REFEREED PAPER

IMPROVING SUGARCANE PRODUCTION IN FROST-PRONE ENVIRONMENTS OF SOUTH AFRICA

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Abstract

The widespread frost experienced in 2014 highlighted the severity of this major production constraint for inland areas. The objectives of this study were to (i) summarise recent variety performance and post-frost deterioration from a series of trials, (ii) identify the best management practices and (iii) highlight future research thrusts to improve production in frost prone areas. Varieties traditionally grown in the midlands (controls) were tested against varieties from the coastal and irrigated programmes and new midlands releases (tests) in a series of four trials in frost pockets from 2007 to 2014. Trials were harvested annually, approximately one month after frost events for three to seven crops. As a group, test varieties outperformed controls by 0.2 to 1.4 tons estimated recoverable crystal (ERC)/ha. The test varieties N36, N41 and N48 performed consistently well across all trials and crops, and should be recommended for frost pockets. On average, N36 and N39 showed the fastest rates of deterioration of 0.25 and 0.27 tons ERC/ha/week, and should therefore be prioritised for harvesting following frosts events. The mid-May to mid-June harvesting period was ideal to maximise ERC yields in frost pockets, irrespective of frost onset and severity. Irrigation, combined with ripener application led to yield improvements of 6.2 tons ERC/ha, and should be considered as mangement options for frost pockets. Variety N36 was shown to maintain higher temperatures at the growing point underneath the canopy compared with other varieties when temperatures dropped below freezing. Future work on frost effects should include dedicated screening of varieties in artificial environments to complement field trials, and the development of a frost damage rating scale.

Keywords: frost, yield loss, canopy temperature, varietal damage scale

Introduction

Frost is a common occurrence in high altitude areas (generally >800 m), where it can have a severe effect on sugarcane productivity. In the midlands north region, frost-prone areas have been shown to consitute approximately 20% of the total area under cane. The 2014 frost in the midlands region was considered as the most severe in living memory, causing widespread damage beyond the traditional frost pockets (considered as low-lying areas that experience frosts in three out of five years). To mitigate the effects of frost in frost pockets, growers in the midlands have adopted a management strategy which involves reducing the harvest age of cane to an annual cycle compared with the traditional 24-month cycle (De Haas, 1981). Essentially, cane is planted in February/March and establishes itself during autumn. Cold temperatures and frost during winter (June to August) often damage or kill any aboveground plant material, while the growing point remains protected underground. Mann (1991) showed that minimum temperatures in frost prone environments in the midlands ranged from 0 to -7.6°C. When warmer conditions and moisture return in spring (September), growth resumes rapidly. The crop is then grown until the the following winter, and is harvested at approximately 15 to 18 months of age, depending on frost onset. Every subsequent ratoon crop is then harvested annually thereafter. The success of the above strategy is dependent on attaining rapid growth and sucrose accumulation during the 12-month growing period.

One of the key elements of succesful implementation of the above strategy is to choose fast-growing varieties that can rapidly accumulate sucrose during the shorter growing period (Mann, 1991). At the time of initiation of the studies presented herein, the recommended varieties with this characteristic included N16, N21, and N31. These varieties complemented the dominant N12, which was grown over approximately 80% of the midlands (including frost-prone areas) at the time (Ramburan, 2013). Currently, no dedicated breeding programmes exist to develop varieties suited to frost-prone environments in South Africa. However, post-release variety evaluation trials routinely test varieties from other breeding programmes (and new midlands releases) for their suitability to frost pockets. The assumption is that varieties bred for the 12-month, warmer environments (coastal short cycle or irrigated regions) may exhibit faster growth and sucrose accummulation in frost pockets, compared with the traditional midlands varieties that were bred for the 24-month harvesting cycle.

In addition to the rapid accumulation of sucrose within 12 months, varieties suited to frost pockets need to exhibit resistance to quality deterioration following frost events. Varietal resistance to quality deterioration following frosts have been well documented elsewhere (Gascho and Miller, 1979; Irvine and Legendre, 1985; Edme and Glaz, 2013), while information on post-frost deterioration of South African varieties is limited. Additionally, there is current uncertainty on the general rates of yield loss following frost events in the midlands region. Such information is critical for growers to plan harvesting schedules and prioritise fields for harvesting. Furthermore, most frost-prone fields are routinely harvested after frost events in an attempt to age cane. There may be opportunities to maximise sugar yields by harvesting earlier, in anticipation of frost occurances. Some clarity on the optimal time of harvesting in frost pockets is therefore needed.

Over the past 10 years the South African Sugarcane Research Institute (SASRI) has conducted a series of trials in frost-prone environments to identify suitable varieties and develop recommendations for management of cane in frost pockets. The objective of this study was to summarise the outcomes and recommendations derived from such trials, addressing the specific issues of (i) yield performance of recommended and test varieties, (ii) post-frost yield deterioration and (iii) other management practices (time of harvest, ripeners and irrigation) in frost pockets. A secondary objective was to gain insights into future research needs to optimise production in South Africa’s frost-prone environments.

Materials and Methods

A series of four variety trials were established between 2004 and 2009 in frost pockets in the midlands region. The trials consisted of control varieties (traditional midlands varieties bred and released for regions with a 24-month harvesting cycle) and various test varieties (varieties from other breeding programmes and new midlands releases). The details of the trials, crops harvested and varieties tested per trial are shown in Table 1.

Table 1. Details of four variety trials established in frost pockets in the midlands region from 2004 to 2009 (Plant, R1, R2, R3 and R4 refer to the plant and subsequent ratoon crops, respectively).

Trial site	Trial code	Soil group	Planting year	Crops harvested	Control varieties	Test varieties
York	YK1	Humic	2004	Plant, R1, R2	N12, N16, N21, N31	N36, N37, N39, N41
York	YK2	Humic	2009	Plant, R1, R2	N16	N35, N36, N37, N39, N41, N48, N50, N52
New Hanover	NH	Red	2007	Plant, R1, R2, R3, R4	N21	HOCP96-540, LCP85-384, N36, N37, N39
Eston	ES	Sandy	2007	Plant, R1, R2, R3, R4	N16, N21, N31	N27, N35, N36, N39, N41, N37, N48

Trials consisted of six to 10 varieties planted in randomised complete block designs with four to six replicates. Experiment plots consisted of five or six rows that were 10 m long, and spaced one metre apart. In all trials, the plant and ratoon crops were harvested annually (12 months old) in August. At harvest, three or four inner rows from each plot were hand cut and weighed using a hydraulic boom to determine cane yield in tons/ha (TCANE). A 12-stalk sample was taken from each plot at each harvest to determine the estimated recoverable crystal (ERC) percentage. The ERC yield (TERC) was calculated as a product of TCANE and ERC. Each trial was analysed individually to investigate the effects of variety, crop, and the variety x crop interaction on TCANE, ERC, and TERC.

