

EFFECTS OF VARIETY, HARVEST AGE AND ELDANA ON COASTAL SUGARCANE PRODUCTION IN SOUTH AFRICA

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Abstract

Information on varietal adaptability to different harvest ages along the coastal belt of KwaZulu-Natal province, South Africa, is currently limiting. The objective of this study was to identify commercial and recently released varieties adapted to different cutting cycles along the coastal region of the South African sugar industry, and to evaluate the effects of *Eldana saccharina* Walker (Lepidoptera: Pyralidae) damage on productivity. The suitability of biplot analysis (a graphical representation of two-way data) for the interpretation of variety x cutting cycle data was also investigated. Two field trials (12 and 18-month harvest), consisting of the same set of 10 varieties were established alongside each other in randomised complete block designs with five replications each, and harvested for six (12-month) and three (18-month) seasons respectively. Tons cane/ha (TCANE), estimated recoverable crystal (ERC%), tons ERC/ha (TERC) and % internodes damaged (%ID) by *E. saccharina* were determined at each harvest. A restricted maximum likelihood (REML) analysis was conducted, and diagnostic biplots were produced using Genstat statistical software. Highly significant ($p < 0.001$) variety x trial interactions were observed for TCANE and TERC. Lower TERC in the 18-month trial was associated with higher *E. saccharina* damage, while varieties N39 and N41 were identified as alternatives to current commercial varieties on the 12-month cycle. Significant variety x ratoon interactions revealed three distinct patterns of ratooning with N27, N39, and N41. Diagnostic biplots allowed quicker interpretation of variety x cutting cycle data and corresponded to variety rankings generated from REML analysis. Higher yields associated with aging cane along the coast can only be achieved through appropriate variety choice, and continued variety x cutting cycle evaluations using the biplot technique will be investigated further.

Keywords: sugarcane, biplot, cutting cycle, *Eldana saccharina*, ratooning, variety

Introduction

The production of sugarcane (*Saccharum* spp.) along the coastal regions of Kwa-Zulu Natal, South Africa, entails the harvesting of successive ratoons on a 12 to 18-month cutting cycle. Age of harvest is one of the most important factors affecting productivity, and varietal differences in growth and maturity rates (Donaldson *et al.*, 2008) must be considered when harvesting decisions are made. In addition to differential varietal maturity rates, environmental conditions, management practices, and pest pressure also influence the optimal harvest age of sugarcane along the coast. Sugarcane varieties developed at the South African Sugarcane Research Institute (SASRI) exhibit pronounced differences in their suitability to different harvest ages (McIntyre and Nuss, 1998), with faster maturing varieties being more suited to the 12-month cycle, and slower maturing varieties being suited to the 18-month cycle along the coast.

Previous research has shown that the optimal physiological and economic harvest age for sugarcane along the eastern coastal areas of South Africa is 18 months (Inman-Bamber, 1991), and prior to the mid-1970s this was the recommended practice for these regions. However, since the proliferation of the sugarcane borer *Eldana saccharina* Walker (Lepidoptera: Pyralidae) in the industry in the 1970s, growers along the coast were compelled to reduce their cutting cycles, as *E. saccharina* damage increases when sugarcane is aged older than 12 months. This reduction in harvest age limits the potential growth of the crop, resulting in lower cane and sucrose yields from relatively immature sugarcane. *E. saccharina* damage is characterised by widespread boring of the cane stalk and generally increases in stressed sugarcane which has been carried over for harvesting the following season. Damage is therefore more widespread in shallow or sandy soils in low rainfall areas along the coast (Anon, 2005).

