THE EFFECTS OF SOIL FERTILITY AND NUTRITION ON SUGARCANE QUALITY: A REVIEW

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Abstract

The fertility status of the soil and the standard of fertiliser management can have an important effect on the chemical composition and quality of cane juice. Both nutrient deficiency and nutrient excess can result in below optimum sucrose contents. Excessive potassium uptake may promote cane lodging and high potassium levels in juice can also influence the exhaustibility of final molasses, the colour and ash content of raw sugars. Juice quality parameters other than sucrose content, such as soluble high molecular weight polysaccharides can interfere with the processing of raw sugar. The level of crop nutrition may also influence the presence of non-sucrose constituents such as total amino acid, phenol and gum content. The results of past fertiliser trials are reviewed to assess the impact of mainly nitrogen, phosphorus, and potassium fertilisation on cane quality and the implications of over and under fertilisation in terms of the RV cane payment system. More than ever before, there is a need for growers to use soil and leaf analysis in order to maximise RV production. Fertiliser use in excess of FAS recommendations is not only wasteful but will be more 'expensive' under the RV system of payment.

Keywords: cane quality, nutrition, fertilisers

Introduction

Raw juice from sugarcane comprises a highly complex system which includes both sugars and non-sugars in molecular, colloidal and suspended forms. The relative proportion of sugars and non-sugars present in juice indicates the quality of juice in sugarcane. The miller is mainly interested in the amount of sugar that can be recovered from each ton of cane that is crushed. The less cane that he has to crush per ton of sugar produced and the lower the level of impurities, the easier it is for him to crystallize sugar from the juice. The most important factors contributing to high recovery of sugar are:

- high sucrose
- high purity
- low fibre
- low level of non-sugars.

The level and nature of non-sugars is of particular importance as this can impact on the cost of processing and refining of sugar. Polysaccharides, which include gums, starch and dextrans, can have deleterious effects on raw sugar manufacture and some of them persist in the raw sugar causing further problems in refining. Other quality parameters which commercial buyers consider when purchasing raw sugar are the ash, colour, filterability, crystal shape and reducing sugar levels.

Field factors that may impact on cane quality include:

- correct selection of varieties
- topping height
- harvesting practices
- harvest to crush delays
- use of chemical ripeners
- disease and pest infestation
- fertiliser management practices.

The nature of soil and the standard of fertiliser management can impact directly on the chemical quality of cane juice (Wood, 1982), not only on sucrose content but also on non-sucrose parameters such as gums, starch, phenols and ash, that can affect sugar recovery in the processing stream. In this paper the impact of nitrogen, phosphorus and potassium fertilisation and liming on cane quality is reviewed. Examples are given which compare the economic consequences of under and over fertilisation under the old Sucrose Cane Payment and the new RV Cane Payment Systems respectively.

Nitrogen

Of the six major nutrients N, P, K, Ca, Mg and S, N plays the dominant role in regulating crop production. In a crop like cane where an increase in biomass may be associated with a reduction in quality, it is important to establish an economic balance with regard to the quantity of fertiliser N required, in order to obtain the maximum amount of sugar and not merely cane per unit time and area.

In general, the primary consequence of increasing N application in cane is to stimulate vegetative growth, but rapid growth invariably implies higher levels of N, moisture and non-sugars and a lower sucrose content within the cane plant prior to harvest. In an autumn/winter cycle variety trial at Pongola, the effect of N on cane quality in three cane varieties was measured from the highest to the lowest sucrose content in seven crops. Increasing amounts of N increased cane yield in all three varieties but the response in tons cane was offset by a linear decrease in sucrose content of cane. The adverse affect in sucrose content and purity from additional N was greater in variety NCo376 than in either N52/219 or J59/3 (Moberly, 1982).