In selected crops of two trials, cane samples were taken from each plot at approximately two-week intervals before and after frost events for determination of ERC. These samplings were accompanied by stalk population counts on two net cane rows and determinations of individual stalk mass. The stalk population, stalk mass, and ERC were used to estimate TERC at each sampling date before and after the major frost events. Post-frost TERC deterioration rates of different varieties were evaluated using a regression analysis. In all trials, temperatures were monitored from weather stations in close proximity, and were used in combination with grower and extension observation to determine the approximate dates of major frost events. The major frost dates were 17 and 25 July for 2009, 16 June for 2010, 01 and 15 June for 2011, 21 May and 11 June for 2012, and 06 May and 10 June for 2013. Ramburan (2014) shows an example of the range of temperatures experienced at the York and Eston sites during the winter period in the 2012 season.

In 2011, an attempt was made to evaluate the effects of chemical ripener application prior to frost onset. The hypothesis was that an application of Ethephon prior to frost onset would increase sucrose content. Thereafter, the frost event itself would ‘simulate’ an application of Fusilade, and by doing so, this treatment would mimic the conventional ‘piggy-back’ ripener application treatment. To achieve this, two replicates of the trial at Eston were sprayed with Ethephon a few weeks before the anticipated frost date. The ERC, TCANE and TERC of these two replicates were determined separately from the other three replicates and used to evaluate the effects of the ripener application.

To evaluate the additional benefits of irrigation and ripener application on the 12-month harvesting cycle in the midlands, the TERC values of the YK2 trial were compared to those of an irrigated 12-month trial in the same region. The mean TERC of seven varieties that were common to these two trials were compared with each other over the 2012, 2013 and 2014 seasons. The irrigated trial was chemically ripened with Fusilade in these seasons, but also experienced frost events, and was therefore harvested at similar ages to the YK2 trial.

In the 2012 season, temperatures within the canopies of three varieties were monitored in the YK2 trial. Pendant type temperature loggers were attached to the uppermost leaves of a randomly selected plant in each plot to monitor temperatures in the vicinity of the apical meristems. Three replicates of varieties N21, N36 and N41 were monitored. The varieties were selected based on their known contrasting canopy densities. All loggers were synchronised, with 10-minute logging intervals for a three month period prior to harvesting. Statistically significant differences in daily minimum temperatures between varieties were tested using ANOVA and least significant differences ($p<0.05$).

Results and Discussion

Yield and quality performance of varieties

Figure 1 shows the TCANE (1a), ERC (1b) and TERC (1c) of all eight varieties averaged over three crops in the YK1 trial. The test varieties (N41, N36, N39 and N37 - blue bars) generally produced significantly higher ERC content than the control varieties N16, N21, N12 and N31 (Figure 1b). Except for N41, all other test varieties produced inferior (some statistically significant) TCANE compared with the control varieties N16, N31 and N21 (Figure 1a). However, all test varieties produced higher average TERC compared to the controls, with N41 and N36 showing statistically significant improvements (Figure 1c). The high cane yields of the control varieties may be the reason for their perceived suitability and recommendations for frost pockets.

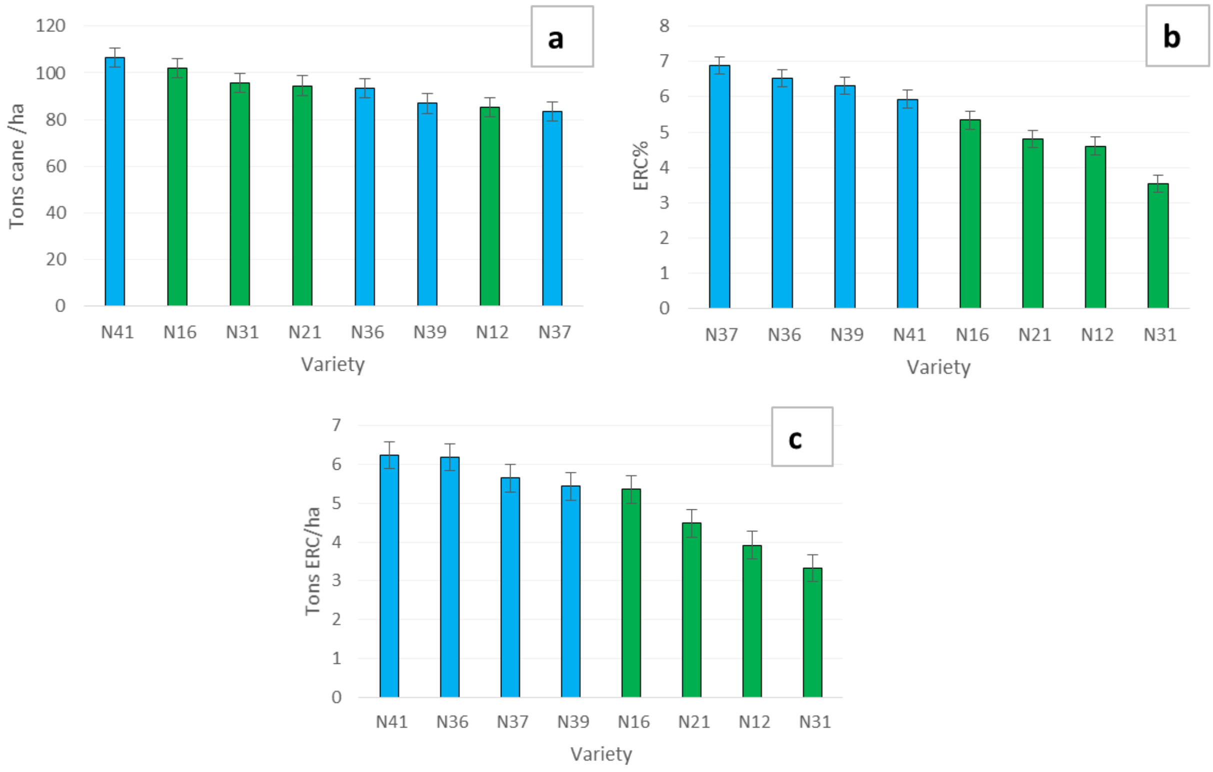


Figure 1. Cane yields (a), estimated recoverable crystal (ERC) content (b) and ERC yields (c) of control (green bars) and test (blue bars) varieties averaged over three crops from a variety trial at York.

In the ES trial (Figure 2), when averaged across five crops, all test varieties produced significantly higher ERC content (Figure 2b) than the control varieties N21, N16 and N31. The control variety N31 produced the highest TCANE (Figure 2a) with the lowest ERC content (Figure 2b) and, as a result, was outperformed by a number of test varieties in terms of TERC (Figure 2c). This once again explains the perceived superior performance in frost pockets due to high cane yields (visual appraisal rather than ERC yield-based recommendations). The test varieties N48, N36, N41 and N39 produced significantly higher TERC than all control varieties (Figure 2c).