Varietal resistance to *E. saccharina* is a priority trait in the coastal 18-month plant breeding programme at SASRI, and current commercial varieties exhibit a wide range of resistance to the pest. The close association between harvest age and *E. saccharina* damage suggests that varieties physiologically adapted to the 18-month cutting cycle should also have suitable levels of *E. saccharina* resistance in order to attain potential yields. Similarly, *E. saccharina* susceptible varieties should be adapted to annual harvesting, where pest pressure is not that high. A range of commercial varieties have been released for coastal production in South Africa; however, information on their relative performance on different cutting cycles when *E. saccharina* is a threat, is lacking. Additionally, various production limitations associated with current commercial varieties such as NCo376 (disease issues), N27 (perceived poor ratooning), and N29 (disease issues), have necessitated the identification of newer commercial varieties for production under these conditions. The objective of this study was to compare current and newly released commercial varieties for adaptation to a 12 and 18-month cutting cycle along the coast, and to evaluate the possible effects of *E. saccharina* damage on the productivity of such varieties. The suitability of biplot analysis (a graphical representation of two-way data using principal component analysis) for the interpretation of variety x trial interactions was also investigated.

Materials and Methods

In 2001, two field trials comprising of the same set of 10 commercial sugarcane varieties (NCo376, N12, N21, N27, N29, N31, N33, N35, N39 and N41) were established alongside each other on a grower co-operator farm in Scottburgh (30° 32'S, 30° 07'E, 139 m asl), on the south coast of KwaZulu-Natal province, South Africa. One trial was harvested on a 12-month cutting cycle for a period of six seasons (plant crop plus 5 ratoons), while the other trial was harvested on an 18-month cycle for three seasons (first, second and third ratoon crops). Each variety was replicated five times within a trial in a randomised complete block design, with trial plots (60 m²) composed of five cane rows (two of which were guard rows) 10 m long and spaced 1.2 m apart. The trials were established on a sandy, Glenrosa soil form derived from a Granite parent material with approximately 20% clay and 500-700 mm effective rooting depth, under rainfed conditions. Trial management in terms of fertilisation, weed control, and ratoon management proceeded as per farm practice according to grower co-operator procedures.

In addition to general trial observations during the growing seasons, important production-influencing factors were also measured at each harvest. Cane yield, in tons cane per hectare (TCANE) was determined from the weight of three net rows from each plot. Cane stalks were

cut and topped according to commercial practice and weighed using a mechanical grab apparatus attached to a scale. Samples of 12 stalks were taken from each plot for quality analysis, and the estimated recoverable crystal percentage (ERC%) was determined in laboratory tests. The ERC is an estimation of the recoverable value payment system utilised in the South African sugar industry. The tons ERC per hectare (TERC) was obtained by multiplying the ERC% and TCANE. Additionally, *E. saccharina* damage, represented by the percentage internodes damaged (%ID), was assessed and rated on each trial plot according to Anon (2005). Details of cropping cycles and climatic conditions during the trial are indicated in Table 1.

The four variables were analysed using the Restricted Maximum Likelihood (REML) procedure - Meta Analysis (Genstat ver.11) in order to assess the magnitude of the variety x trial interactions. Variety, trial, and variety x trial were the fixed effects, while ratoon and replicate were considered as random effects in the analysis. Significant differences between treatment means were tested using the Holm-Sidak all-pairwise multiple comparison test at the 5% level of significance (Genstat ver.11). Separate, further analyses of variety x ratoon interactions were conducted using REML analysis. To enable quick visual interpretation of the variety x trial interactions, biplot analyses developed by Yan *et al.* (2000) was conducted. This analysis uses the variety x trial matrix of means as an input to produce a graphical representation of the relationship between variety performance and the two cutting cycles. Each variety and trial is represented by a point (marker) on the biplot defined by their scores on the first and second principal components (Yan *et al.*, 2000).

Table 1. Details of cutting cycles and environmental conditions during the experiment. Temperatures are from the nearest weather station (Sezela), while rainfall figures are from the neighbouring farm.