Under the conventional sucrose based payment system, reduction in cane quality with increasing amounts of N between 50 and 150 kg N/ha, averaged 0.38 units % cane for each additional 50 kg N/ha applied to NCo376, while quality was largely unaffected in the other two cane varieties. The response in terms of sucrose yield to more than 50 kg N/ha, did not appear worth-

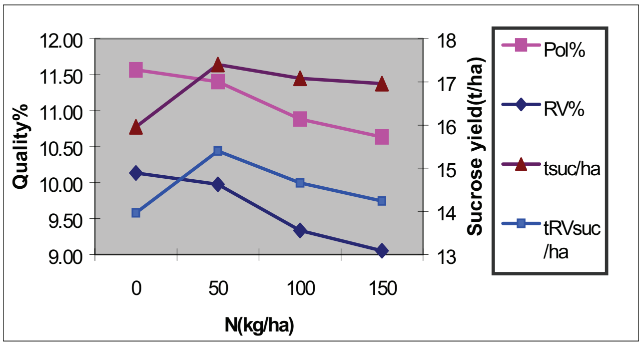


Figure 1. Effect of N on sucrose quality and yield of NCo376.

while for NCo376, whereas for the other two varieties maximum sucrose yields were achieved with 100 kg N/ha (Figure1).

Under the RV cane payment system, which accounts for the effect of non-sucrose and fibre content on the recovery of sucrose, it is evident that overall sucrose recovery for NCo376 was more adversely affected by increasing N level compared with the direct sucrose payment system. Reduction in cane quality with increasing amounts of N between 50 and 150 kg N/ha, averaged 0.45 units RV% cane for each additional 50 kg N/ha applied to NCo376, while quality for the other two varieties was unaffected. The greater impact of above average N applications under an RV cane payment system is also reflected by a sharper fall in the RV rand value per ton of cane for variety NCo376. This decline is more clearly seen from a comparison of gross revenues generated under the two systems of payment (Table 1). In general the effect of N on fibre was small with a tendency for fibre to be reduced.

An assessment of available data from a number of nutritional trials has shown that extra N does not always have an adverse effect on cane quality. Cane grown on an autumn/winter cycle is more likely to be affected by lower purity and a reduction in RV% with increasing N fertiliser levels. It is also important to take into account the variable capacity of industry soils to supply N through mineralisation as an over-abundance of N is likely have an adverse effect on purity and therefore recoverable sugar under the RV system of cane payment. The results from a number of past N trials have shown that sugar yields from treatments where no N was applied, ranged from 7-15 tons sucrose/ha/annum. This was due primarily to the fact that the capacity of the soils to supply N to the crop through mineralisation of soil organic matter (N) covered a wide range from <70 to >140 kg N per hectare (Meyer *et al.,* 1986). Fortunately FAS recommendations for N matched the N mineralisation potential of soils thereby reducing the risk of over-applying N. Excessive use of N may also cause lodging which can lead indirectly to a decline in recoverable sucrose.

Another consequence of over-application of N fertiliser is the risk of increased eldana infestation and damage to cane with an adverse effect on recoverable sucrose. Available data from a rates of N trial conducted at La Mercy on a Kroonstad form soil illustrate the effect of increasing rates of N on the number of stalks damaged by eldana and the negative influence on Pol% and RV%. Increasing the amount of N between 50 and 200 kg N/ha, resulted in an average decline of 0.94 units of RV% cane for each additional 50 kg/ha applied. Over the same range of N treatment, eldana counts increased from an average of 11.8 to 41.8 eldana per 100 cane stalks (Figure 2).

Although the total non-sugars did not show an appreciable increase due to N treatment, it is likely that the organic component in the non-sugar will increase at the expense of the inorganic component. In a two year field study to assess the effect of N application on the composition of sucrose and non-sugars in cane juice, researchers in India found that organic non-sugars appreciably increased due to N application while inorganic non-sugars decreased, presumably due to a dilution effect (Asokan and Raj, 1984). Under organic non-sugars, the authors claimed that the total amino acid and phenol content increased, whereas the colloid and gum content decreased with increasing N.

Potassium

Potassium is essential for plant growth and photosynthesis; it plays an important role in the moisture economy of the plant and translocation and storage of sucrose. Of the essential elements, K is the most abundant in cane juice to the extent that between 30 to 50% of ash in cane juice comprises K_2O. An application of K fertilisers to a soil deficient in K, may improve sucrose recovery through an increase in the pol and a reduction in fibre content (Table 2). However, in many of the former N/K fertiliser trials, a response to K in terms of yield and sucrose was accompanied by an increase in sucrose % cane. Of the three major nutrients, K is by far the most effective in reducing the starch content of cane, a large reduction in starch usu-

Table 1. Effect of increasing N treatment on overall gross return under sucrose and RV payment systems (Pongola trial RVT(N1)79, average data from seven crops).

