Improving sugarcane (Saccharum spp. hybrid complex) growth, yield and quality through balanced fertilization: an overview

Melhorando o crescimento, o rendimento e a qualidade da cana-de-açúcar (complexo híbrido Saccharum spp.) por meio de fertilização balanceada: uma visão geral

Mejorar el crecimiento, el rendimiento y la calidad de la caña de azúcar (complejo híbrido Saccharum spp.) mediante una fertilización equilibrada: una visión general

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Abstract

The yield and quality of the sugar cane produced are influenced by the fertility status of the soil, as well as the farmers' fertilization schedule. Excess or deficiency of nutrients influence the concentration of sucrose in sugar cane. There is a significant interaction between nutrients, for example, potassium, together with phosphorus and nitrogen, are crucial, but excess of these nutrients can stimulate cane lodging and have a negative impact on the quality of the juice and sugar production. To determine the effects of underdosing or overdosing nitrogen, phosphate and potassium fertilizers on juice quality, studies of fertilizer doses and fertilizer application times are necessary. Excessive fertilization, in addition to being wasteful, increases production costs and can pollute the environment. Furthermore, some new interventions, such as the use of a multinutrient fertilizer, “polyhalite” (K₂Ca₂Mg(SO₄)4.2H₂O) with conventional muriate of potassium (KCl) @ 80 kg K₂O ha⁻¹ in

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the proportion of 50% each and the use of rice compost (@5.5 t of rice compost) on the balanced nutrition of sugarcane was also discussed. As there is currently no K recommendation for sugarcane, in the Indo-Gangetic plains of Indian Punjab, it is necessary to develop and standardize the recommended K, particularly in K-deficient regions, to improve growth, yield and recovery, by on the one hand, while improving the sugarcane farmer's livelihood, on the other.


**Resumo**

O rendimento e a qualidade da cana-de-açúcar produzido são influenciados pelo estado de fertilidade do solo, bem como pelo calendário de fertilização dos agricultores. O excesso ou a deficiência de nutrientes influenciam na concentração de sacarose da cana-de-açúcar. Há interação significativa entre os nutrientes, por exemplo, o potássio, juntamente com o fósforo e o nitrogênio, são cruciais, mas excesso destes nutrientes podem estimular o acamamento da cana e ter um impacto negativo na qualidade do caldo e na produção de açúcar. Para determinar os efeitos da subdosagem ou superdosagem de fertilizantes de nitrogênio, fosfato e potássio na qualidade do caldo são necessários estudos de doses de adubação e época de aplicação do fertilizante. A fertilização excessiva, além de um desperdício, aumenta os custos de produção e pode poluir o meio ambiente. Além disso, algumas novas intervenções, como o uso de um fertilizante multinutriente, “polihalita” (K₂Ca₂Mg(SO₄)₄.2H₂O) com muriato convencional de potássio (KCl) @ 80 kg K₂O ha⁻¹ na proporção de 50% cada e o uso de composto de arroz (@5.5 t de composto de arroz) na nutrição balanceada da cana-de-açúcar também foi discutido. Como atualmente não há recomendação de K para cana-de-açúcar, é necessário desenvolver e padronizar o K recomendado nas planícies indo-gangéticas do Punjab indiano, particularmente em regiões deficientes em K, para melhorar o crescimento, o rendimento e a recuperação, por um lado, melhorando ao mesmo tempo subsistência do agricultor de cana, por outro.


**Resumen**

El rendimiento y la calidad de la caña de azúcar producida están influenciados por el estado de fertilidad del suelo, así como por el programa de fertilización de los agricultores. El exceso
o deficiencia de nutrientes influye en la concentración de sacarosa en la caña de azúcar. Existe una interacción significativa entre nutrientes, por ejemplo, el potasio, junto con el fósforo y el nitrógeno, son cruciales, pero el exceso de estos nutrientes puede estimular el acame de la caña y tener un impacto negativo en la calidad del jugo y la producción de azúcar. Para determinar los efectos de una sobredosis o una subdosis de fertilizantes nitrogenados, fosfatados y potásicos sobre la calidad del jugo, son necesarios estudios de las dosis y tiempos de aplicación de los fertilizantes. La fertilización excesiva, además de ser un desperdicio, aumenta los costos de producción y puede contaminar el medio ambiente. Además, algunas nuevas intervenciones, como el uso de un fertilizante multinutriente, “polihalita” \((\text{K}_2\text{Ca}_2\text{Mg(SO}_4)_2\cdot\text{H}_2\text{O})\) con muriato convencional de potasio (KCl) @ 80 kg K₂O ha⁻¹ en una proporción del 50% cada uno y la También se discutió el uso de compost de arroz (5,5 t de compost de arroz) para la nutrición equilibrada de la caña de azúcar. Como actualmente no existe una recomendación de K para la caña de azúcar, es necesario desarrollar y estandarizar el K recomendado en las llanuras indogangéticas del Punjab indio, particularmente en las regiones con deficiencia de K, para mejorar el crecimiento, el rendimiento y la recuperación, por un lado, y al mismo tiempo mejorar el sustento de los agricultores de caña de azúcar, por el otro.


**Introduction**

Sugarcane is an important industrial crop grown world wide due to its economic benefits. Approximately 4732 thousand hectares were planted with cane in India in 2017–2018, with a maximum yield of 79.6 t ha⁻¹, a maximum production of 348 million tonnes, and a recovery rate of 10.73% (ICAR 2021). Over 115 thousand hectares of sugarcane were planted in Punjab, India, between 1975 and 1976. The average yield and production were 53.8 t ha⁻¹ and 61.8 × 10⁹ kg, with an 8.5% recovery rate. CSTs, or climate-smart technologies, were developed, evaluated, and suggested to cane growers. Recovery increased to 9.8% with improved yields and output of 83.6 t ha⁻¹ and 80.3 × 10⁹ kg from 96,000 ha over 2017–2018 (PAU 2022).
Barber (1931) believed that the thin Indian canes most likely came from certain plants closely related to Saccharum spontaneum (Kans) in the damp regions of northeastern India. The class monocotyledons, order glumaceae, subfamily panicoidae, tribe Andripogoneae, and subtribe saccharininea are the families to which sugarcane belongs in the Poaceae family. In the agricultural sector, sugarcane accounted for 2.6% of India's gross cultivated area in 2006–07 and contributed 7% of the overall value of agriculture output. Sugarcane is the second largest agro-based industry, behind the textile industry. The nutritional information from ESHA research indicates that a serving of sugarcane juice (28.35 grammes) provides 111.13 kJ (26.56 kcal) of energy, 27.51 g of carbohydrates, 0.27 g of protein, 11.23 mg (1%) of calcium, 0.37 mg (3%) of iron, 41.96 mg (1%) of potassium, and 17.01 mg (1%) of sodium.

This makes sugarcane juice a useful food source for humans. The ratio of sugars to non-sugars in juice can be used to determine the quality of sugarcane juice. High sugar recovery only from canes with high sucrose, high purity, low fibre, and low non-sugar content. Differential quality parameters of the canes include colour, filterability, lowering sugar levels, and crystal form. Important variables influencing juice quality include the right kinds, topping height, harvesting techniques, harvest to crush delays, usage of chemical ripeners, disease and insect infestation, and fertilizer management techniques. The soil textural class and fertilizer management have a direct impact on the chemical quality of cane juice, including characteristics such as sucrose concentration and non-sucrose factors that can affect sugar recovery in the processing stream (Wood, 1982).