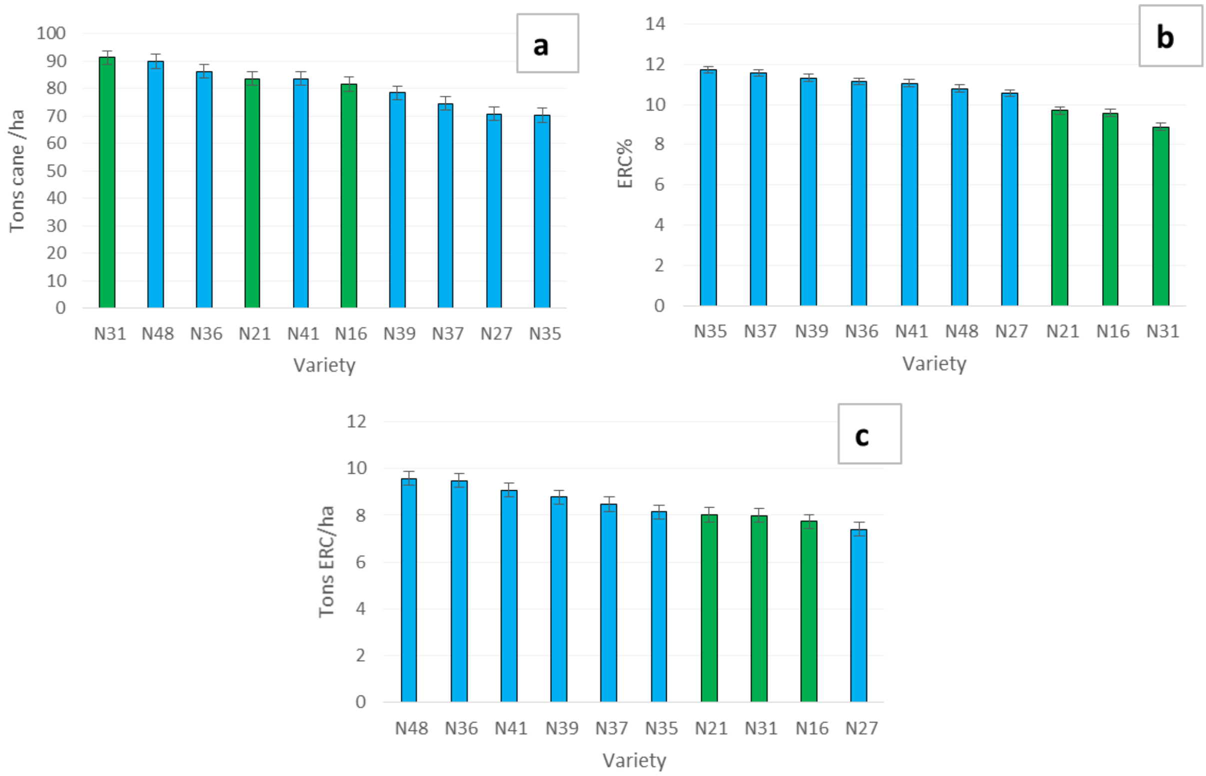


Figure 2. Cane yields (a), estimated recoverable crystal (ERC) content (b) and ERC yields (c) of control (green bars) and test (blue bars) varieties averaged over five crops from a variety trial at Eston.

The NH trial, which was harvested over seven crops, was comprised of a single control variety, N21 (Figure 3). Once again, the control variety produced the highest TCANE (Figure 3a), but the lowest ERC content (Figure 3b). The TERC of the test varieties HOCP96-540, LCP85-384 and N36 were similar and superior to the control N21 and two other test varieties (N37 and N39) (Figure 3c). The good performance of the two USA varieties (HOCP96-540 and LCP85-384) over seven crops was encouraging, and further testing of these varieties may be needed under different soil types to assess their potential for commercial production in South Africa.

In the trial YK2, which was conducted on a humic soil, variety N16 was used as the single control variety (Figure 4). When averaged over five crops, N16 was outperformed in terms of TCANE (Figure 4a), ERC content (Figure 4b) and TERC (Figure 4c) by a range of test varieties. The TERC of test varieties N41, N48, N36 and N35 were significantly higher than all other varieties (Figure 4c), once again proving their suitability for frost pockets. A new midlands release N52 produced very low ERC content (Figure 4b), with a resultant low TERC value (Figure 4c). This highlights the important contribution of ERC content to overall TERC for production in frost pockets.

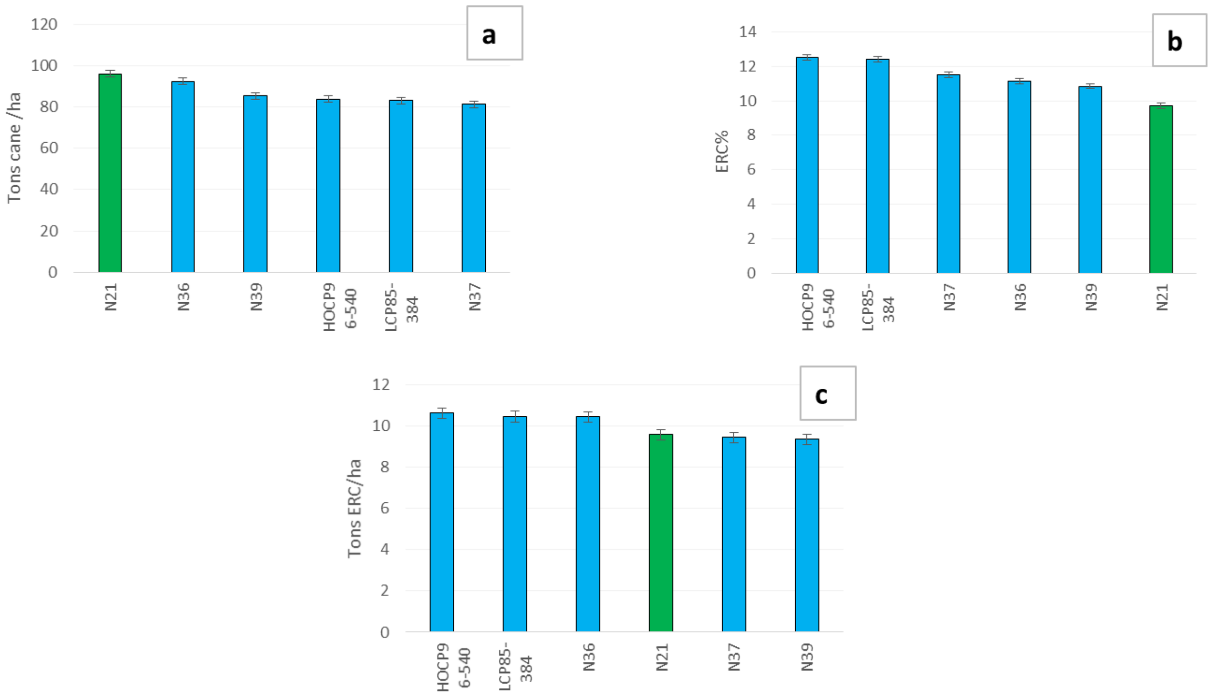


Figure 3. Cane yields (a), estimated recoverable crystal (ERC) content (b) and ERC yields (c) of control (green bars) and test (blue bars) varieties averaged over seven crops from a variety trial at New Hanover.

