The Effects of Potassium on Growth, Development, Yield and Quality of Sugarcane

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Abstract

Potassium (K) is the most abundant cation accumulating in the cell sap of sugarcane plant. A healthy sugarcane crop indeed contains generally more than 200 kg K ha^{-1} in its aerial parts. Though in the absence of an adequate K supply, leaf area, tiller density and number of green leaves per mother shoot may not be affected, the height of millable stalks at harvest and to a lesser degree the number of stalks may be impaired. By acting mainly as an enzyme activator in plant metabolism, K is fundamental to the synthesis and translocation of sucrose from the leaves to the storage tissues in stalks. It also plays a significant role in controlling the hydration and osmotic concentration within the stomata guard cells. Responses of sugarcane to K fertilization reflect to a large extent the available K status of soil, significant responses being obtained only in soils low in available K. Evaluating the response of sugarcane to K fertilization must also take into account the semi-perennial nature of sugarcane plant. In this context as sugarcane is able to mine the soil of its K reserves, responses to K fertilizers are frequently not observed in plant cane and often even in first and second ratoons. The importance of a balanced nutrition particularly between nitrogen (N) and K in the attainment of the maximum yield should also not be overlooked. In general sugarcane responds to K fertilizers by an increase in cane yield without any change in sucrose concentration in the cane. As an excessive uptake of K by the sugarcane depresses the recovery of sucrose during milling, K fertilization of sugarcane must be kept just adequate to produce an optimum yield and to help regulate maturity so that maximum sugar is recovered from the millable canes.

Introduction

Sugarcane is one of the most important field crops in the tropics. Indeed, according to FAO (2001), sugarcane is grown in not less than 105 countries and presently it covers a total acreage of about 19 million hectares for a world production of approximately 1.3 billion metric tonnes of cane and 127 million tonnes of sugar. Botanically, as reviewed by Malavolta (1994), sugarcane belongs to the *Andropogonae* tribe of the family *Graminae*. The subtribe is *Sacharae* and the genus is *Saccharum*. Most of the sugarcane which is grown today are hybrids of *Saccharum officinarum*. Sugarcane is capable of rapidly depleting soil of nutrients, particularly potassium. Under South African conditions, for instance, the aerial parts of an adequately fertilized 12 month-old rainfed plant cane crop has been reported to contain 214 kg K ha^{-1} (Wood, 1990). Under irrigation, a cane crop of similar age and variety may remove as much as 790 kg K ha^{-1}. In the Histosols of Florida, an average of 343 kg K ha^{-1} was removed from the field at harvest of the sugarcane (Coale *et al.*, 1993). In Mauritius, more than 250 kg K ha^{-1} was recovered by sugarcane from soils high in available K even when no K was applied (Cavalot *et al.*, 1990). In Australia the average kg K ha^{-1} in the aboveground biomass of a crop of 84 tonnes cane ha^{-1} was 198 kg K ha^{-1} (Chapman, 1996). It is thus clear that for the long term and sustainable use of sugarcane lands, the removal of such large quantities of K needs to be balanced by adequate K inputs if a decline in soil fertility is to be avoided – hence the importance of K manuring in sugarcane cultivation. The effect which the K applied has on the growth, development, yield and quality of sugarcane is reviewed in this report.

Sugarcane growth

Sugarcane is a ratooning crop generally propagated by planting cut pieces of cane. In Mauritius, this provides the plant cane 15 to 18 months later. After harvesting the plant cane by cutting at ground level, (during the period July-November in Mauritius), the regrowth gives rise to the first ratoon crop which is in turn similarly harvested 12 months later. The crop is ratooned repeatedly until the yield declines to such an extent that replanting is worthwhile (up to nine ratoons may be grown in Mauritius). When grown at the 1.25 to 1.50 m interrow distance, sugar cane, depending upon the variety, needs 90 to 120 days to establish full ground cover. Establishment of sugarcane canopy in fact entails 2 overlapping processes: *tillering* (shoot population development) and *leaf area formation*. Leaf area development generally lags behind shoot population increases (**Fig. 1**). Moreover **Figure 1** shows that in ratoon cane active absorption of K is out of phase with logarithmic synthesis of dry matter. Indeed most of the K needed by sugarcane will be taken up during shoot population development while dry matter accumulation will be most intense when maximum leaf area has been attained. Maximum leaf area in fact will coincide with the peak number of millable stalks rather than with total shoot number. The pattern of growth, growth rate, number of green leaves per mother shoot, leaf area and tiller density as described above have reportedly