This review aims to examine the economic effects of under- and overfertilization by focusing on the various fertilizers—nitrogen, phosphorus, and potassium—as well as their management strategies and how they affect cane quality.

**Balanced Fertilization víz-a víz Sugarcane Growth, Yield and Quality**

### 2.1 Nitrogen (N)

N is the primary nutrient that controls crop output out of the six major nutrients (P, K, Ca, Mg, and S) (Bhatt et al., 2022). It is crucial to create an economic equilibrium regarding the amount of fertilizer N needed in order to maximise the amount of sugar and not just cane per unit, time, and area in a crop like cane where an increase in biomass may be linked to a decrease in quality. The main effect of increasing N application in cane is to promote
vegetative growth; however, fast growth usually means higher N, moisture, and non-sugar content in the cane plant, as well as a lower sucrose content before harvest. In 1982, Moberly assessed the sucrose concentration in seven crops from the highest to the lowest and examined the impact of N on cane quality in three different cane varieties: NCo376, N52/219, and J59/3. More N had a negative impact on the purity and sucrose content of variety NCo376 than it did on N52/219 or J59/3. All three types of cane yielded more when N levels were raised, but the response in tonnes of cane was countered by a linear drop in the sucrose content of the crop.

The quality of cane decreased with rising N levels between 50 and 150 kg N ha\(^{-1}\) under the traditional sucrose-based payment scheme, averaging 0.38 units % cane for every 50 kg N ha\(^{-1}\) added to NCo376. The other two cane varieties saw almost unchanged quality. For NCo376 the maximum sucrose yields were obtained at 100 kg N ha\(^{-1}\), while for the other two types the response to more than 50 kg N ha\(^{-1}\) did not seem worth-while. It is clear that raising the N level had a greater detrimental impact on the overall sucrose recovery for NCo376 than it did under the direct sucrose payment system because the RV cane payment method takes into consideration the impact of non-sucrose and fibre content on the recovery of sucrose. Cane quality decreased as N levels increased between 50 and 150 kg N ha\(^{-1}\); for every 50 kg N ha\(^{-1}\) added to NCo376 on average, 0.45 units RV% of cane were lost; quality for the other two kinds were unchanged. A larger decline in the RV rand value per tonne of cane for variety NCo376 also reflects the greater impact of above average N applications under an RV cane payment scheme.

A comparison of the gross income produced under the two payment systems makes this reduction easier to detect. N generally had a negligible impact on fibre, with a tendency to decrease fibre. Extra N does not always have a negative impact on cane quality, according to an analysis of data from several nutritional trials. Reduced RV% and decreased purity are more likely to occur in cane grown on an autumn/winter cycle when N fertilizer levels rise. It's also critical to consider the industry soils' erratic ability to deliver nitrogen through mineralization, since too much nitrogen will probably have a negative impact on purity and, thus, recoverable sugar under the RV cane payment scheme. Previous N study results indicate that sugar yields from treatments without N applied ranged from 7 to 15 tonnes sucrose/ha/year. The main cause of this was that the soils' ability to provide crop N through soil organic matter (N) mineralization ranged widely, from less than 70 to more than 140 kg N per hectare (Meyer et al., 1986). Thankfully, the recommendations for N from Punjab Agricultural University, Ludhiana, matched the soils' capability for N mineralization,
lowering the possibility of overapplying N. Overuse of nitrogen may also result in lodging, which can obliquely to a decrease in recoverable sucrose and increase the danger of infestation and insect-pest assault. Researchers in India conducted a two-year field study to evaluate the impact of nitrogen (N) application on the composition of sucrose and non-sugars in cane juice.

They discovered that while inorganic non-sugars decreased, likely as a result of a dilution effect as total amino acid and phenol content increased, the colloid and gum content decreased with increasing N (Asokan and Raj, 1984). Numerous studies assessing the fertilisation of sugarcane with macronutrients, particularly nitrogen, indicate a strong relationship between the number of stems and yield (Vale et al., 2012). Naturally, far more N is needed to reach that yield level in total above- and below-ground biomass. However, understanding the amount of N that crops require does not mean that we know how much fertilizer N to apply. Instead, we need to find out about the intrinsic fertility of the soil before applying fertilizers to make any impact.

The highest treatment rate of 160 pounds N per acre frequently resulted in a decrease in sugar content, confirming the need to lower rates and allaying concerns that N deficits would arise at lower rates. However, for cane that receives heavy rainfall, scientists should be aware that some N may be lost by leaching and denitrification. Cane fertilised before the suggested dates, when the crop is not actively using the fertilizer, may be more susceptible to loss. Despite the fact that different experiments yielded optimised varieties at varying rates, these variations in responsiveness to variation were not significant enough to produce distinct N recommendations for specific varieties.

According to Srivastava and Suarez (1992), the recommended global rates of nitrogen fertilizer for sugarcane production range from 45 to 300 kg N ha\(^{-1}\) yr\(^{-1}\), contingent on the prevailing agro-climatic zones and soil textural class. Ratoon crops respond more to N fertilisation than plant-cane crops do, and in many places, the ideal rate of N fertilizer for sugarcane is between 100 and 200 kg N ha\(^{-1}\) yr-1 (de Geus, 1973). According to studies carried out in Louisiana by Curtis and Loupe (1975), the majority of areas should receive 90 to 135 kg N ha\(^{-1}\) for plant-cane crops, while all areas should receive 135 to 157 kg N ha\(^{-1}\) yr-1 for ratoon crops. Two thirds of the entire dose should be delivered in April or early May, with the remaining fertilizer being applied in June, when these recommended doses equal 135 kg N ha\(^{-1}\) yr-1 or more.

Studies on sugarcane nutrients Southern Texas's Rozef (1990) suggested 56 and 90 kg N ha\(^{-1}\) for the plant-cane crop following a fallow cycle, as well as for the subsequent crop.
Improving sugarcane (Saccharum spp. hybrid complex) growth, yield and quality through balanced fertilization: an overview

In contrast to South Africa, where the ideal N rate for the first ratoon crop was different (0 to 100 kg N ha\(^{-1}\)) and gradually increased for each subsequent ratoon crop (50 to 150 kg N ha\(^{-1}\) yr\(^{-1}\)), Inman-Bamber's (1984) recommendations for ratoon crops were 100 to 157, 134 to 190, and 168 to 202 kg N ha\(^{-1}\) for the first, second, and third crops, respectively. In Australia, the majority of regions currently recommend applying 120 to 150 kg N ha\(^{-1}\) of N fertilizer for plant-cane crops following a fallow period, and 160 to 200 kg N ha\(^{-1}\) for subsequent plant-cane and ratoon crops. According to Canegrowers (2002), recommended rates were lower in locations with peat or alluvial soil and annual rainfall of less than 1200 mm.