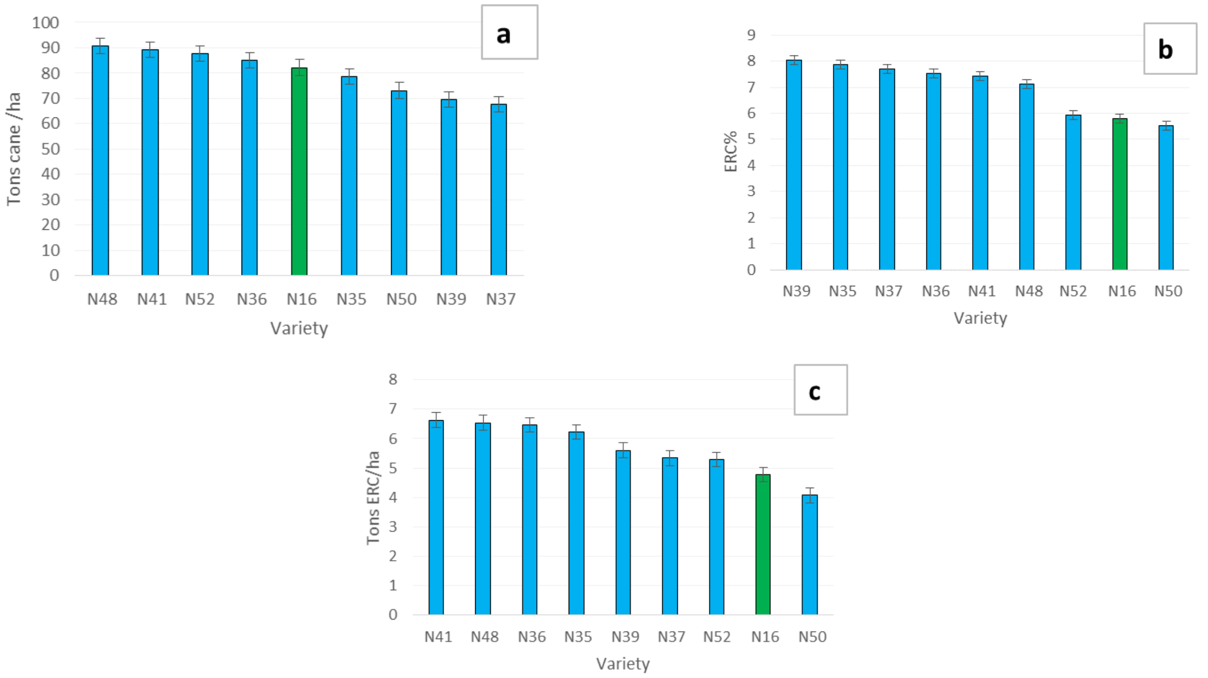


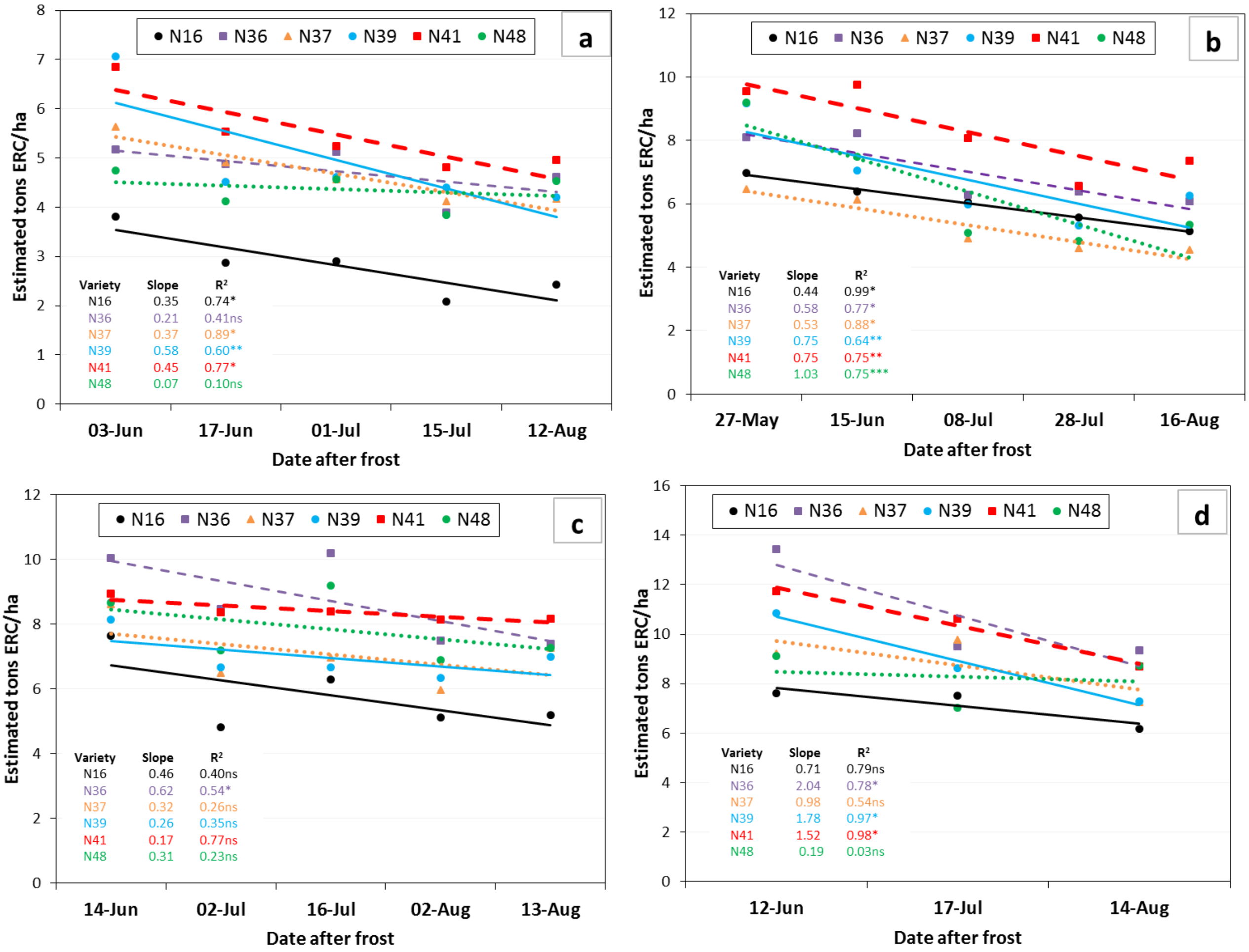
Figure 4. Cane yields (a), estimated recoverable crystal (ERC) content (b) and ERC yields (c) of control (green bars) and test (blue bars) varieties averaged over five crops from a variety trial at York.