N (kg/ha)	Rand per ton			Overall gross return (R)		
	Sucrose*	RV**	Difference	Sucrose	RV	Difference
N0	128.31	123.59	4.72	17 705	17 055	650
N50	126.43	121.75	4.68	18 323	17 619	704
N100	120.65	113.95	6.70	17 890	16 838	1052
N150	117.89	110.41	7.48	17 621	16 427	1194

*Sucrose value R1109/t   **RV value R1220/t

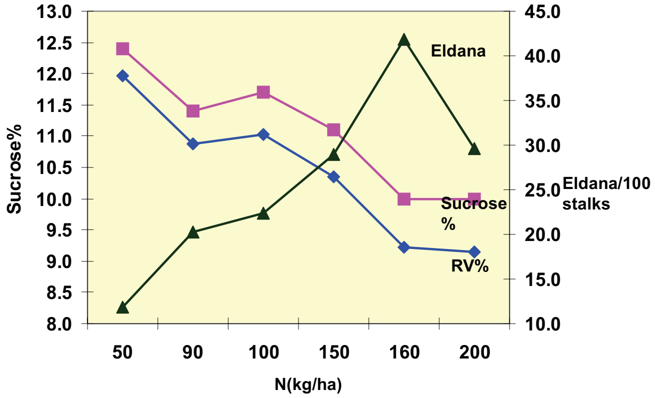


Figure 2. Effect of N on cane quality and eldana for variety NCo376.

ally accompanying substantial increases in yield on K deficient soils (Wood, 1962).

In Australia between 1961 and 1964 Yates (1965) reported that of 34 K trials showing a response in cane yield to applications of K fertiliser at rates of 0,92 and 184 kg K/ha, in no case had cane quality been significantly affected. The same conclusion was reached for trials that responded to applied K on base saturated soils in Mpumalanga and Swaziland (Donaldson *et al.,* 1990). Increasing rates of K in the absence of a K response also seemed generally to have had little effect on cane quality. There was an indication in one N/K trial in the Midlands of a depression in sucrose % cane (reduced from 13,1 to 12,6) where a very high level of K (375 kg K/ha) was applied, but this was not statistically significant. Stewart (1969) also reported a significant depression in sucrose % cane following application of 183 kg K/ha to a soil with an exchangeable K content of 155 ppm.

There is the perception that a depression of sucrose in cane juice resulting from heavy applications of N fertiliser can be obviated by applications of potash. An examination of available trial data suggests that this may happen in soils with a very low K level, where a response to K can be expected. Interactions between N and K under these conditions were observed in a number of Regional Fertiliser Trials (RFTs), the best example being one on a TMS (Cartref series) soil containing 64 ppm K (Stewart, 1969). In this trial the application of N fertiliser in the absence of potash steadily decreased sucrose % cane. However, as shown in Table 3, the addition of K counteracted this trend, producing a good response in terms of sucrose % cane at high levels of N. RV% would have followed the same trend as sucrose % cane.

The use of potassic fertiliser in sugarcane has increased substantially in the last four decades to the point that in a number of areas there is clear evidence from leaf analysis of luxury

Table 2. Cane, sucrose and RV% and sucrose yields (average 16 to 18R). Trial FT11N/74 – Pongola – Hutton form soil – 114 ppm K.

kg K/ha applied	t/ha cane	Fibre %	Suc % cane	Brix %	RV %	T/ha sucrose
0	145	10.7	11.7	15.3	9.9	17.0
75	154	10.2	12.0	15.0	10.3	18.7
150	147	10.2	12.0	15.5	10.3	17.8

Table 3. The interaction between N and K in terms of sucrose % cane and tons sucrose/ha from RFT trial.