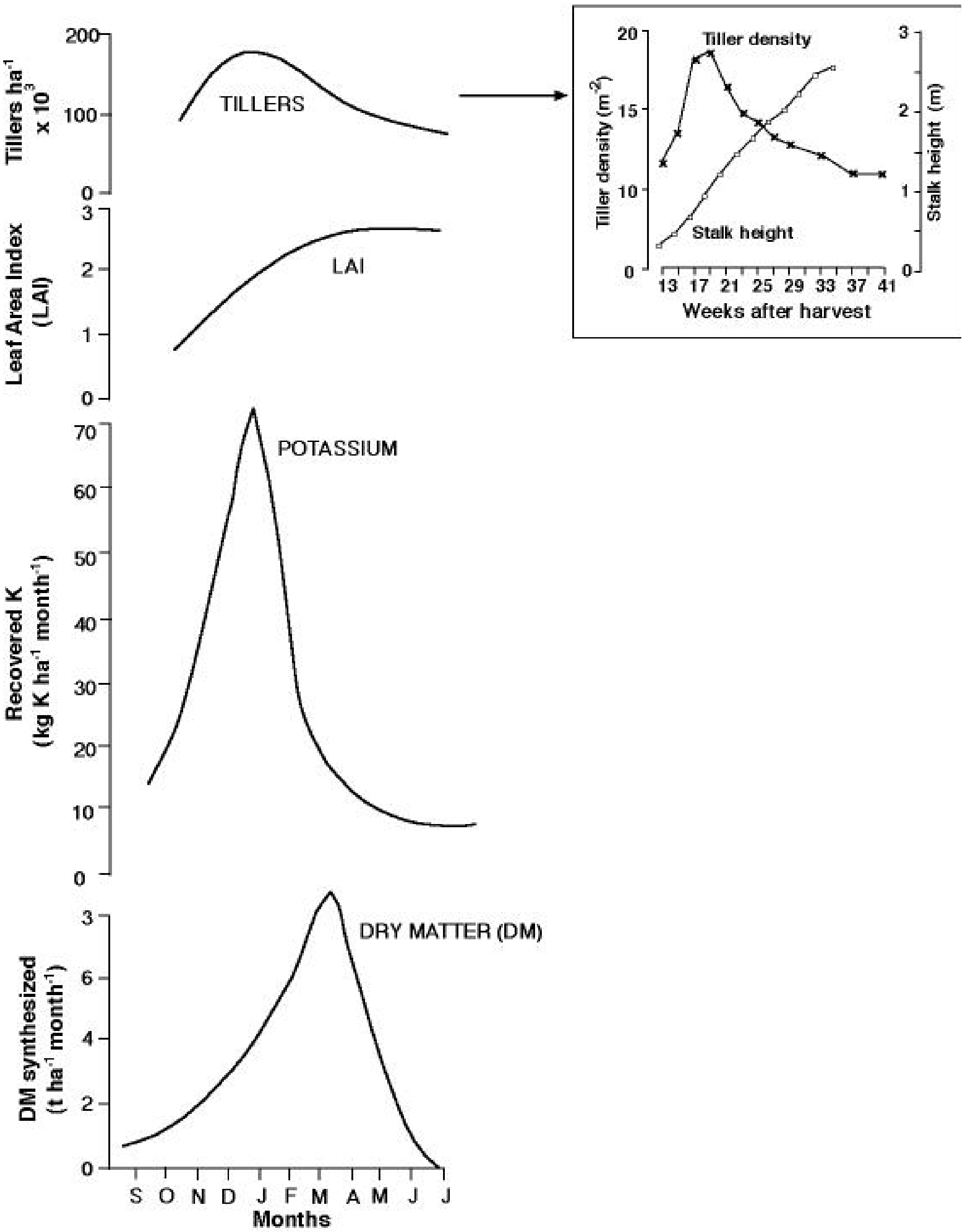

Fig. 1: *Dry matter and K accumulation rates, tillers and leaf area formation in rainfed ratoon cane harvested in August and fertilized in September in Mauritius*

been found to be little affected by K manuring (Abayomi, 1981) unless there is a severe K deficiency (Chatterjee *et al.*, 1998).