The use of slow-release nitrogen applied in four split applications on a complex of Pompano and Leon fine sand at Delray, Florida, produced the highest yields of sugarcane at N rates of 224 and 448 kg ha\(^{-1}\) for plant-cane and first ratoon crops, respectively. Various cultivars had varying N use efficiencies (Gascho, 1983). Obreza et al. (1998) discovered that, at the same rate of N fertilisation (224 kg N ha\(^{-1}\) yr\(^{-1}\)), the sugarcane yield of cultivar CP 72-1210 on a Basinger sand was higher with more split applications (five splits for plant-cane and four splits for ratoon) than with less split applications (three splits for plant-cane and two splits for ratoon). Nonetheless, there was no significant change in the quantity of split applications in the second crop of ratoons. The recommended N rate for Florida sugarcane is currently 90 kg N ha\(^{-1}\) yr\(^{-1}\); however, Kidder et al. (2002) found that the rate was determined by studying sugarcane syrup production. The University of Florida recommended 202 kg N ha\(^{-1}\) yr\(^{-1}\) for sugar cane grown on sandy, mucky-sandy, and sandy-muck soils; however, Rice et al. (2002) found that the nutritional requirements for those soils appear to be 202, 123, and 34 kg N ha\(^{-1}\) yr\(^{-1}\), respectively, when applied in split applications during the growing season.

For plant-cane and first ratoon crops, the N fertilizer rate had no discernible effect on stalk weight. Notwithstanding, the weight of the second ratoon crop stalk grew somewhat with N (g stalk\(^{-1}\) = 0.51 kg N ha\(^{-1}\) yr\(^{-1}\) + 515; R2= 0.25, P=0.0962). The yields of sugar and cane at no harvest dates in any crop (P>0.10) were not affected by the rate of N fertilizer. Nonetheless, there was a numerical rise in sugar output with higher N rates at every harvest that was reported for all crops. Even the lowest test rate (170 kg N ha\(^{-1}\)) on sandy Florida soils may have been at or above the critical N rate for sugar cane production, given the lack of response to N fertilizer rates utilised in this study. According to this study, the amount of N fertilizer applied in each split application may also have an impact on the lack of yield response to N fertilizer. According to Borden (1948), sugarcane yield would increase if the final N
application on a crop that lasted 12 or 18 months was finished by the fourth or sixth month. Moreover, Samuels (1969b) noted that sugarcane's N requirements were highest during the germination and early development phases of the "boom stage."

According to Glaz and Ulloa (1995), the relative sugar yields of the various crops were typical for the production of sugar cane in fallow on sandy soils. The yield of the first ratoon crop was 126% of the plant-cane crop, whereas the second ratoon crop was 74% of the plant-cane crop. When sugar cane is grown on fallow land, plant cane harvests generally yield more sugar overall, whereas subsequent ratoon crops yield less sugar overall. The planting time is most likely the cause of the crop's comparatively reduced sugar output. In contrast to the usual planting season of August through October, this study took place in December. Therefore, higher sugar yields for the first ratoon crop relative to the plant-cane crop as found in this study would not be surprising. But the remarkable thing was the 41% decrease in sugar yield between the first and second ratoon harvest. For the majority of the second growing season, N was essentially immobilised by soil microorganisms trying to decompose the organic stuff in the waste blanket (Muchovej and Newman, 2004). Wood (1964) and De Geus (1973) noted a decrease in sugar cane yield from consecutive ratoon crops, which they linked to a reduction in soil nitrogen.

2.2 Potassium (K)

Potassium is necessary for photosynthesis and plant growth. It moves and stores sucrose, which is important for the plant's moisture economy (Bhatt et al., 2022). Cane juice contains the highest concentration of K among all the basic elements; in fact, K₂O makes up between 30 and 50 percent of the ash in cane juice. Applying K fertilizers to a K-deficient soil can increase the percentage of poles and decrease the fibre content, which will improve sucrose recovery. In many of the earlier N/K fertilizer trials, however, a response to K in terms of sucrose and yield was accompanied by a rise in the percentage of sucrose cane.

K is by far the most effective of the three key nutrients in lowering the starch content of cane; on soils lacking in K, a significant decrease in starch usually corresponds with significant yield improvements (Wood, 1962). 34 K trials conducted in Australia between 1961 and 1964 revealed a cane yield response to K fertilizer applications at rates of 0, 92, and 184 kg K ha⁻¹; however, the cane's quality was not appreciably impacted (Yates, 1965). For tests that responded to K being sprayed on base saturated soils, the same conclusion was made.
Improving sugarcane (*Saccharum* spp. hybrid complex) growth, yield and quality through balanced fertilization: an overview in Mpumalanga and Swaziland (Donaldson et al., 1990). In the absence of a K response, increasing rates of K also typically did not appear to have much of an impact on cane quality.

In one N/K study in the Midlands, when a very high level of K (375 kg K ha\(^{-1}\)) was applied, there was a suggestion of a depression in sucrose percent cane (reduced from 13.1 to 12.6); however, this was not statistically significant. Stewart (1969) also noted a considerable decrease in the percentage of cane sucrose following the application of 183 kg K ha\(^{-1}\) to soil containing 155 ppm of exchangeable K. There is a belief that potash treatments could prevent the depression of sucrose in cane juice caused by high N fertilizer applications. According to an analysis of test data that is currently available, this can happen in soils with very low K levels where it is expected to react to K. Under these circumstances, interactions between N and K were noted in a number of Regional Fertilizer Trials (RFTs); the most notable example was one conducted on a soil with 64 ppm K (Stewart, 1969) TMS (Cartref series).

In this experiment, the percentage of cane saccharose has been used to gradually reduce the amount of N fertilizer applied in the absence of potash. Table 3 illustrates how K's addition, however, reversed this tendency and produced an excellent response in terms of sucrose percent cane at high N levels. RV% would have followed the same pattern as a saccharose percentage cane. Potassic fertilizer use in sugarcane has expanded significantly over the past forty years, to the point where leaf analysis clearly shows K's luxury uptake in certain places. Even on soils with sufficient K levels, potassium is frequently sprayed excessively in the northern irrigated areas with the assumption that this will raise the levels of sucrose. 35 percent of Mpumalanga leaf samples had K levels of luxury, according to a recent review of leaf analysis FAS findings, confirming the overuse of this nutrient. Excessive potassium consumption has not been shown by other researchers to increase recoverable sugar under comparable circumstances.

Actually, the opposite occurs as a result of K and saccharose forming a complex, which keeps saccharose in solution (Clarke, 1981). Overall, this means that sucrose becomes more soluble when K levels in juice, syrup, or molasses rise. This indicates that when high K syrups are boiled, the crystal yield will be smaller than usual and a greater amount of saccharose will remain in solution and congeal in the molasses. This produces high-purity molasses and lower-purity molasses with exhaustion values (Irvine, 1979). A formula has been devised by the staff at the Sugar Milling Research Institute (SMRI) to anticipate the desired level of purity in the final molasses and to recover sucrose based on the amount of ash, fructose, and glucose in the
mixed juice. Juice contains a significant amount of ash, and the more potassium there is, the more soluble ash there is and the less sucrose can be recovered from molasses.