kg K per ha	kg N per hectare							
	0		110		220		440	
	Suc %	t/ha suc	Suc %	t/ha suc	Suc %	t/ha suc	Suc %	t/ha suc
0	17,3	10,9	16,6	9,6	16,2	9,0	15,7	8,0
92	17,0	12,4	18,3	17,1	17,3	16,4	16,4	13,3
184	17,3	11,5	17,3	18,1	17,6	16,2	17,6	17,8
368	17,4	11,5	17,6	17,4	17,1	17,8	17,4	14,0

uptake of K. Potassium in the northern irrigated areas is frequently applied in excess even on soils showing adequate K levels in the belief that such applications will increase sucrose levels. A recent survey of leaf analysis results from FAS has shown that 35% of the leaf samples from Mpumalanga contained luxury levels of K, confirming excess use of this nutrient. Various researchers have shown that extreme uptake of potassium under similar conditions does not increase recoverable sugar. In fact the opposite occurs, as K forms a complex with sucrose and thereby holds sucrose in solution (Clarke, 1981). The net effect is that the solubility of sucrose is increased when K levels in juice, syrup or molasses increase. This means that when high K syrups are boiled, the crystal yield will be smaller than usual and much more sucrose will remain in solution and end up in the molasses. This results in high purity molasses and poorer molasses exhaustion values (Irvine, 1979; Clarke, 1981). Sugar Milling Research Institute (SMRI) staff have developed a formula for predicting the target purity of final molasses and recovery of sucrose as a function of the ash, fructose and glucose contents in mixed juice. Potassium comprises an important part of the ash in juice; the higher the concentration of K in juice the greater the soluble ash content and the lower the recovery of sucrose from molasses.

In Australia it has also been recorded that extreme uptake of K may promote crop lodging, which results in higher extraneous matter levels such as tops and undesirably high colour levels (Anon, 1995). Excessive K uptake by the crop can also contribute to high ash levels in raw sugars. Ash can affect the colour of refined sugar through impairment of decolourisation by the char due to incorporation of ash in the char matrix. In a study conducted in the Australian sugar industry, increasing concentrations of potassium and chloride ions in juice showed the strongest associations with a decline in juice purity (Stevenson *et al.,* 1970; Kingston, 1982). It has been reported that several inorganic salts of alkaline earth metals such as K may produce a decrease in the specific rotation of sucrose solutions (Browne and Zerban, 1955).

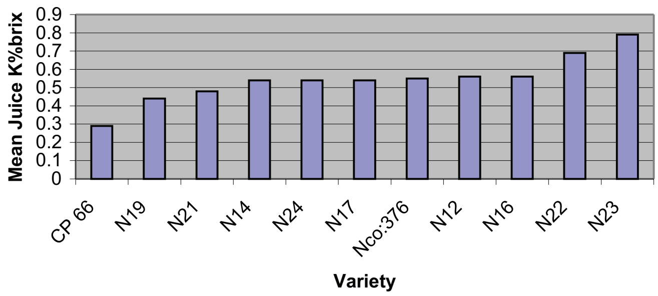


Figure 3. The effect of variety on the K content of juice.

In a cooperative investigation conducted between the SMRI and SASEX, in which juice samples were analysed for a range of constituents from 26 varieties emanating from 19 Agronomy variety trials, the impact of factors such as location, variety and month of harvesting on a range of constituents in cane juice were investigated. The constituents included potassium, colour, inorganic phosphates, sulphated ash and soluble silica and most were significantly affected by locality, variety and month of harvesting (Lionnet, 1997; Naidoo and Lionnet, 2000). The effect of variety on average K content in juice is illustrated in Figure 3. Varietal differences in leaf K content have been known for some time and, where the differences are significant, the threshold value for K is adjusted accordingly, as is currently the case for N14.

Phosphorus

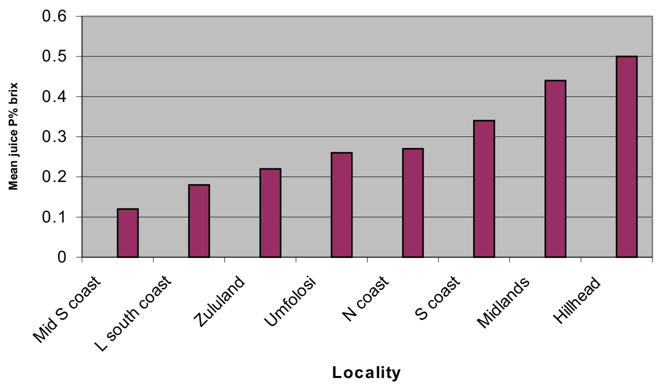
Although an average crop of cane may take up a relatively small amount of P (about 20 kg/ha on average), this nutrient plays an important role in photosynthesis, root development and tillering, to mention just a few areas of importance. An application of P fertiliser to a soil highly deficient in P may significantly increase both cane yield and quality as shown in the plant crop results of two experiments on Inanda series soils (Table 4). It may be inferred that RV% will show a similar trend.