Two critical ontogenic events will occur concurrently after the period of 90 to 125 days after planting or harvest, namely shoot population starts to decrease and cane growth begins as illustrated by the continued increase in stalk height in inset of **Fig. 1**. With the onset of cane growth, shoots can then be divided into categories of *millable* stalks, those having at least one exposed elongated basal internode and *non-millable* stalks, those without evident cane growth. The effects of K on stalk height and population can be seen in **Table 1** as reported by Donaldson *et al.* (1990).

Table 1: Effect of K manuring on height, stalk population and yields of sugarcane (Donaldson *et al.*, 1980)

kg K ha^{-1}	*t cane* ha^{-1}	*Pol % cane**	*t sugar* ha^{-1}	*Stalk height (cm)*	*Stalk population* ($x10^3$)
0	88	13.2	11.6	240	86
300	112	13.5	15.1	273	93
600	114	13.3	15.1	278	88
LSD = (P=0.05)	17	0.9	2.5	17	14

*amount of sucrose in cane

Thus stalk height will generally be impaired by K deficiency while the effect on the number of millable stalks will not be significant (P = 0.05) unless K deficiency is severe (Chatterjee *et al.*, 1998).

Role of K in sugarcane

Potassium, which is absorbed as K^+, is the most abundant cation accumulating in the cell sap of sugarcane. The functions of K in sugarcane are many and have been extensively reviewed by Filho (1985). Among those functions which may be singled out is the main role of K as an enzyme activator in plant metabolisms such as in photosynthesis, protein synthesis, starch formation and translocation of proteins and sugars. With respect to the latter context, Humbert (1968) stated that while the downward movement of sugarcane from the leaves to the storage tissues in stalks proceeds at the rate of approximately 2.5 cm $minute^{-1}$ in a well-fertilized sugarcane, a lack of K reduces the rate to below half that value. Therefore without an adequate K in the plant, some of the sugar may remain in the leaves instead of being transported, stored and harvested in the stalks. Furthermore if the K supply is inadequate, hydrolytic activity of invertase may be intensified resulting in cane with high reducing sugars but low sucrose level (Filho, 1985).

Since K is a highly mobile nutrient in the plant, early symptoms of K deficiency are first seen in the older leaves. Leaf borders and tips will show yellow-orange chlorosis with numerous chlorotic spots that subsequently coalesce into brownish chlorotic blotches. This reduces the green leaf area in which photosynthesis takes place thereby depressing the growth of sugarcane. As rate of photosynthesis decreases with increasing severity of K deficiency, plant growth is retarded, internodes become shorter and the stalks themselves are shorter (as illustrated in **Table 1**) and smaller in diameter than those of well-fertilized sugarcane plants. Working with varieties *H37-1933* and *H50-7209* Hartt and Burr (1967) found that K deficiency suppressed photosynthesis when the foliar K concentration fell to about 0.40 K% dry matter.

The influencial role of K in the water economy of the sugar cane plant is also worth pointing out. Sudama *et al.* (1998) showed in pot experiments that application of K at time of planting under water stress conditions significantly increased the stomatal diffusive resistance, thereby decreasing transpiration rate and increasing the leaf water potential, cane length, sucrose content in juice and cane yield. Potassium is in fact reported to control the hydration and osmotic concentration of the stomata guard cells. When K is deficient it causes a loss of turgor pressure resulting in closing of the stomata and a reduction in the rate of transpiration and CO_2 assimilation (Humbert, 1968). For sugarcane grown under moisture stress, application of extra K has even been reported to give higher cane and sugar yields (Filho, 1985).

Effects of K on sugarcane yields

(i) Response from field trials: The yield components of sugarcane commonly measured are the millable stalk populations and cane fresh weight. In addition juice purity, sucrose concentration of the fresh cane stalk are determined to estimate recovery of sugar from milled cane. The effects of K on sugarcane yields particularly in Brazil and the rates of K used in different sugar-producing countries have been reviewed by Filho (1985) and Malavolta (1994). Sugarcane yield responses to K manuring are in fact very variable. Thus, Yang and Chen (1991) reported that only 33% of the sites studied in Fiji showed a response to K fertilization. Lakholine *et al.* (1979) showed in a 3-year study under Vidarbha conditions in India that there was no response to

K applied at 50-100 kg K ha^{-1}. Similarly Olalla *et al.* (1986) showed that at 0-300 kg K ha^{-1}, there were no difference in cane and sugar yields at Malaga during the first 2 years of K fertilizer use and during the next 2 years when K fertilization was withheld. Prasad *et al.* (1996), on the other hand, found in a sandy loam calcareous soil of North Bihar that cane yield was increased from 50 t ha^{-1} without K fertilization to 74.5 t ha^{-1} with only 60 kg K ha^{-1}. At 11 locations in Sao Paulo State of Brazil, Korndorfer (1990) indicated that raising application of K to 150 kg K ha^{-1} progressively increased cane yield.