Crop	Start	Harvest	Age (months)	Total rainfall during cycle (mm)	Avg. Max. Temp. during cycle	Avg. Min. Temp. during cycle
12-month cycle						
R 0	02-Oct-02	16-Oct-03	13	632	25.2	16.7
R 1	16-Oct-03	13-Oct-04	12	967	24.4	16.1
R 2	13-Oct-04	13-Oct-05	12	744	25.3	16.2
R 3	13-Oct-05	12-Oct-06	12	878	25.0	16.5
R 4	12-Oct-06	24-Oct-07	12	1157	25.1	16.5
R 5	24-Oct-07	22-Oct-08	12	1330	25.8	17.5
18-month cycle						
R 0	02-Oct-02	16-Oct-03	13*	632	25.2	16.7
R 1	16-Oct-03	28-Apr-05	18.4	1570	25.1	16.8
R 2	28-Apr-05	02-Oct-06	17.1	2110	24.7	15.5
R 3	02-Oct-06	16-Apr-08	18.5	1931	25.7	17.3

*Excluded from 18-month analysis

Results and Discussion

Highly significant differences ($p < 0.001$) were observed between varieties for all four variables investigated (Table 2). Significant ($p = 0.037$) differences in TCANE and highly significant differences in ERC%, TERC, and %ID were observed between the different trials.

The variety x trial interaction was highly significant for TCANE and TERC, while no significant interactions were observed with the other two variables (Table 2). On average, the 12-month trial exhibited a significant 2.84 and 3.29 unit increase in TCANE and TERC respectively, relative to the 18-month trial. Varieties such as N27, N29, N33, N35, N39 and N41 produced higher (most non-significant) cane yields when harvested at 12 months, while N12, N21, N31 and NCo376 yielded better in the 18-month harvest cycle (Figure 1a). The ERC% of all varieties were significantly higher in the 12-month trial compared to the 18-month trial (Figure 1b), and this resulted in a similar pattern for TERC, except for N21 (Figure 1c). Conversely, the 18-month trial exhibited greater levels of %ID compared to the 12-month trial for all varieties (Figure 1d). This was expected, as *E. saccharina* damage is known to increase as cane is aged older than 12 months (Anon, 2005).

Table 2. Main and interaction effects of varieties and trials for tons ERC per hectare (TERC), estimated recoverable crystal % (ERC%), cane yield (TCANE) and % internodes damaged (%ID).

Source of variation	d.f	TERC	ERC%	TCANE	%ID
		F. prob			
Variety	9	<0.001	<0.001	<0.001	<0.001
Trial	1	<0.001	<0.001	0.037	<0.001
Variety x trial	9	<0.001	0.115	<0.001	0.317