Much of the time the application of P, whilst increasing yields and tons sucrose/ha, does not affect sucrose % cane significantly, as evidenced by results from P fertiliser trials conducted by the Experiment Station in the Midlands and reported by Meyer and Dicks (1979). In one of these trials however, high yielding broadcast treatments resulted in a significant lowering of ERS % cane when compared with treatments which received no broadcast supers (Table 5).

Du Toit (1962) reported that where ratoons had received somewhat excessive amounts of phosphate, the effect of P in lowering sucrose per cent cane was most pronounced, particularly in later ratoons, which had received the topdressing. In general, the effect of luxury uptake of P was to reduce ERS% cane by an average of 0.20 units for each increment of 45 kg P/ha. It is well established that a certain minimum P content in juice is essential for clarification because it is needed to react with lime to form a precipitate. Work at the SMRI showed that poor sugar filtrability was nearly always associated with high P contents in sugar (Lionnet, 1997). However, this could be caused by poor clarification often due to low levels or unreactive P in juices, the residual P then finding its way into the sugar; thus, low levels of P in juice can lead to high levels in sugar. Further results from the cooperative SMRI investigation showed that locality has a highly significant impact on the P content of juice and is strongly influenced by soil and past fertiliser practices (Figure 4). Soil P levels have built up in a number of areas in the sugar industry and it is likely that the high P content in juice in the Hillhead trial was directly related to the very high P levels at this site due to a history of filtercake use.

Lime and filtercake

Although large responses in cane yield to liming have been obtained on Midlands soils, in many cases there has not been an adverse effect on cane quality. However, in one trial situated on a high N mineralising soil, lime treatments significantly depressed sucrose % cane from an average value of 13,4% in the control treatment to 12,4% in the lime treatment. This decline was accompanied by a general increase in leaf N values. This relationship proved to be statistically significant for cane sampled at 8 and 10 months of age. It was found that in the 8-month-old cane, leaf values in excess of 2,5% were associated with poor ERS% values all below 11% (Meyer, 1976). Further investigations indicated that the excess inorganic N from increased mineralisation of N which follows the liming of acid soils led to the decline in sucrose content of cane grown in this trial.



*Data from report by Lionnet 1997

Figure 4. Effect of locality on juice P content*

Table 4. Response to superphosphate – plant cane.

Treatments	Inanda			Melmoth		
	t/ha cane	Suc % cane	t/ha suc	t/ha cane	Suc % cane	t/ha suc
Control – No P	66,7	13,4	8,9	19,9	15,7	3,1
Supers – 1 100 kg/ha	166,4	14,9	24,8	95,6	17,5	16,8

Table 5. Cane yield, ers % cane and tons ers/ha. Trial FT9P – Harden Heights, Inanda series soil.

Treatments	t/ha cane	ERS % cane	t/ha ERS
50 kg P in furrow	90	8,4	7,5
100 kg P in furrow	93	7,9	7,4
50 kg P (if) + 124 kg P (bc)	98	7,3	7,1
50 kg P (if) + 249 kg P (bc)	109	7,5	8,1
LSD (0,05)	14,4	0,9	1,4

Filtercake, which is used primarily as a phosphatic fertiliser, has been applied in large quantities in the Midlands and excellent responses to P have been obtained especially on high P fixing soils. In many cases cane quality has also been significantly depressed due to the presence of excessive amounts of N, which is also supplied by the filtercake. Mineralization of N which follows the liming of acid soils can lead in many instances to a decline in sucrose content of cane grown in the Natal Midlands. The average reduction in ERS% cane due to treatment with filtercake in the various trials was 0.84, 0.48 and 0.16% on Midlands clay loams (N category 4), loamy sands (N category 2) and coastal sands (N category 1) respectively (Moberly and Meyer, 1978). This is one reason why N fertiliser recommendations for this region are adjusted for N. Poultry litter, which has an inherently high N and P content, will also affect cane quality adversely if used in excessive amounts or where the material is not correctly balanced with supplemental fertiliser.