(ii) Available K in soil: The very variable response to K fertilization reported in field trials can to a large degree be explained by the availability of K in the soil. As shown in **Fig. 2** which relates to studies on K fertilization of sugarcane in Mauritius, significant responses (at P = 0.05) in cane and sugar yields to K fertilizer were only observed in soils low in available K (<0.30 cmol kg^{-1} extractible in 0.1M H_2SO_4) while insignificant yield responses were found in soils with high available K (> 0.60 cmol kg^{-1} soil). These results are in agreement with observations of Humbert (1968) who found that above 0.23 cmol exchangeable K kg^{-1} soil in Hawaii, there was little likelihood of significant cane response to K fertilizers. Similarly in South Africa, Wood and Burrows (1980) recommended no K fertilization to the plant cane and to the next 4 ratoons when the soil exchangeable K exceeds 0.70 cmol kg^{-1}.

Lack of sugarcane response to K fertilization however had also been reported even when available K in the soils was low. Thus Reis and Cabala-Rosand (1986) found no response to K fertilization even with available levels of this nutrient in the range of 0.07 to 0.14 cmol K kg^{-1}. The frequent absence of yield response to fertilizer K in soils with low available K is an indication that under certain conditions, e.g. when K buffering capacity of the soil is high, sugarcane can acquire sufficient K from the non-exchangeable K reserves in the upper layers of the soil and from the sub-soil.

(iii) The perennial nature of sugarcane plant: In addition to the availability of K in soils, the yield response of sugarcane to K fertilizers is influenced by the semi-perennial nature of the sugarcane crop. In fact the real benefits when sugar cane is grown depends on how many ratoons are possible. All those factors which affect its productivity, fertilizers included, should be studied over the whole cycle of the plant cane plus number of ratoons worthwhile before replanting. In this context, as illustrated in **Table 2**, K already released by weathering together with K moved into the subsoil but returned to the surface layer during land preparation for replanting may be