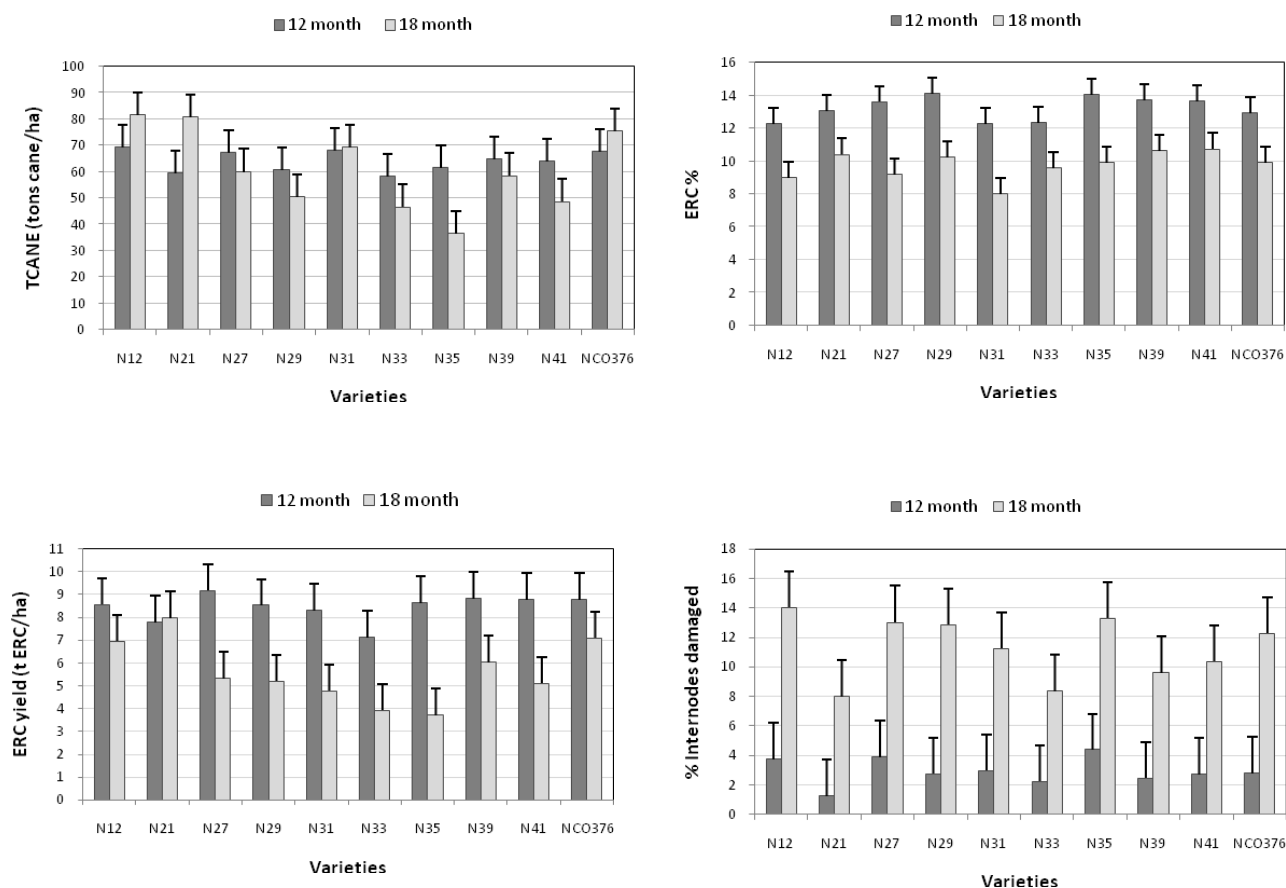


Figure 1. Variety x trial interactions for TCANE, ERC%, TERC and %ID. Vertical bars represent Sidak statistics at the 5% level of significance.

The higher ERC% and TERC associated with the 12-month trial is not in keeping with general trends in the industry, as it has been shown previously that the physiological and economic optimal age of harvesting cane along the coastal belt is 18 months (Inman-Bamber, 1991). It is hypothesised that the loss in productivity in the 18-month trial relative to the 12-month trial may be attributed to the significantly higher levels of *E. saccharina* damage observed (Figure 1d). This hypothesis is supported by the fact that stalk height was significantly higher in the 18-month trial compared to the 12-month trial (Figure 2), suggesting that more growth was achieved in the longer cycle. However, this additional growth did not lead to any improvements in productivity due to greater pest damage, and the inverse relationship between TERC (actual) and %ID demonstrates this phenomenon (Figure 3). Furthermore, industry guidelines indicate that every 1% ID leads to an approximate 1.5% reduction in ERC% (Anon, 2005). Using this relationship, the estimated TERC of both trials in the absence of *E. saccharina* was calculated (Figure 3). The results show that in the absence of *E. saccharina*, the 18-month trial has a significant TERC advantage over the 12-month trial (as per industry trends), thereby further illustrating the above concept.