Minor elements

Generally it seems that minor element fertilisers produce no significant increases or decreases in sucrose content. In zinc trials there have been significant responses in yield to zinc application, but none of those examined showed any significant effects on sucrose content. In the case of iron, however, there was a significant increase in sucrose per cent cane where chlorotic cane was sprayed with ferrous sulphate, as well as a substantial increase in yield and tons sucrose.

Effect of soil soluble salts on juice quality

Fogliata and Aso (1965) reported that an increase in soluble salts in the soil caused a consequent accumulation of salts in the cane juice which in turn lowers purity and the sucrose percentage (Table 6).

The effects of cane grown in saline fields is related to the inhibitory effect of the chloride ion and N and P absorption, resulting in poor foliage. These results have been corroborated by similar investigations conducted in Australia (Kingston, 1982). Highly significant associations were revealed between soil salinity in the 0-500 mm depth soil samples and concentrations of sodium, potassium and chloride ions in first expressed juice.

Poor quality irrigation water may also indirectly contribute to increased ash levels in raw sugars (Anon, 1995). A recent survey of the quality of irrigation water in the northern irrigated areas has shown that during the period of low flow in the dry winter months, the quality of water from some river sources becomes marginal for irrigation (Meyer and van Antwerpen, 1995). In another investigation an industry-wide assessment of soil and leaf sample analysis covering nearly a 20-year period has shown a build-up of Ca and Mg levels in soils under irrigation (Meyer *et al.,* 1998).

Conclusions

There can be little doubt that fertiliser management practices and soil type can have a major impact on cane quality.

- Excessive use of N, P or K can impact negatively on recoverable sugar and on the economics of cane production.
- Luxury N and K uptake promotes crop lodging which results in higher extraneous matter entering the millyard. Too much amino acid in the leaves and tops may contribute to colour problems during processing.
- Over-application of N fertiliser increases the risk of eldana damage to cane, with an adverse effect on recoverable sucrose.
- Excessive K fertilisation will yield high K levels in juice and this can affect the exhaustibility of final molasses, as well as the colour and ash content of raw sugars.
- Soil salinity and poor water quality can impact negatively on cane quality, as well as producing higher ash levels in raw sugars.

More than ever before, there is the need for growers to use soil and leaf analysis through FAS in order to balance nutrient uptake and maximise RV production. Fertiliser use in excess of FAS recommendations is not only wasteful but will be more ‘expensive’ under the RV system of payment compared to the previous system. FAS offers the grower and miller-cum-planter a comprehensive range of inexpensive services including whole cycle fertiliser advice, leaf analysis for checking on the adequacy of fertiliser recommendations and which is continually being updated by the latest results from research. The recently patented soil test implemented by FAS for measuring potential N loss from urea fertiliser as well as the six decision support program package (Schumann, 2000), will assist growers to reduce their fertiliser cost as well as improving sucrose recovery.

The relationship between nutrient uptake patterns in commercial cane varieties and sucrose contents needs to be investigated. It is possible that high sucrose varieties may be associated with inherently low N, P and K profile uptake patterns. As far back as 1979 in Louisiana, it was suggested by Irvine that minimising excessive K uptake by variety selection and judicious fertiliser management might be an effective low cost method of improving molasses exhaustion. The effect of management practices on non-sucrose content and the characterisation of non-sucrose constituents will need to feature more prominently in future research programmes, given the change in emphasis in the cane payment system.

Table 6. Effect of soil salts on the quality of sugarcane juice.

Soil salts %	Juice salts %	Juice chloride %	Brix %	Sucrose %	Purity %	Glucose %
0,062	0,060	0.019	21,2	20,1	95,0	0,39
0,145	0,099	0,047	21,0	19,2	91,2	0,56
0,147	0,140	0,068	19,0	16,1	84,6	0,63

To this end the the cooperative project between SMRI and SASEX should be extended to fertiliser and other trials to quantify the effect of fertiliser practices on cane juice quality with special reference to the sucrose and non-sucrose fractions over a range of soil.

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