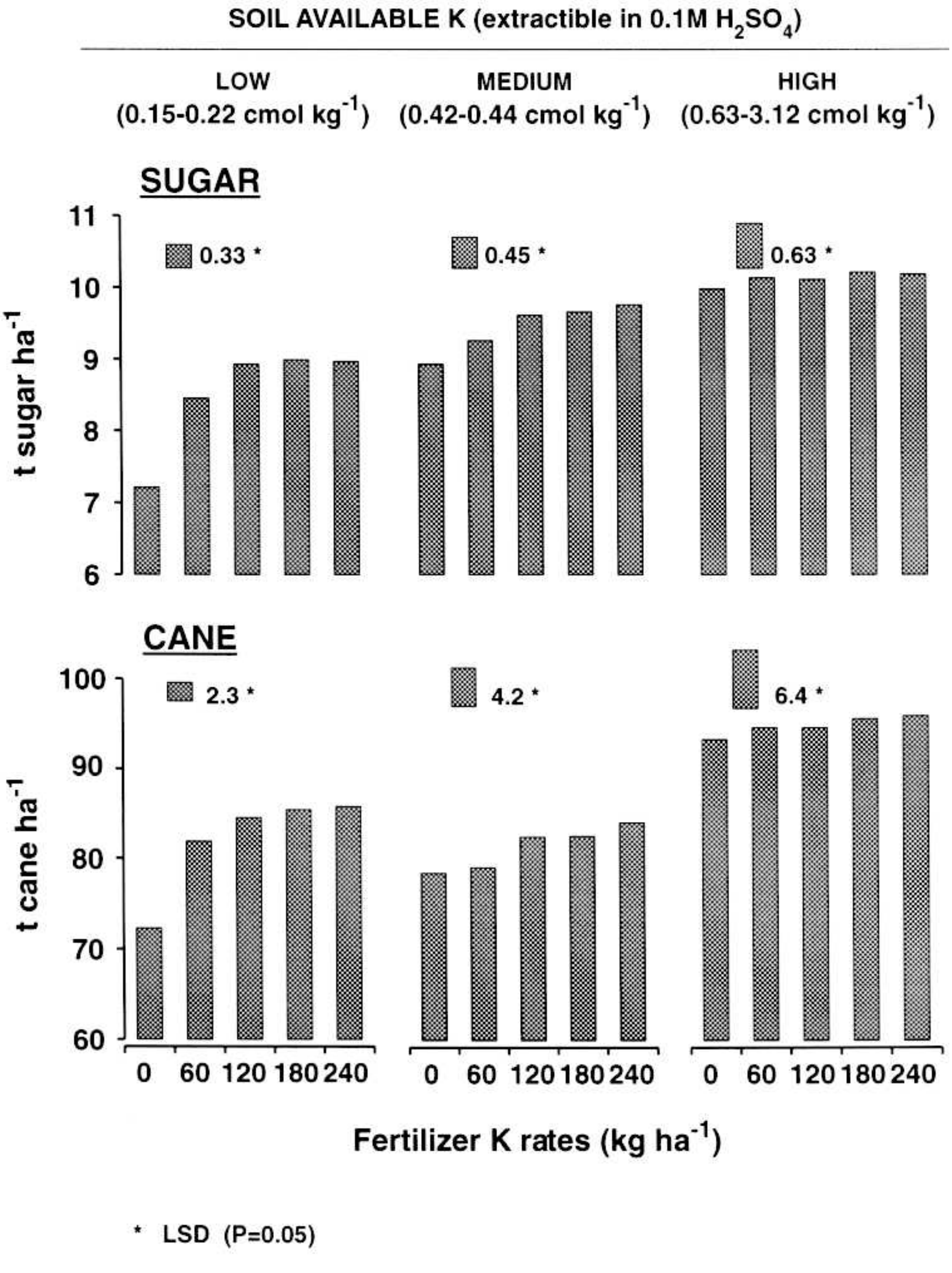

Fig. 2: *Response of sugarcane to increasing rates of K in soils of Mauritius with low, medium and high available K as extracted in 0.1M* H_2SO_4

sufficient to meet the K requirements of the plant cane but not those of the subsequent ratoons.

Table 2: Response of sugarcane found from 1990 to 1993 at a site in Mauritius (Sans Souci) with only 0.16 cmol exchangeable K kg^{-1}

Kg K ha^{-1}	*t cane ha^{-1}*			*t sugar ha^{-1}*			*IRSC**	
	Plant crop	*First ratoon*	*Second ratoon*	*Plant crop*	*First ratoon*	*Second ratoon*	*First ratoon*	*Second ratoon*
0	106.6	94.6	77.2	11.59	10.69	9.25	11.3	11.3
60	98.7	103.3	93.6	11.01	11.98	11.32	11.6	11.3
120	103.9	108.9	92.3	11.46	12.63	11.57	11.6	11.2
180	110.1	108.2	91.1	11.86	12.94	10.77	11.5	11.0
LSD (P=0.05)	13.3	10.1	10.3	1.77	1.54	1.54	0.7	0.9

*Industrial Recoverable Sucrose % Cane

Sachan *et al.* (1993) also observed that plant cane crop did not respond to fertilizer K application while the first ratoon crop only did so slightly in a mollisol of Uttar Pradesh. Paneque *et al.* (1992) in Brazil reported that neither plant cane nor the first ratoon responded to K but cane yields increased by 23 and 39 t ha^{-1} at the end of the second and third ratoons, respectively.

Any reduction in K fertilizer use may therefore take a few years to materially affect yields of sugarcane. Rabindra *et al.* (1993) demonstrated that sugarcane grown continuously from 1971 on a red sandy loam soil at Karnataka in India gave cane yield of 63 t ha^{-1} in 1971 with and without fertilizers, but in 1988 while the cane yield with N alone (250 kg N ha^{-1}) was 30-34 t ha^{-1}, application of NPK with K at 125 kg K ha^{-1} gave cane yield of 130-136 t ha^{-1}.