Extreme K intake has also been linked to crop lodging in Australia, which can lead to greater levels of extraneous matter such tips and undesirably high levels of colour (Anon, 1995). High ash content in raw sugars can also be attributed to overcrowding of K. Ash's presence in the char matrix can cause decolorization, which can alter the colour of refined sugar. Increased potassium and chloride ion concentrations in juice demonstrated the strongest correlations with decreasing juice purity, according to research done in the Australian sugar sector (Stevenson et al., 1970; Kingston, 1982).

It has been noted that a number of inorganic salts containing alkaline earth metals, such as K, can cause sucrose solutions' specific rotation to decrease (Browne and Zerban, 1955). Location, variety, and harvest month had a substantial impact on majority of the components, which included potassium, colour, inorganic phosphates, sulphated ash, and soluble silica (Lionnet, 1997; Naidoo and Lionnet, 2000). The impact of variation on the average juice content of K is shown in Figure 3. Since it has long been known that there are variations in the amount of K in leaves, the threshold value for K is modified when these variations are substantial, as is the situation with N14 at the moment.

In comparison to the national average of 85 kg of nitrogen (N) and 21 kg of phosphorus (P) per hectare, Pakistan uses less than 1 kg of K fertilizer per hectare, which is practically negligible. Pakistan's soils have developed micaceous alluvium, which is why people generally believe that the country has adequate K supplies. However, crops become more receptive to K fertilisation with the advent of high yielding cultivars and the maintenance of intensive cropping techniques. Insufficient potassium negatively affects sugarcane photosynthesis and carbohydrate transport; high potassium rates are necessary for the highest possible commercial cane output. Since both sources were equally effective, the K source had no effect on the growth, yield, or quality of ratoon sugarcane.

As K fertilizer application rates increased, so did the number of millable canes per unit area, cane diameter, and internode length; nevertheless, as will be discussed later, K application rate had a major impact on growth, yield, and quality. Using 200 kg K₂O ha⁻¹, the longest canes (2.5 m) were created. In either 150 or 200 kg K₂O ha⁻¹ treated plots, the maximum weight per stripped cane (1.23 kg) was reached; for canes collected from 100 kilogramme K₂O ha⁻¹ treated plots, the weight per stripped cane dropped to 1.12 kg. The plots
Improving sugarcane (*Saccharum* spp. hybrid complex) growth, yield and quality through balanced fertilization: an overview

treated with 200 kg K$_2$O ha$^{-1}$ yielded the highest amount of stripped cane (101 t ha$^{-1}$). From the control plots, the minimum yield of stripped cane (77 t ha$^{-1}$) was gathered (Khosa, 2002).

The cane juice from the control plots had 14.6 percent sucrose, while the 200 kg K$_2$O ha$^{-1}$ treated plots had a considerably higher sucrose concentration of 16.5 percent. The trend seen in the percentage of commercial cane sugar (CCS) and sucrose content was similar when K rates were raised. Cane juice from 200 kg K$_2$O ha$^{-1}$ plots had a considerably higher CCS (11.2 %) than the minimum CCS (9.6%) recorded in control plots (Khosa, 2002). Sugarcane can quickly deplete soil nutrients, particularly potassium. According to Wood (1990), under South African conditions, an appropriately fertilised 12-month plant cane crop that was rain-fed contained 214 kg K$_2$O ha$^{-1}$, but a cane crop of the same age and variety may extract up to 790 kg K ha$^{-1}$ under irrigation. When sugarcane was harvested in Florida, an average of 343 K$_2$O ha$^{-1}$ of histosols were removed from the field (Coale et al., 1993).

Even in the absence of potash application, sugar cane in Mauritius recovered about 250 kg K$_2$O ha$^{-1}$ from soils with high accessible K (Cavalot et al., 1990). Chapman (1996) reported that the above-ground biomass of an 84-ton cane ha$^{-1}$ crop in Australia averaged 198 kg K$_2$O ha$^{-1}$. It follows that sufficient K inputs for the long-term and sustainable usage of sugarcane lands must be provided to offset the high amounts of K removed in order to prevent a deterioration in soil fertility. As a result, this paper looks at the value of K manuring in sugarcane farming as well as the impact of K application on sugarcane growth, development, yield, and quality. Unless there is a significant K deficiency, it is reported that K manuring has no effect on the growth pattern, growth rate, number of green leaves per mother shoot, leaf area, and tiller density (Abayomi, 1981; Chatterjee et al., 1998).

After 90 to 125 days of planting or harvesting, two crucial ontogenic events will happen at the same time: the shooting population is starting to drop and cane growth is starting, as seen by the ongoing increase in stalk height in the inset. Shoots can be classified as non-millable—those without visible cane growth—and millable—those with at least one exposed, extended internode basal—once cane growth begins. According to Donaldson et al. (1990), K affects population and stalk height. K shortage will often reduce height unless it is quite severe, but it has no discernible influence on the quantity of millable stalks (P= 0.05). (Chatterjee & Associates, 1998). Bhatt et al. found significant improvements in germination, number of millable canes, root length density and cane yields (Table 1) at PAU, the regional research station in Kapurthala, India, in 2022 when compared to the control and 40 kg K$_2$O ha$^{-1}$. However, differences between plots receiving 80 kg K$_2$O ha$^{-1}$ and 120 kg K$_2$O ha$^{-1}$ were
comparable. As a result, 80 kg K$_2$O ha$^{-1}$ was found to be a sustainable potash dose for the deficient sites in Punjab, India, significantly improving the cane quality (Bhatt et al., 2022).

Table 1

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Germination (%)</th>
<th>NMC (000/ha)</th>
<th>RLD (cm cm$^{-3}$)</th>
<th>Cane yield (Mg ha$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I$_1$</td>
<td>49.76a</td>
<td>47.75a</td>
<td>87.6a</td>
<td>0.439a</td>
</tr>
<tr>
<td>I$_2$</td>
<td>46.81a</td>
<td>44.79a</td>
<td>87.2a</td>
<td>0.449a</td>
</tr>
<tr>
<td>K$_1$</td>
<td>40.95c</td>
<td>41.91c</td>
<td>77.72b</td>
<td>0.429a</td>
</tr>
<tr>
<td>K$_2$</td>
<td>46.55b</td>
<td>44.52b</td>
<td>82.34b</td>
<td>0.436a</td>
</tr>
<tr>
<td>K$_3$</td>
<td>51.17a</td>
<td>49.17a</td>
<td>94.14a</td>
<td>0.458a</td>
</tr>
<tr>
<td>K$_4$</td>
<td>54.18a</td>
<td>52.15a</td>
<td>95.31a</td>
<td>0.454a</td>
</tr>
</tbody>
</table>

Superscript letters are based on the data analyzed using the SAS program and subjected to analysis of Variance (ANOVA) and the treatments means were compared by Duncan’s multiple range test (DMRT); I$_1$ and I$_2$ represent the main plot treatments of irrigated and stressed plots while K$_1$, K$_2$, K$_3$, and K$_4$ represents subplots treatments where potash applied as 0, 40, 80 and 120 Kg K$_2$O ha$^{-1}$, respectively; NMC and RLD represents number of millable canes and root length density (Source: Bhatt et al., 2022)

According to Filho (1985), sugar cane grown under moisture stress can have its hydrolytic invertase activity intensified, leading to highly reduced sugar cane but low sucrose levels. Additional K was also reported to produce even higher cane and sugar yields. Applying K during planting under water stress conditions greatly increased stomatal diffusive resistance, as demonstrated by Sudama et al. (1998) in pot experiments. This led to decreased transpiration rates and increased leaf water potential, cane length, sucrose content in juice, and cane yield. It has been discovered that potassium regulates the osmotic concentration and hydration of stomata guard cells. A K deficit results in a reduction of turgor pressure, which closes the stomata and lowers transpiration and CO$_2$ absorption rates (Humbert, 1968).