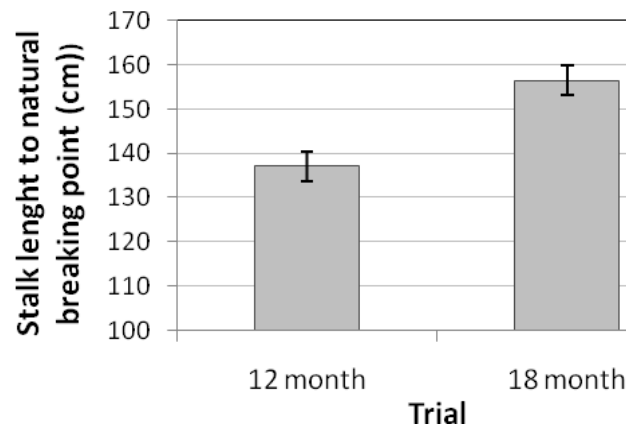


Figure 2. Differences in stalk length to the natural breaking point in the 12 and 18-month trials. Standard errors are represented by vertical bars.

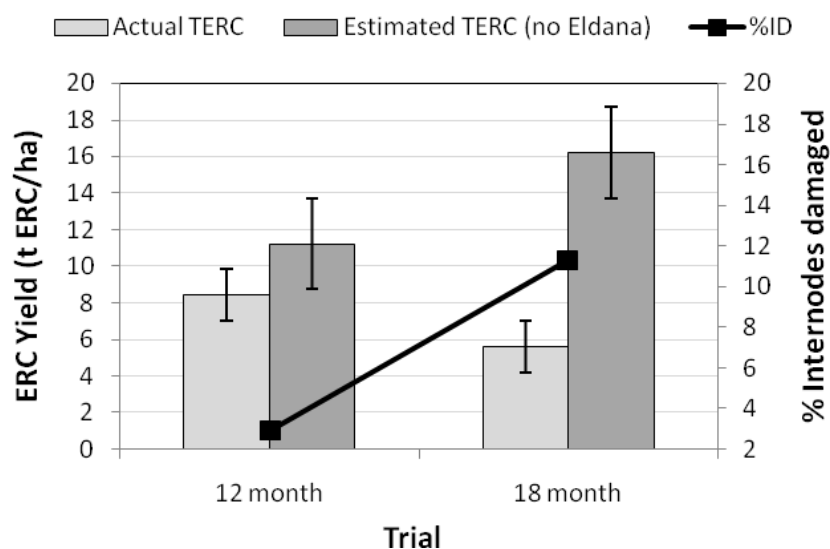


Figure 3. Relationships between TERC (actual and estimated) and %ID for the 12 and 18-month trials. Standard errors for trial differences are represented by vertical bars.

Ratooning ability

A significant ($p < 0.05$) variety \times ratoon interaction was observed for TERC in the 12-month trial. For the purposes of facilitating interpretation, only the top three varieties (N27, N39 and N41) ranked on TERC in the 12-month trial will be discussed. Figure 4 shows the TERC for each of these varieties expressed as a percentage of the trial mean in each of the six crops. This was done to eliminate the confounding effects of season on ratooning ability. Distinct patterns of ratooning were observed, as N27 consistently remained above the trial mean, N39 showed a gradual decrease in performance relative to the trial mean after the first ratoon, and N41 showed a consistent improvement in performance relative to the mean from the plant crop up until the third ratoon. The improved ranking of N41 with successive ratoons may be linked to similar patterns of increasing rainfall (Table 1), possibly suggesting that this variety performs better in years of good rainfall relative to the other two varieties in Figure 4. The consistent ratoon performance of N27 in this trial contradicts the widespread reports of poor ratooning of this variety in the industry and recommendations should be made cautiously. The drop in productivity of N39 is a concern, while the improvement in TERC of N41 with consecutive ratoons is an excellent characteristic for a variety in the industry.