Post-frost yield deterioration

Linear regression lines were fitted for selected control and test varieties for four crops from trial YK2 (Figure 5) and two crops from trial ES (Figure 6). In all crops, the deterioration in TERC was monitored from the time of peak TERC, through to harvest. In trial YK2 (Figure 5), varieties exhibited differences in deterioration rates in all four crops. In general, variety N41 maintained higher TERC than most varieties across the sampling period. Similarly, variety N36 also showed higher TERC than other varieties across the sampling period in three out of the four crops. Although N36 showed high TERC across the sampling period, this was also coupled with faster deterioration rates, particularly in the second and third ratoon crops (Figure 5c,d). The control variety N16 generally showed slow rates of deterioration (low slope values); however, this benefit was offset by the fact that its TERC values were generally the lowest across sampling dates. Variety N48 showed varied responses, with slow deterioration rates in the plant (Figure 5a) and third (Figure 5d) ratoon crops, a high deterioration rate in the first ratoon (Figure 5b), and a moderate rate of deterioration in the second ratoon (Figure 5c). Variety N39 also exhibited quick deterioration rates in general.

In trial ES, deterioration rates were generally higher in the third ratoon (Figure 6b) compared to the second ratoon crop (Figure 6a). Once again, N41 generally maintained high TERC across the sampling periods in both crops, and this was coupled with low to moderate rates of deterioration. Variety N36 once again showed high rates of deterioration in both crops. The control variety N21 showed the fastest rate of deterioration in the third ratoon crop (Figure 6b), while N37, N39 and N48 showed moderate rates of deterioration.

In general, the amount of cross-over interaction between peak TERC and harvest was minimal. This suggests that varieties that show high TERC at the time of frosts are most likely to remain superior until harvest. Exceptions to this were N36 and N39, which occasionally showed quicker deterioration rates than other varieties. When averaged across all crops, N36 and N39 showed the fastest rates of TERC deterioration of 0.25 and 0.27 TERC units per week, respectively. Variety N48 showed the lowest average deterioration rate of 0.14 TERC units per week. Therefore, among the three top performing varieties identified in this study (N36, N41, and N48), variety N36 should be prioritised for harvesting following frost events. Across all selected varieties and crops harvested, the rate of TERC loss ranged from 0.02 to 0.45 TERC/ha/week, with an average loss of 0.21 TERC/ha/week.



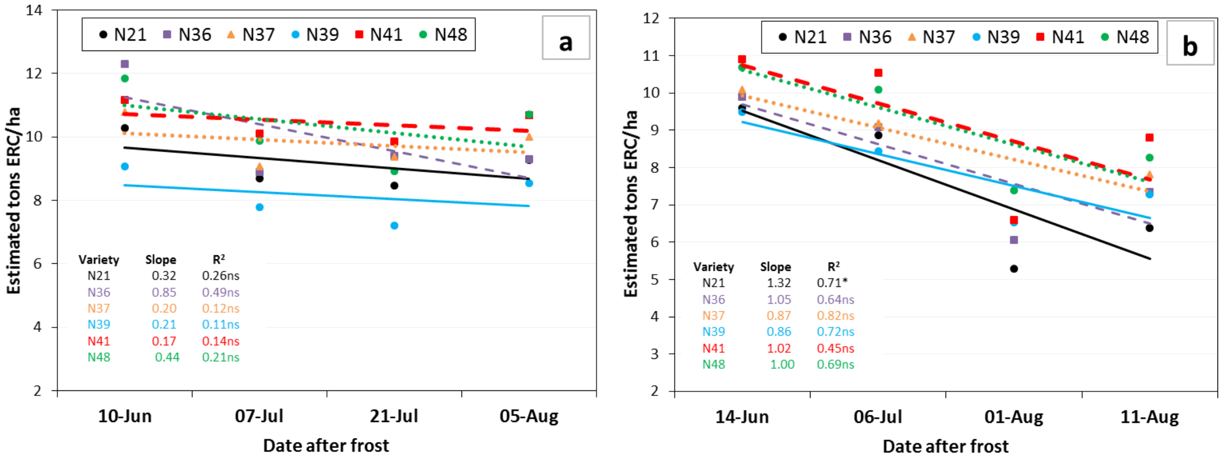
Variety	Slope	R²
N16	0.35	0.74*
N36	0.21	0.41ns
N37	0.37	0.89*
N39	0.58	0.60**
N41	0.45	0.77*
N48	0.07	0.10ns

Variety	Slope	R²
N16	0.44	0.99*
N36	0.58	0.77*
N37	0.53	0.88*
N39	0.75	0.64**
N41	0.75	0.75**
N48	1.03	0.75***

Variety	Slope	R²
N16	0.46	0.40ns
N36	0.62	0.54*
N37	0.32	0.26ns
N39	0.26	0.35ns
N41	0.17	0.77ns
N48	0.31	0.23ns

Variety	Slope	R²
N16	0.71	0.79ns
N36	2.04	0.78*
N37	0.98	0.54ns
N39	1.78	0.97*
N41	1.52	0.98*
N48	0.19	0.03ns

Figure 5. Fitted linear regression lines for estimated recoverable crystal yields (TERC) of varieties N16 (control), N36, N37, N39, N41 and N48 from peak TERC to harvest in the plant (a), first (b), second (c), and third ratoon (d) crops of trial YK2. The variety regression coefficients (slope) and R^2 values are indicated. ***P<0.001, **P<0.01, *P<0.05; ns = not significant.



Variety	Slope	R²
N21	0.32	0.26ns
N36	0.85	0.49ns
N37	0.20	0.12ns
N39	0.21	0.11ns
N41	0.17	0.14ns
N48	0.44	0.21ns

Variety	Slope	R²
N21	1.32	0.71*
N36	1.05	0.64ns
N37	0.87	0.82ns
N39	0.86	0.72ns
N41	1.02	0.45ns
N48	1.00	0.69ns

Figure 6. Fitted linear regression lines for estimated recoverable crystal yields (TERC) of varieties N16, N36, N37, N39, N41 and N48 from peak TERC to harvest in the second (a), and third ratoon (b) crops of trial ES. The variety regression coefficients (slope) and R^2 values are indicated. ***P<0.001, **P<0.01, *P<0.05; ns = not significant.