Fresh cane weight and millable stalk populations are the two most often measured sugarcane yield components. To evaluate sugar recovery from milled cane, fresh cane stalk sucrose content is measured in addition to juice purity. The effects of K on sugarcane yields, namely in Brazil, and the rates of K utilised in different sugar-producing nations were evaluated by Filho (1985) and Malavolta (1994). In actuality, there is a wide range in the sugarcane yield's reaction to K manuring. According to Yang and Chen (1991), just 33 percent
of the Fijian study sites had responded to K fertilisation. Lakholive et al. (1979) conducted a 3-year study in Vidarbha conditions in India and found no reaction to K applied at 50-100 kg K ha\(^{-1}\). Olalla et al. (1986) found no difference in cane and sugar yields at 0-300 kg K ha\(^{-1}\) in Malaga between the first two years of K fertilizer use and the next two years when K fertilisation was not applied. However, in a sandy loam calcareous soil in North Bihar, Prasad et al. (1996) discovered that cane yield increased from 50 t ha\(^{-1}\) without K fertilisation to 74.5 t ha\(^{-1}\) with only 60 kg K ha\(^{-1}\).

At eleven different locations in the Brazilian state of Sao Paulo, Korndorfer (1990) showed that applying K at a higher rate-up to 150 kg K ha\(^{-1}\) progressively boosted cane production. In Hawaii, Humbert (1962) discovered that cane reaction to K fertilizers was unlikely to be substantial over 0.23 cm of exchangeable K kg\(^{-1}\). Similarly, Wood and Burrows (1980) in South Africa advised against K fertilisation for cane and the next four ratoons when the soil exchangeable K level was greater than 0.70 cmol kg\(^{-1}\). Even in cases when soil K levels were low, sugarcane did not react negatively to K fertilisation. Thus, even with the available amounts of this nutrient, Reis and Cabala-Rosand (1986) reported no response to K fertilisation in the range of 0.07 to 0.14 cmol K kg\(^{-1}\).

When the soil's buffering capacity is adequate, for example, sugar cane can obtain enough K from the non-exchangeable K reserves in the upper layers of the soil and subsoil. This is indicated by the frequent absence of yield response to fertilizer K in soils with low accessible K. In 1971, sugar cane grown continuously on red sandy loam soil in Karnataka, India, produced 63 t ha\(^{-1}\) both with and without fertilizers, as shown by Rabindra et al. (1993). However, in 1988, the yield of N alone (250 kg N ha\(^{-1}\)) was 30-34 t ha\(^{-1}\), and the yield of NPK with K at 125 kg K ha\(^{-1}\) produced 130-136 t ha\(^{-1}\) in cane. Fertilizer K was applied, and the plant cane crop did not respond, although the first ratoon crop in an Uttar Pradesh mollisol did respond, albeit very minimally (Sachan et al., 1993).

According to Paneque et al. (1992), cane yields in Brazil increased by 23 and 39 t ha\(^{-1}\) at the end of the second and third ratoons, while neither plant cane nor the first ratoon responded to K. As correctly pointed out by Rodella (1990), another consequence of sugar cane's semi-perennial character that has not received much attention is the significant impact of other variables on the K sugar cane response tests. A high degree of interaction exists within the sugarcane crop cycle, as demonstrated by Rodella (1990). For instance, plant cane's K rates can affect the first ratoon reaction to K fertilisation, or plant cane's P rates can influence
the first ratoon response to K. The difficulties in assessing the sugarcane response to K manuring are unavoidably increased by these interactions.

2.2.1 Potash *viz-a-viz* sugarcane quality/recovery

One of the most crucial strategies for the sugarcane industry to increase profitability is to improve cane quality. It is actually far more profitable to grind cane with a high percentage of recoverable sucrose because the cost per unit tonne of generated sugar will be lower. Since the highest production of sucrose is determined by the juice's quality, this is an important consideration (Bhatt et al., 2022). Regrettably, though, variety, climate, and the relatively minimal amount of fertilizer applied all have a major impact on the sucrose content of cane. most K fertilizer studies revealed that cane yield response to K was not followed by a rise in cane sucrose, despite suggestions that K can improve sugar yield without a corresponding increase in cane yield (Dang and Verma, 1996).

In South Africa, Wood (1990) found that raising the rate of K had minimal effect on cane quality when there was no cane yield response. Gulati et al. (1998) also noted that juice quality was unaffected in India even though K application produced the maximum cane yield and number of millable canes in two equal splits (50 percent at sowing and 50 percent at monsoon end). The most significant finding was that high K uptake from the soil reduces saccharose recovery during milling. Filho (1985) states that throughout the processing of sugar, K tends to increase the solubility of sucrose, preserving a specific amount of saccharose in solution by binding up a saccharose molecule with one K+. In 2022 at PAU, regional research station, Kapurthala Bhatt et al observed significant improvements in commercial cane sugar (%) as compared to the control and 40 kg K₂O ha⁻¹ while differences were at par between plots receiving 80 kg K₂O ha⁻¹ and 120 kg K₂O ha⁻¹; thereby 80 kg K₂O ha⁻¹ reported to be sustainable potash dose for the deficient sites for significantly improving the cane quality in Punjab, India (Bhatt et al., 2022).
2.3 Phosphorus (P)

P may only be required in relatively tiny amounts by an ordinary cane crop (approximately 20 kg/ha), but it is crucial for photosynthesis, root formation, and tillering, to name a few critical processes. The findings of two studies on Inanda soils demonstrate that P cane production and quality can rise greatly when P fertilizer is applied to a highly deficient soil. It follows that the RV % will follow a comparable pattern. The results of P fertilizer

