0.3433	0.4737
21	S09-0098	−0.2798	0.5536	RB867515	−0.2858	0.4908	S09-0098	−0.5695	0.2353
22	S09-0144	−0.3567	0.4503	S09-0069	−0.4527	0.2757	S09-0153	−0.6351	0.1859
23	S09-0069	−0.439	0.353	S09-0022	−0.5598	0.1781	S09-0146	−0.691	0.1504
24	S09-0038	−0.4733	0.3168	S09-0080	−0.5765	0.1656	S09-0036	−0.751	0.1183
25	S09-0001	−0.542	0.2519	S09-0153	−0.7323	0.0789	SP813250	−0.8515	0.0769
26	S09-0153	−0.9648	0.0424	S09-0007	−0.7852	0.0597	S09-0007	−1.1126	0.0213
27	S09-0007	−1.2119	0.0111	S09-0001	−1.272	0.0025	S09-0040	−1.4477	0.0029
28	S09-0154	−2.1933	<0.001	S09-0040	−1.7185	<0.001	S09-0038	−1.7828	0.0003
29	S09-0040	−2.7808	<0.001	S09-0154	−2.5698	<0.001	S09-0154	−2.7127	—
TM[1]	—	13.00 **C**	—	—	14.13 **A**	—	—	13.45 **B**	—

[1]TM with different letters indicate significant (p value<0.05) by T-test (LSD).

Table 8: Pearson's correlation coefficients between average performance parameters for 29 genotypes across three different planting material types, using predicted genotypic differences (PDG) from Tables 5 to 7, for each performance parameter.

Performance parameter		MBS	MPB	SBS
POL_Brix	MBS	—	0.82	0.85
	MPB	—	—	0.75
TCH	MBS	—	0.85	0.79
	MPB	—	—	0.65
TPH_TBH	MBS	—	0.77	0.78
	MPB	—	—	0.61

$N = 29$ for all correlations (Prob > (r) < 0.05 under rho = 0.

traits. In this study, the pooled variation due to genotype (Table 4) was found to be sufficient to select the top genotypes to advance to the next stage. We found a weaker but still significant interaction ($p \leq 0.1$) of genotype by planting material, suggesting that the rank ordering of genotypes could be affected depending on the planting material type used in the trial. In contrast, planting material alone had a highly significant effect only on variation of POL_Brix. These results were verified by the differences in the rank ordering of clones we observed the TPH_TBH, TCH, and POL_Brix performance parameters (Tables 5–7).

Changes in rank order of genotypes can impact the effectiveness of clonal selection in sugarcane breeding. For example, the TPH_TBH parameter can be considered the most important one for selection in the intermediate phases of a program. Selection indices in different breeding stages vary by breeding program, as shown by [19]. In our breeding program, a 10 to 20% selection index was used in the third stage. A selection index of 20% from the trials described in this study, and considering data from 2 harvest cycles, would advance 6 clones to the next phase. If we consider conventional MBS planting material as the most relevant to the current commercial sugarcane planting practice, clones S09-0146, S09-0031, S09-0114, S09-0038, S09-0052, and S09-0140 would then be selected. However, of these 6 clones, only 4 (S09-0146, S09-0114, S09-0038, and S09-0052) would be advanced if using the SBS planting material, and only 3 (S09-0114, S09-0140, and S09-0031) would be advanced by using MPB planting material.

Orgeron et al. [15], studying whole stalks planting rating effect in 8 different genotypes, found no planting rate by genotype interaction for cane and sugar yield. Similarly, Netsanet and Tegene [14], comparing three different commercial varieties and their behavior in terms of intrarow spacing and buds per setts, found no significant interaction effect or spacing used on sugar and cane yield. On the contrary, what we found in the present study was that planting material type by genotype interaction is significant. The different conclusions between the studies possibly are due to the higher number of genotypes, and the genotypes per se, used in the present study and due to the different planting material used (MPB and SBS), compared with the other cited studies.

On an average, good correlations of performance parameter were observed between the different types of planting material. These correlations mask the significant effect on the ranking of individual clones in these trials. MPB and SBS planting methodologies have generated enormous interest in the Brazilian sugarcane industry and have undeniable advantages in terms of reduction of planting costs and material handling logistics. However, the use of these new planting methodologies in a sugarcane breeding program will result in likely selection of genotypes well adapted to the particular type of planting material used, but may not have the best agronomic performance if used in commercial plantings using other planting systems, such as the current conventional MBS planting system.

Our study indicates that trial quality does not necessarily improve with the use of MPB or SBS planting materials compared with the conventional MBS. Additionally, the type of planting material has a significant effect on the ranking of sugarcane genotypes. Because of that, when considering the use of new planting technologies in breeding trials of sugarcane, this needs to be taken into consideration for the selection of genotypes for cane yield and sugar parameters.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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