Time of harvest

Estimates of TERC were made at each sampling date using stalk population, stalk weight, and ERC determinations. The changes in average TERC of all varieties across sampling periods of four crops in trial YK2 and two crops in trial ES are shown in Figures 7a and 7b, respectively. The fitted curves showed that TERC generally improved (all R^2 values were greater than 0.8) as sampling progressed from April into May across all seasons (crops). Major frost events usually occurred between late May and mid-June, after which TERC generally declined until harvest. These results show that the optimal time of harvest to maximise TERC in general would be between mid-May and mid-June.

The above would be a useful harvesting strategy for frost pockets, as the onset of frosts is largely unpredictable, especially in valleys where frost development is highly dependent on air flow. This must be considered in light of strict harvesting schedules which limit growers from responding to frost after the event. In most cases, assessing the damage caused by frost, predicting likely deterioration, and adjusting harvesting schedules are impractical. The optimal harvesting times identified here are therefore of practical relevance. Past studies on frost tolerance in sugarcane have focused on cultivar tolerance post-frost (Legendre *et al*., 2010), and no attempts have been made to optimise harvest times in anticipation of frost, for practical purposes.

The greater losses in TERC at YK2 (Figure 7a) compared with losses at ES (Figure 7b) were attributed to differences in frost severity. The site YK2 is traditionally known for more severe frost events. The lowest temperature experienced at York during the sampling period was -6°C, compared to -4°C at Eston. Additionally, minimum temperatures were generally lower at York than at Eston, especially when temperatures dropped below -2°C. These temperature differences between the sites are believed to produce frosts of different intensities, and hence different post-frost responses in the varieties. Despite these differences in frost onset and severity, however, the optimal time of harvest (mid-May to mid-June) was the same for both sites.

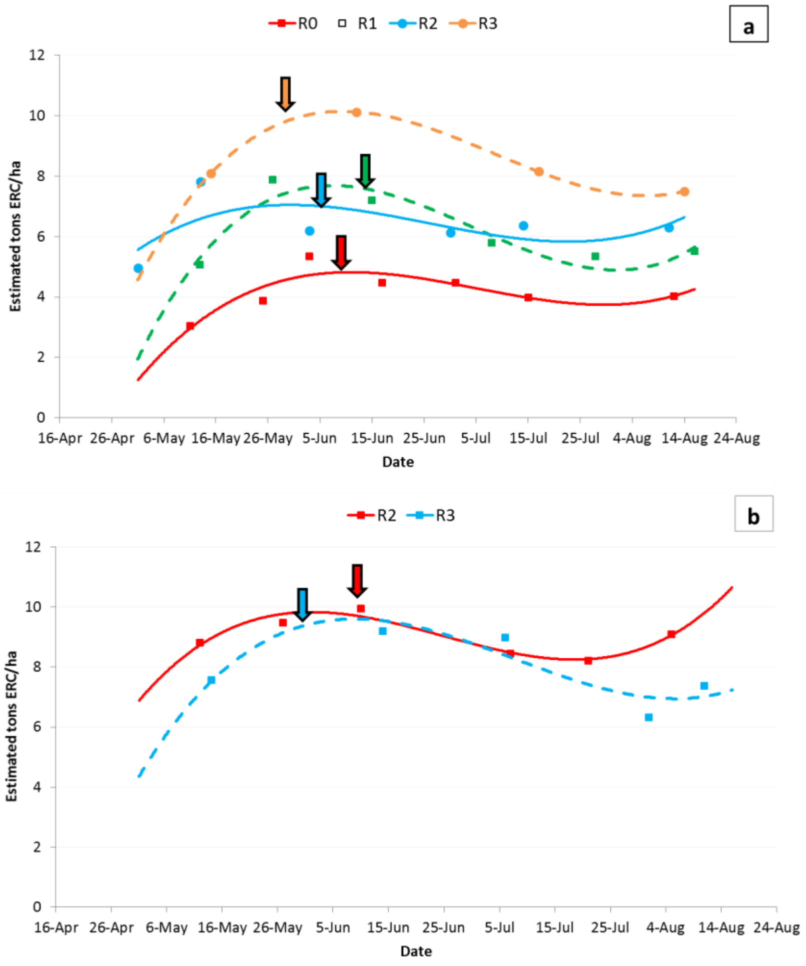


Figure 7. Fitted curves of estimated recoverable crystal yields derived from sequential sampling before and after major frost events during four crops in trial YK2 (a) and two crops in trial ES (b). Arrows represent the approximate dates of major frost events for the corresponding crop.

Effects of ripener application

The application of Ethephon led to an increase in average ERC over the two sprayed replicates compared with the unsprayed replicates (Figure 8a). However, TCANE was reduced with Ethephon application (Figure 8b). The cane yield penalty associated with Ethephon application resulted in a non-significant reduction in TERC (Figure 8c). This meant that the strategy of applying a chemical ripener to frost-prone cane was not successful. However, it must be noted that this was a preliminary, once-off observation of this possibility rather than a fully replicated experiment. Furthermore, the effects of seasonal differences were not evaluated. It is acknowledged that the cane yield reduction associated with the ripener application may be season and variety dependent.