Table 2

<table>
<thead>
<tr>
<th>Brix (%)</th>
<th>Pol (%)</th>
<th>Purity (%)</th>
<th>Extraction (%)</th>
<th>CCS (%)</th>
<th>Sugar yields (t/ha)</th>
<th>Brix (%)</th>
<th>Pol (%)</th>
<th>Purity (%)</th>
<th>Extraction (%)</th>
<th>CCS (%)</th>
<th>Sugar yields (t/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I₁</td>
<td>21.20a</td>
<td>19.18a</td>
<td>90.48a</td>
<td>53.33a</td>
<td>13.42a</td>
<td>10.39a</td>
<td>21.19a</td>
<td>18.90a</td>
<td>89.19a</td>
<td>54.63a</td>
<td>13.13a</td>
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<tr>
<td>I₂</td>
<td>20.70b</td>
<td>19.06a</td>
<td>92.02a</td>
<td>51.59a</td>
<td>13.40a</td>
<td>10.34a</td>
<td>20.94a</td>
<td>18.80a</td>
<td>89.18a</td>
<td>54.25a</td>
<td>13.05a</td>
</tr>
<tr>
<td>K₁</td>
<td>20.54b</td>
<td>18.65b</td>
<td>90.85a</td>
<td>51.63a</td>
<td>13.07b</td>
<td>9.97b</td>
<td>20.58b</td>
<td>18.44c</td>
<td>89.57a</td>
<td>54.25a</td>
<td>12.83b</td>
</tr>
<tr>
<td>K₂</td>
<td>20.74ab</td>
<td>18.89b</td>
<td>91.16a</td>
<td>52.44a</td>
<td>13.25b</td>
<td>10.18b</td>
<td>20.67b</td>
<td>18.74bc</td>
<td>90.67a</td>
<td>55.49a</td>
<td>13.11ab</td>
</tr>
<tr>
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<td>19.45a</td>
<td>91.47a</td>
<td>53.12a</td>
<td>13.67a</td>
<td>10.66a</td>
<td>21.48a</td>
<td>18.99ab</td>
<td>88.35b</td>
<td>54.18a</td>
<td>13.12ab</td>
</tr>
<tr>
<td>K₄</td>
<td>21.29a</td>
<td>19.48a</td>
<td>91.52a</td>
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<td>19.22a</td>
<td>88.17b</td>
<td>53.85a</td>
<td>13.28a</td>
</tr>
</tbody>
</table>

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Wood (1990) observed a notable decrease in the content of cane saccharose following an application of 183 kg K₂O ha⁻¹ in South Africa. Chapman (1980) found in long-term trials conducted in Australia that 196 kg K₂O ha⁻¹ slightly reduced the concentration of sucrose in cane when compared to no K treatment. Korndorfer (1990) found that when vinasse (distillery slopes) was applied at 120 m³ ha⁻¹ to a dark red dystrophic latosol in Brazil, cane yield increased from 98 to 127 t ha⁻¹, but recoverable cane concentration decreased from 15.0 to 13.1%. Consequently, the literature's data demonstrates that, although while K plays a significant function in sugarcane plants, it needs to be maintained at a level that will generate optimal yields and control maturity in order to extract the most sugar possible from the millable stalks.
studies done at the Midlands Experiment Station and reported by Meyer and Dicks (1979) show that while P application increases yields and tonnes of saccharose / ha, it often has little effect on saccharose % cane. In contrast to treatments that did not get any supers broadcast, high yielding broadcast treatments in one of these experiments led to a considerable decrease in the percentage of ERS cane.

According to Du Toit (1962), the effect of P was most noticeable in lowering the percentage of sucrose in cane when ratoons got relatively excessive levels of phosphate, particularly in later ratoons that received topdressing. In general, P's luxurious absorption resulted in an average decrease of 0.20 units in the percentage of ERS cane for every 45 kg P / ha increase. Juice must have a minimum of a particular amount of P in order to clear because lime must react with the juice to generate a precipitate. Research using SMRI has demonstrated that a high sugar P concentration has nearly always been linked to poor sugar filterability (Lionnet, 1997).

Low amounts of P in juice can, however, result in high levels of sugar because of unreactive or low levels of P, which are frequently the result of inadequate clarity. Remaining P can then make its way into the sugar. Further findings from the collaborative SMRI study indicated that soil and previous fertilizer applications, as well as location, have a significant impact on juice P content. Due to a history of filter cake use, soil P levels have accumulated in a number of sugar industrial locations. As a result, it is likely that the high P concentration in juice from the Hill Head trial was directly related to the extremely high P levels at this site.

Cane quality has not always suffered despite the fact that liming has produced significant increases in cane production on mid-land soil, lime, and filter cake. On the other hand, in an experiment conducted on a soil with considerable nitrogen mineralization, the percentage of sucrose cane in the control treatment was dramatically reduced by lime treatments, going from an average of 13.4% to 12.4% in the lime treatment. Alongside this decrease, leaf N levels generally increased. For the cane sampled, this association was statistically significant at 8 and 10 months of age. In the eight-month-old cane, leaf values higher than 2.5 percent were linked to bad ERS percent values, all of which were below 11 percent (Meyer, 1976). Additionally, studies showed that the extra inorganic N that was produced by the enhanced mineralization of N brought about by liming acid soils caused the amount of cane grown in this trial to decline. Large amounts of filter cake, which is mainly used as phosphatic fertilizer, were applied in the Midlands, and great P reactions were seen, especially on high P fixing soils.
In many situations, cane quality has also been markedly reduced due to the presence of excessive amounts of N, which is also provided by the filter cake. The amount of cane grown in the Natal Midlands can frequently drop as a result of the mineralization of nitrogen that occurs after acid soils are limed. The average reduction in ERS % cane owing to filter cake treatment on Midlands clay loams (N category 4), loamy sands (N category 2), and coastal sands (N category 1) was 0.84, 0.48, and 0.16 percent, respectively, in the four trials (Moberly and Meyer, 1978). For this reason, the N fertilizer recommendations for this region have been modified. Because poultry litter naturally contains a significant amount of N and P, using too much of it or failing to balance it with additional fertilizer will also negatively impact the quality of the cane.

2.4 Micro Nutrients Viz-a-Viz Sugarcane Performance

It seems that minor element fertilizers typically result in non-significant changes to the sucrose concentration. Zinc applications resulted in considerable yield responses, however none of the experiments that were looked at had any discernible influence on sucrose content. On the other hand, in the case of iron, there was a notable rise in the yield and tonnes of sucrose, as well as in the proportion of sucrose cane where chlorotic cane was sprayed with ferrous sulphate. There is a constant search for the best fertilizer and balanced fertilisation to achieve optimal productivity. When fertilising sugarcane, the macro- and micronutrients required to initiate the physiological processes of the plant that impact crop output should be applied. The micronutrients play essential roles in plant metabolism or as components of substances that are in charge of metabolic and/or physiological processes as enzyme activators (Malavolta et al., 1974; Epstein, 1975).

Studies in Sao Paulo have had a significant impact on stem production in the Oxisol Dark, sandy phase, with the application of Cu and Zn in the form of chelates (Alvarez, 1984) and Yellow Red Latosol, sandy phase, with the use of Zn (Cambria et al., 1989), despite the fact that the majority of work done in the Center-South of Brazil did not show responses of sugarcane to the application of micronutrients (Alvarez and Wutke, 1963; Siqueira et al., 1979 and Azeredo and Bolsanello, 1981). In the country's northeast, symptoms of micronutrient deficiencies have been prevalent, and applying Cu and Zn has been associated with positive outcomes (Marinho and Albuquerque, 1981). Regarding boron, Alvarez and Wutke (1963) investigated the application of different micronutrients to sugarcane that was planted in...
Argisol Red Yellow and Purple Latosol and showed positive boron reaction on the base. Orlando et al. (2001) report that sugar cane frequently exhibits the phenomena of "hidden hunger" with regard to micronutrients, which is a situation in which the plant lacks a nutrient that would economically limit productivity but shows no symptoms. Numerous elements affect sugarcane, including crop variety, primary soil type, and plant age at which micronutrients are absorbed (Orlando et al., 1983). In the order of iron (Fe) > manganese (Mn) > zinc (Zn) > copper (Cu) > boron (B) > molybdenum (Mo), sugarcane micronutrients are exported.