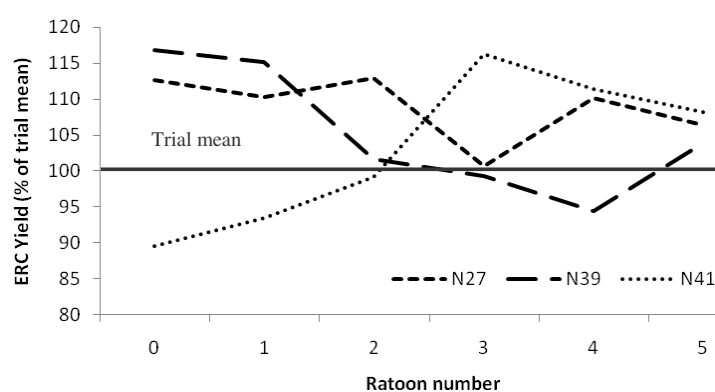


Figure 4. ERC yields of N27, N39, and N41 expressed as a percentage of the trial mean for each successive crop in the 12-month trial.

The variety \times ratoon interactions for the 18-month trial were not significant ($p = 0.058$), however, minor differences in TERC between varieties over the three ratoons were observed (Figure 5). All varieties produced their highest TERC in the R2 crop, and this was attributed to this cycle growing through two winters and being harvested in the peak sucrose period (Table 1), while the R1 and R3 crops were harvested early in the season when ERC% is normally lower. A similar pattern was observed with ERC%, thereby confirming the above, while TCANE showed a typical drop with subsequent ratoons. Additionally, %ID in the R2 crop was significantly lower, thereby contributing further to the improved TERC (Figure 6).

Biplot analysis

Diagnostic biplots were produced to allow for rapid visualisation of the variety \times trial interactions for all four variables (Figure 7). Important aspects of the interactions that could be rapidly visualised included: (i) the main effects of varieties, (ii) the main effects of the trials, (iii) the relative variety rankings within trials, and (iv) the relative suitability of varieties to the different trials. Rankings of the varieties for each trial could be quickly interpreted by constructing straight lines from the trial markers through the origin of the biplot. Thereafter, perpendiculars that originate from the variety markers and intersect these straight lines can be used to rank the varieties. Essentially, the closer the variety and trial

markers are, the more adapted is the variety to the cutting cycle. The rankings interpreted from the biplots showed an almost exact correspondence with the REML variety rankings for all variables (data not shown), suggesting the suitability of biplot analysis for the quicker interpretation of variety x trial interactions.

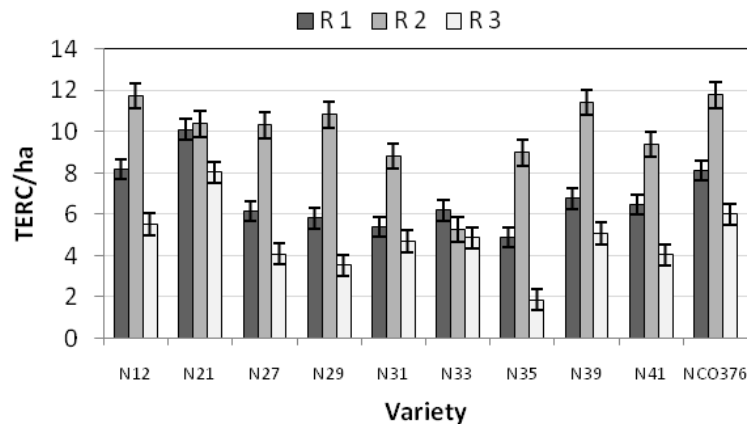


Figure 5. Ratoon x variety interactions for TERC in the 18-month trial. Standard errors are represented by vertical bars.