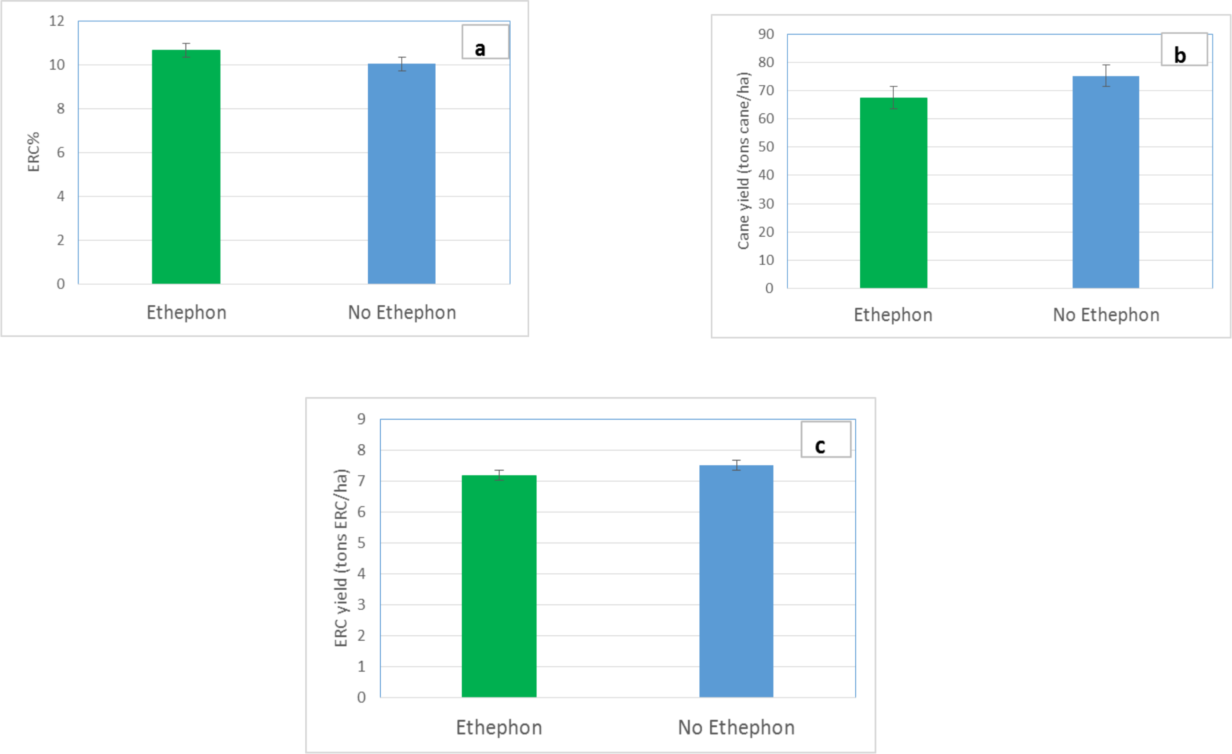


Figure 8. Effects of Ethephon application on ERC (a), TCANE (b), and TERC (c) after frost in the trial at Eston. Vertical bars represent standard errors.

Effects of irrigation

As expected, the TERC of the irrigated trial was always superior to the TERC of the rainfed trial in the frost pocket (Figure 9). The TERC difference ranged from 4.5 tons ERC/ha to 7.7 tons ERC/ha. On average, the yield difference across seasons was 6.2 tons ERC/ha. This difference represents the additional benefits associated with applying irrigation (and ripening) on a 12-month cutting cycle in the midlands. It must be noted that the irrigated trial also experienced frost events, and was harvested at the same age as trial YK2. These results highlight the potential benefits of using irrigation to improve productivity in frost pockets.

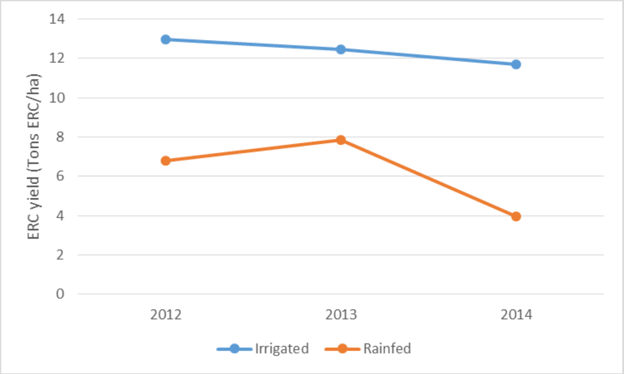


Figure 9. Mean TERC of seven common varieties in an irrigated and rainfed trial in the midlands north region during the 2012, 2013 and 2014 seasons.

Insights into varietal resistance to frost

The mean daily minimum temperature at the growing point of varieties N21, N36, and N41 during three occasions when temperatures dropped below -1°C are shown in Figure 10. From 6 to 13 June 2012 (Figure 10a), 28 June to 1 July 2012 (Figure 10b), and from 29 July to 2 August 2012 (Figure 10c) variety N36 showed higher daily minimum temperatures inside the canopy compared with the other varieties. The temperature differences in the canopies of N36 and the canopies of other varieties ranged from being non-significant, to highly significant ($P<0.001$), depending on the date. Varieties N21 and N41 generally showed no significant differences in daily minimum temperatures at their growing points. Variety N36 is a wide-leaved, dense canopying variety, while N21 and N41 are sparse canopying, narrow-leaved varieties. These results are the first to demonstrate that this trait (canopy architecture) may have a buffering effect on the minimum temperature reached within the crop canopy. This first result of temperature differences within the canopy of varieties during frost confirms that this may be a possible mechanism for frost tolerance, as suggested by Irvine and Legendre (1985). Further monitoring of growing point temperatures, with associated frost damage and post-frost deterioration, are required to confirm whether the dense canopy trait does indeed impart any degree of frost resistance. An associated rating for actual frost damage (leaf, growing point and bud damage) will be required for this.

In addition to the above, widespread anecdotal evidence also suggests that SASRI varieties do exhibit differences in their actual frost tolerance. Figure 11 shows the different degrees of frost damage experienced by three SASRI varieties grown under the same conditions in the midlands. Additionally, in the variety trials discussed in this study, varieties such as N37 and N39 have consistently retained more green leaf material than other varieties following frost events. These examples, and others, suggest that screening of SASRI varieties for actual frost tolerance may lead to the successful identification of varieties that can persist through frost events, thereby allowing them to be aged. Screening techniques for sugarcane frost tolerance have been shown to be successful elsewhere (Irvine, 1977; Tai et al., 2004). Furthermore, the ability of varieties to ‘overwinter’ (i.e. continue growing) during the early crop establishment phase may allow for the harvesting of older, more mature cane in the plant crop. As a result, ‘true’ frost tolerance in the midlands context should be defined as varieties that can, firstly, overwinter in the crop establishment phases in the plant crop, and secondly, have the ability to tolerate actual frost damage in the mature phase of growth. Future research should therefore focus on developing screening methods for these two characteristics. Additionally, Van Heerden et al (2009) suggested that some varieties exhibit acclimation to frost through exposure to pre-frost cold spells. Future work should therefore incorporate this aspect in order to identify frost tolerant varieties.