The importance of nutritional culture, such as borate ions like complex sugars, should be noted, indicating the likelihood of their involvement in the transport of carbohydrates from the leaves of tooth organs, an important fact in the sugar cane culture, even though the application of micronutrients in the planting furrow did not affect the leaf content of these essential elements (Orlando et al., 2001). Furthermore, boron may have an impact on cell division, maturation, differentiation, lignification of the cell wall, and inhibition of starch formation through its interaction with the active phosphorylase site, which stops sugars from being excessively polymerized during local synthesis (Sobral and Weber, 1983).

One of the most significant micronutrients in sugarcane is copper, which activates a number of enzymes, including fenolase, laccase, polifenoxolidase, and others. It contributes significantly to the plastocyanine electron transport mechanism during photosynthesis as well (Taiz and Zeiger, 2004). Manganese participates in several Krebs cycle processes and is essential for protein synthesis, cell division, photosynthesis, and sugarcane enzyme activation (Sobral and Weber, 1983). Because molybdenum directly affects nitrate reductase and nitrogenase enzymes, sugarcane biological nitrogen fixation and NO₃ assimilation in organic compounds can occur when sufficient nutrition containing this crucial mineral is provided (Sobral and Weber, 1983; Orlando et al., 2001).

Because zinc is necessary for the synthesis of tryptophan, an intermediate of indole acetic acid (IAA), which creates the enzymes responsible for cell development and elongation, zinc has a direct impact on the growth of sugarcane plants. This micronutrient also plays a role in activating many enzymes (Sobral and Weber, 1983; Orlando et al., 2001; Taiz and Zeiger, 2004). According to Gomes (1974), the optimal time of day for sugarcane cultivation is between 6 and 8 a.m. Climate fluctuations, particularly cloudiness, and cultivation age all have an impact on the concentration of nutrients in sugarcane leaves. Therefore, it would seem
Improving sugarcane (Saccharum spp. hybrid complex) growth, yield and quality through balanced fertilization: an overview

that a variety of circumstances can affect the amount of nutrients present, which would account for the variations between the levels observed and those documented in the literature.

Planting bills were able to apply micronutrients due to the sugarcane output. Nevertheless, the amounts of total recoverable sugars (ATR) are not subject to this regulation. Applying 1.0 and 1.5 L ha\(^{-1}\) of Wuxal Semillion resulted in yields that were 10% and 15% greater than the control yield, respectively. Research on the impact of applying micronutrients to sugarcane started in the 1960s (Fernanda et al., 2017). Alvarez and Wutke (1963) discovered that isolated applications of B, Mo, Fe, and Cu produced positive reactions in Argisol, increasing sugarcane production in 21.6; 12.1; 1.6; and 8.3 t ha\(^{-1}\), respectively.

Alvarez (1984) used copper and zinc in the form of chelates and saw an increase in stem formation in rhodic, sandy textures. Azeredo and Bolsanello (1981) reported a 30% increase in sugar cane plant productivity when they used 5 kg ha\(^{-1}\) Mn in the groove or sprayed a solution containing 5 g L\(^{-1}\) micronutrient. Regarding the use of B and Zn, Franco et al. (2011) discovered that sowing plant cane with 2 and 4 kg ha\(^{-1}\) of B increased the amount of stems produced. However, the researchers discovered that Zn enhanced ratoon's average total rate (ATR) and production (14 t ha\(^{-1}\) in the control). In eight key sugarcane-producing locations of Sao Paulo, Mellis et al. (2008) assessed the reaction of plant cane for Cu, Zn, Mn, and Mo. They discovered substantial responses for Zn, Mn, Mo, and Cu, verifying an 18% increase in stem production and achieving the highest response for Zn and Mo.

In this ratoon stalk production, notable responses have been noted as a result of the application of Zn, Cu, Mn, and Mo. These findings suggest that the most practical method for managing micronutrients in sugarcane production may be to apply them in the planting furrow (Mellis et al., 2010). When administered at concentrations of 1.0 and 1.5 L ha\(^{-1}\), the micronutrient sources of Cu, Mn, and Zn chelate linked with K\(_2\)O, B, and Mo sources improved stem production (TCH) by 10% and 15%, respectively. Sugar cane productivity did not increase when zinc sulphate and boric acid were used only in dosages of 2.03 kg ha\(^{-1}\). According to Fernanda et al. (2017), applying micronutrient sources to stems did not significantly enhance the amount of total sugar recoverable sucrose.

2.5 Soluble Salts Viz-a-Viz Juice Quality

According to Fogliata and Aso (1965), a rise in soil soluble salts led to a build-up of salts in cane juice, which decreased the juice's purity and sucrose percentage (Table 6). Poor
foliage is a consequence of cane grown in salty fields because of the inhibitory effect of chloride ions on N and P absorption. Analogous studies conducted in Australia (Kingston, 1982) confirmed these findings. Very substantial correlations between soil salinity and amounts of sodium, potassium, and chloride ions in the first expressed juice were found in the 0-500 mm deep soil samples. Raw sugar ash levels may also be indirectly impacted by poor irrigation quality (Anon, 1995). Meyer and van Antwerpen (1995) conducted an assessment on irrigation water quality in the northern irrigated areas and found that during the low flow phase during the dry winter months, the quality of water from some river sources becomes marginal for irrigation. In a different study, an industry-wide survey of soil and leaf samples spanning over 20 years revealed higher amounts of calcium and magnesium in irrigated soils (Meyer et al., 1998).

New Interventions for Sugarcane Fertilization

With time for improving the sugarcane yields and quality new more promising technologies/interventions recommended to the farmers. In agriculture, muriate of potash (MOP) has long been utilised to satisfy crop potassium requirements. The ideal MOP dosage for sugarcane farming has not been established (Bhatt et al., 2022). Along with potassium, continued sugarcane production often depletes other nutrients from the soil. "Polyhalite" (K$_2$Ca$_2$Mg(SO$_4$)$_4$·2H$_2$O) is a multi-nutrient fertilizer that includes sulphur (48% SO$_3$), magnesium (6% MgO), potassium (14% K$_2$O), and calcium (17% CaO). In the North Sea, off the northeastern coast of the United Kingdom, polyhalite is mined 1,200 metres below the surface of the Earth. Compared to other fertilizers, polyhalite has less of an adverse effect on the environment. In comparison to conventional fertilizers, polyhalite releases nutrients more gradually, which could lead to a higher rate of fertilizer usage efficiency.

Corn (Zea mays, L.), sorghum (Sorghum bicolor, L.), kiwifruit (Actinidia deliciosa), potatoes (Solanum tuberosum), tomatoes (Solanum lycopersicum), cabbage (Brassica oleracea var. capitata), and mustard (Brassica) have all been studied in relation to the effectiveness of polyhalite. It has been demonstrated that polyhalite extends the period of time that soil potassium is available to plants in comparison to fertilizer potassium in other forms, such as potassium chloride (KCl). Polyhalite's efficacy in comparison to traditional MOP has not yet been assessed for the semi-arid tropical sugarcane (Saccharum officinarum) crop grown in India. For plant membrane stability, cell integrity, cell division, and elongation, as
well as for different signal transduction pathways and activation, calcium (Ca) is supplied by polyhalite. Furthermore, because calcium is transferred into plants by xylem sap, canes are unable to reabsorb calcium from older tissues.