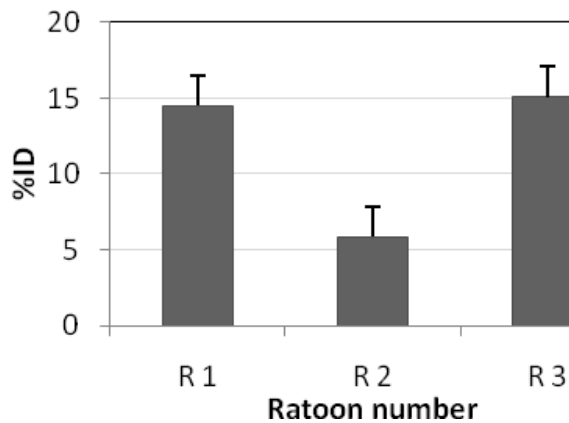


Figure 6. Average %ID for the three ratoon crops of the 18-month trial. Vertical bars represent Sidak statistics at the 5% level of significance.

Figure 7b demonstrates the approach employed to interpret variety rankings from the biplots according to Yan *et al.* (2000). The perpendicular constructed from variety N29 is the first to intersect the straight line originating from the 12-month trial marker, indicating that this variety is ranked number one for that trial. Similarly, the sequence in which variety perpendiculars intersect the straight line then determines the subsequent rankings. The biplots allow for interpretation of both trial results simultaneously and also gives an indication of the relative stability of varieties.