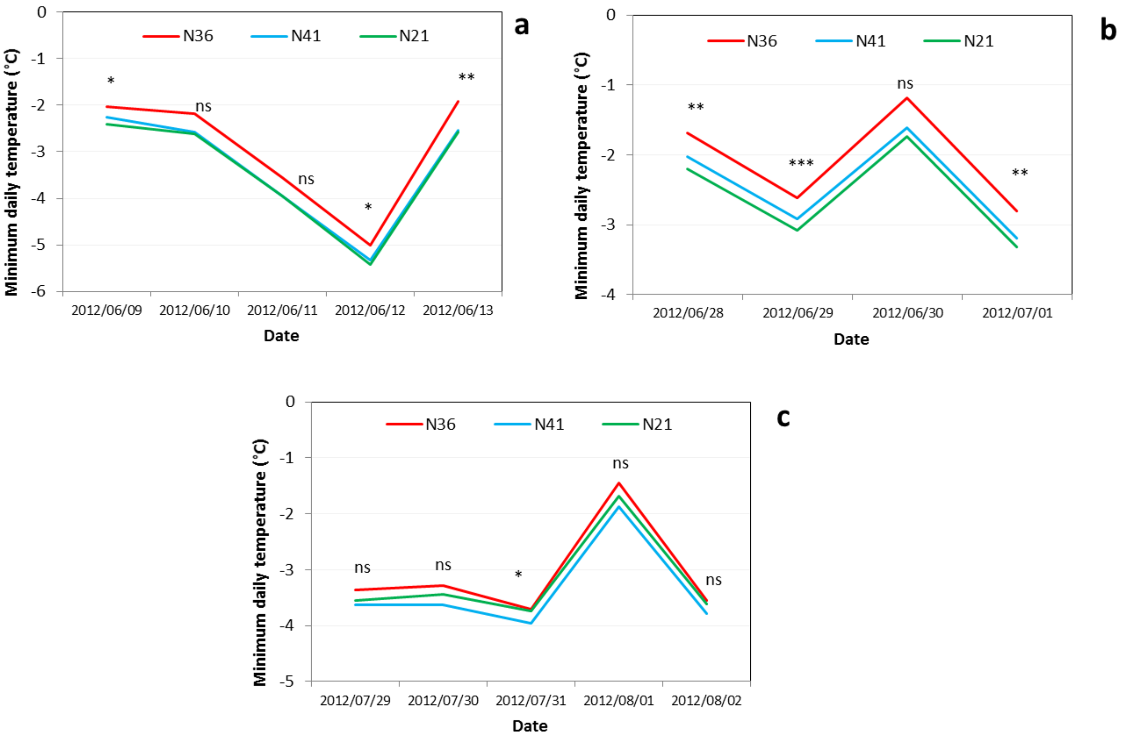


Figure 10. Minimum daily temperatures at the growing point of three varieties on three occasions when temperatures dropped below -1°C in the YK2 trial in 2012. The three cold spells were 6 to 13 June (a), 28 June to 1 July (b), and 29 July to 2 August (c).

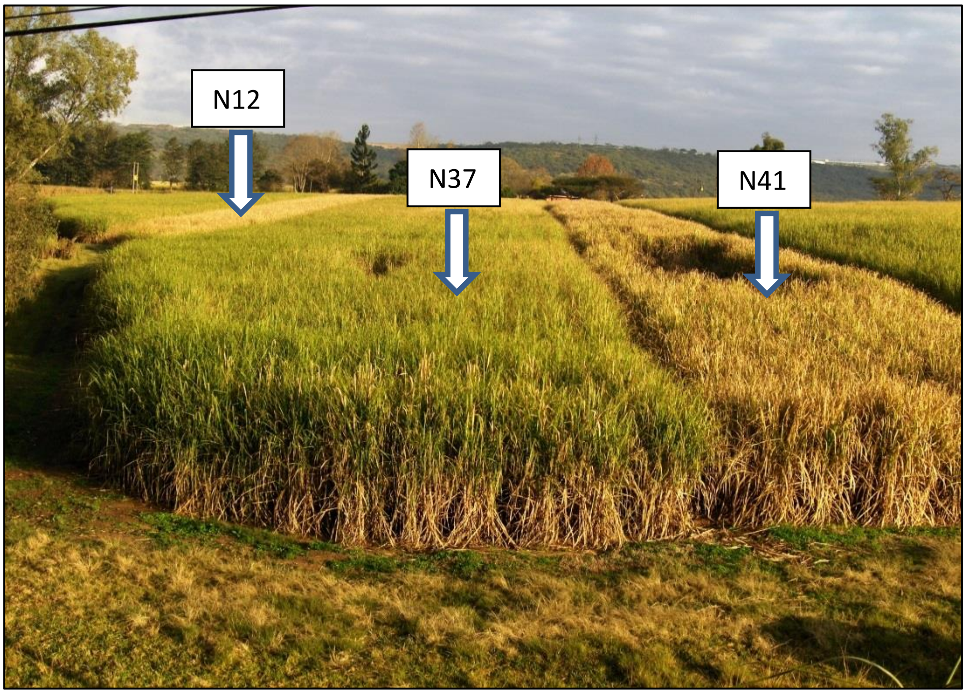


Figure 11. Different degrees of frost damage in a commercial field in the midlands north area, planted to varieties N12 (left), N37 (middle) and N41 (right) under the same growing conditions.

Conclusions

Traditional midlands varieties N12, N16, N21 and N31 were outperformed in terms of TERC by a range of varieties developed by other breeding programmes in South Africa. The routine testing of varieties released for the coastal short cycle and irrigated programmes should therefore continue, to improve on the productivity levels of the varieties identified here. Of all varieties tested, N36, N41 and N48 were identified as superior performers in frost pockets, and future recommendations should be adjusted accordingly. Other varieties such as N37 and N39 have also shown acceptable performance in frost pockets, and exhibited less frost damage than other varieties. Except for N48, all other varieties released recently from the midlands breeding programme did not perform well in frost pockets. Varieties such as N50 and N52, which are known for their high cane yields, have extremely low ERC% at 12 months of age, and their planting in frost pockets should therefore be discouraged.

The loss of TERC following frost events is highly dependent on prevailing environmental conditions in that season, as well as the severity and duration of frost events. In this study, N41 and N48 generally showed slower rates of TERC loss after frost, while varieties N36 and N39 showed the fastest TERC losses. Such varieties (N36 and N39) should therefore be prioritised for harvesting following frost events. Across trials, the loss of TERC following frost events was 0.21 TERC/ha/week. This value could be used as a rule of thumb by growers to calculate potential losses incurred from leaving frosted cane standing.

Periodic sampling before and after frost events has identified the mid-May to mid-June period as an optimal window to maximise TERC in frost pockets. This is seen as an ideal time to gain the benefits of natural ripening moving into winter, before the onset of frost. It is recommended that this harvesting window should be targeted by growers whenever possible. Other management practices that could be implemented include the use of irrigation in frost pockets. However, the cost-benefit ratio of such a strategy should be investigated first, using the yield benefits shown in this study. When combined with irrigation, the use of ripeners to improve TERC on the 12-month cutting cycle is valid. However, responses to ripener under rainfed conditions are variable, and could result in loss of cane yields.

Future work on improving production in frost pockets should involve dedicated screening for varietal tolerance to frost. Resource limitations restrict the extent of measurements and monitoring possible in field trials. Therefore, screening in artificial environments (e.g. cold rooms) may be a valid option to determine genetic differences in frost tolerance. This may allow for the screening of more genotypes, as well as more controlled environmental conditions to develop a rating scale. Such a frost rating scale could then be validated with complementary field trials.

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