For this reason, in the Ca-deficient soils used to grow sugarcane in the Indian Punjab, a calcium fertilizer source, such as polyhalite, is crucial. Magnesium (Mg), which polyhalite also provides, is necessary for plant photosynthesis and glucose partitioning, both of which are associated with noticeably elevated SPAD values. Sulphur (S) increases the efficiency of nitrogen fertilizers, which raises crop yields. A balanced application of nutrients is required to boost sugarcane yield and quality sustainably; failure to do so would likely result in lower crop yields and worsened soil health. Fertilizer containing potassium is essential for the metabolic and physiological processes in sugarcane plants.

It functions as a catalyst for numerous enzymes, regulates stomatal openings, transfers plant resources throughout the entire plant, lessens the frequency and intensity of insect pest attacks, encourages root growth, and increases nutrient, pesticide, and water use efficiencies while lowering input requirements. Translocation of photosynthates and their transport throughout the entire sugarcane plant are significantly impacted when potassium levels are low. Bhatt et al., 2021 recommended that in Punjab, India in addition to other fertilizers used as advised, we advise sugarcane growers in the potassium- and calcium-deficient soils of the Indian Punjab to combine MOP and polyhalite equally to obtain an application rate of 80 kg K$_2$O ha$^{-1}$ (Bhatt et al., 2021). The advantages noted at the lower potassium fertilizer application rate were diminished when applications of potassium fertilizer were increased to 120 kg K$_2$O ha$^{-1}$.

The addition of calcium to these calcium-deficient soils is probably what will benefit polyhalite and MOP together. Longer-term studies are required to determine the ideal concentrations of important nutrients, such as calcium, magnesium, and sulphur, and to develop accurate fertilizer management plans for the various edaphic circumstances found in the area where sugarcane is grown.

Secondly, paddy straw management is an important issue as otherwise it burnt before wheat sowing, resulting in many sustainability issues such as declining soil health, lowering yields and emission of green house gases. To address this issue, Bhatt et al. 2022 highlighted the use of paddy compost @ 5.5 t ha$^{-1}$ along with recommended dose of nitrogen (RDN) for improving the growth, yield and quality parameters of sugarcane in the region. This
intervention open up scope for sustainable and climate smart management of paddy straw while on other hand also improved the cane yields and profitability in the region.

**Conclusions**

There's no denying that cane quality can be greatly influenced by the type of soil and fertilizer management techniques used. Overuse of N, P, or K can have a negative impact on the economies of recoverable sugar and cane production. Increased crop lodging caused by luxury N and K take-up leads to a larger influx of foreign matter into the mill yard. Colour issues may result from processing leaves and tops with an excessive amount of amino acids. Applying too much nitrogen fertilizer raises the possibility that eldana will harm cane, which will have a negative impact on recoverable sucrose. High quantities of K in juice from excessive K fertilisation might impact raw sugar colour and ash content, as well as the final molasses' exhaustiveness.

Higher levels of ash in raw sugars can result from salinity in the soil and low-quality water, which can also negatively affect cane quality. Growers are more dependent than ever on using soil and leaf analysis through FAS to balance nutrient intake and maximise RV production. In addition to being inefficient, applying fertilizer outside of the FAS guidelines will cost more under the RV payment plan than it did under the prior setup. FAS provides growers and miller-cum-plantera with a wide range of affordable services, such as full-cycle fertilizer advice, leaf analysis to confirm the adequacy of fertilizer recommendations, and ongoing updates on the most recent research findings.

Growers will save fertilizer expenses and enhance sucrose recovery with the aid of FAS's recently patented soil test to evaluate possible N loss from urea fertilizer and its bundle of six decision assistance programmes (Schumann, 2000). Growers will benefit from a suite of decision assistance programmes (Schumann, 2000) and a recently patented soil test conducted by FAS to evaluate possible N loss from urea fertilizer.

These programmes will lower fertilizer costs and enhance sucrose recovery. It is imperative to examine the correlation between saccharose concentration and nutrient absorption patterns in commercial cane types. Elevated sucrose varieties could be linked to low N, P, and K profile absorption patterns by nature. As early as 1979, Irvine proposed that reducing excessive K intake by variety selection and prudent fertilizer management could be a low-cost, practical way to improve molasses exhaustion in Louisiana.
Given the change in focus in the cane payment system, future research initiatives will need to consider the effects of management practices on non-sucrose content and the classification of non-sucrose components. In order to achieve this, the collaborative study between SMRI and SASEX had to be expanded to include tests on fertilizer and other substances in order to measure the impact of fertilizer applications on the calibre of cane juice, specifically with regard to the proportions of non-sucrose and sucrose in a variety of soil types.

The following are some of the more significant research findings from the previous studies:

1. Du Toit (1960) threshold values for evaluating soil and leaf analysis;
2. Research on P nutrition and nitrogen utilisation efficiency using radioisotopes (Wood & Wood, 1967);
3. Updated P guidelines that account for soil P fixation (Meyer, 1978);
4. Reducing soil acidity and creating an exchangeable Al Saturation Index to gauge the amount of lime needed (Schroeder et al., 1995);
5. Bhatt et al., 2023 standardized potash dose as 80 kg K₂O ha⁻¹ for reducing insect-pests and diseases and for improving growth, yield and quality parameters;
6. Soil-specific recommendations for nitrogen fertilizer, based on near-infrared measurements of N mineralization potential, have led to significant reductions in N use for numerous producers (Meyer et al., 1986);
7. Evaluating the organic amendments sugarcane farmers use to enhance the physical, chemical, and biological characteristics of the soil (Van Antwerpen et al., 2003);
8. N carrier recommendations based on an assay to gauge ammonia volatilization from N carriers sprayed on soil (Schumann, 2000);
9. Clay and the (Ca+Mg)/K ratio-based variable threshold values for K (Donaldson et al., 1990);
10. Better N recommendations derived from dividing cultivars into groups with low, medium, and high N consumption efficiency (Schumann et al., 1998);
11. In the potassium- and calcium-deficient soils of Punjab, India, sugarcane growers have to apply MOP and polyhalite equally to reach an application rate of 80 kg K₂O ha⁻¹, in addition to other fertilizers (Bhatt et al., 2021);
12. Bhatt et al., (2022) reported that the plant sugarcane growth, yields, and quality parameter in the region were significantly improved by 25% higher Recommended dose of nitrogen (RDN) with 5.5 t of paddy compost at N-deficient sandy loam soils.
This, on the one hand, opens up new opportunities for paddy residue management, and, on the other, enhances the cane farmers' livelihoods in a more sustainable and climate-smart way.

**Acknowledgements**

The authors would like to thank the cane researchers who provided their research articles for the successful compilation of this review on balanced fertilization in sugarcane which further helps in improving the overall sugarcane yields and hence livelihoods of the cane farmers.

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Received: 05.14.2024
Accepted: 06.04.2024