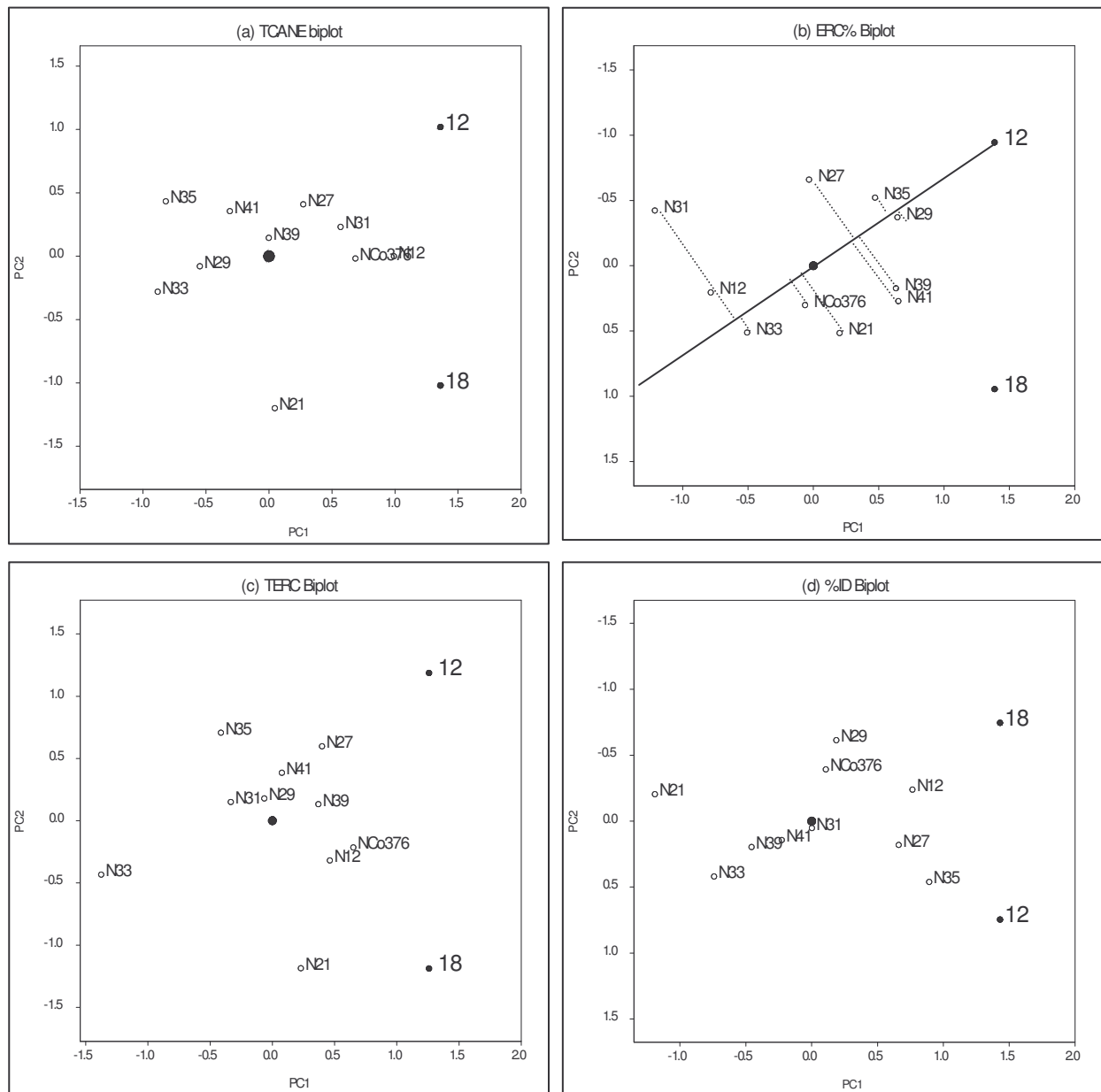


Figure 7. Diagnostic biplots for TCANE (a), ERC% (b), TERC (c), and %ID (d). The 12 and 18-month trials are represented by the ‘12’ and ‘18’ markers, respectively.

In general, variety performances interpreted from the biplots were in keeping with general variety characteristics. For example, *E. saccharina* resistant varieties N21 and N33 are located far away from the trial markers in Figure 7d, indicating expected lower levels of damage. Also, the suitability of variety N21 to the 18-month trial compared to the 12-month trial can also be easily identified due to its proximity to the 18-month trial marker (Figure 7c). Additionally, high ERC% varieties like N29, N35, N27, N39 and N41 were clustered together in Figure 7b, away from the low ERC% variety N31. Although only two trials (environments) were considered in this study, the interpretation of the variety x trial interactions from a traditional means table proved to be much more difficult compared to the use of the biplots. In the South African sugarcane industry, numerous multi-environment variety trials are conducted annually, and the biplot technique was shown here to be an appropriate tool to interpret such results.

Conclusions

The study has shown that the expected yield benefits associated with aging cane along the coastal belt cannot be achieved due to the associated increases in *E. saccharina* damage. This phenomenon was previously known, however, actual evidence in combination with varietal responses were lacking in the industry. Quick maturing varieties produced higher cane yields on the 12-month cycle, while slower maturing varieties yielded higher on the longer cycle. The significant drop in ERC% of all varieties in the 18-month trial was attributed to *E. saccharina* damage, and this led to subsequent reductions in TERC. The low ERC% associated with the early season harvest of the R1 and R3 18-month crops may have also influenced the overall performance of this cutting cycle, and further in-depth analysis of these effects will be conducted after the harvesting of the R4 18-month crop from this trial. Ideal varieties for the 18-month cycle include those with a high TERC in combination with good *E. saccharina* resistance, such as N21. On the 12-month cutting cycle the varieties N39 and N41 have been identified as suitable alternatives for N27, N29 and NCo376 under commercial conditions. Varieties exhibited different patterns of ratooning, and the technique of expressing productivity relative to the trial mean has been appropriate, as it encompassed environmental yield potential and catered for differences in seasons. Biplot analysis was identified as a useful tool for the interpretation of variety x trial interactions and further applications of this technique within the discipline of variety evaluation will be investigated. It was found that the Genstat statistical package was not the most appropriate for biplot analysis due to processing time and limited program flexibility, and other known alternatives will be investigated in future.

Acknowledgements

The authors wish to acknowledge the excellent assistance from the grower co-operator at Landers Estate in Scottburgh. The efforts of Kerry Redshaw in establishing the trials are acknowledged. Furthermore, the ongoing support from SASRI's technical team is appreciated, especially given the practical difficulties experienced when harvesting these trials. Valuable comments from Graeme Leslie are also appreciated.

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