A further aspect that follows from the semi-perennial nature of sugarcane, and one that, as rightly mentionned by Rodella (1990), has seldom been considered is the strong influence which other factors have in the K response trials with sugarcane. As illustrated by Rodella (1990), a high degree of interaction exists within the sugarcane crop cycle with, for instance, response of the first ratoon to K fertilization being affected by K rates in plant cane or response of first ratoon to K influenced by P rates applied to plant cane (**Fig. 3**). These interactions inevitably enhance the difficulties associated with an evaluation of the response of sugarcane to K manuring.

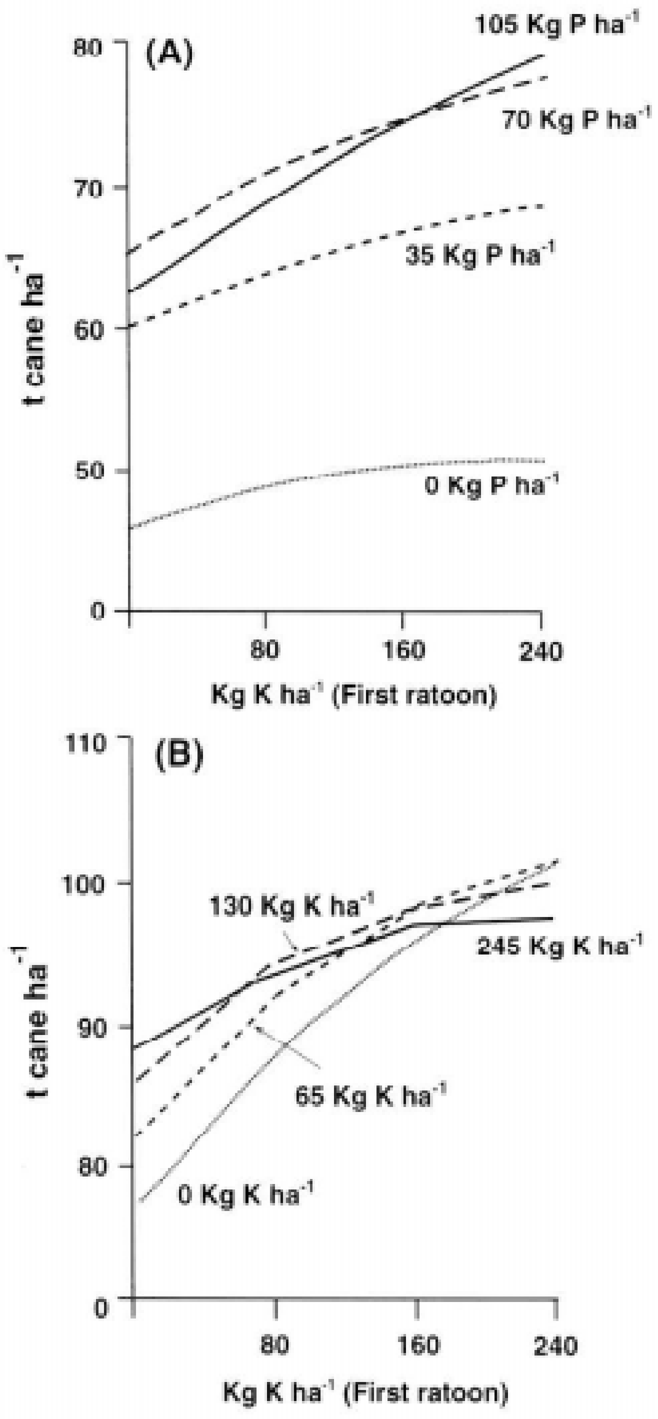

Fig. 3: *Sugarcane first ratoon response to K as affected by (A) P rates and (B) K rates in plant cane (Rodella, 1990)*

(iv) Importance of a balanced nutrition: Although no consistent statistically significant interaction has been shown to exist between N and K fertilization, a review of the literature shows that inputs of N and K must be balanced to optimize sugarcane production. For high yield (and good juice quality), K fertilizers are required in amounts equal to or greater than N (and P). In most sugarcane producing countries of the world, NPK ratios of 2:1:3 or 2:1:2 or 3:1:5 are commonly used (Wood, 1990). While N strongly stimulates growth, expansion of the crop canopy and interception of solar radiation (Milford *et al.*, 2000) to primarily produce more millable cane, a large amount of K is needed as an osmotic solute to maintain the necessary cell turgor to drive this N-stimulated growth (Humbert, 1968). Fields with poor yields normally tend to have high N and critically low K levels resulting in high reducing sugars and low sucrose (Humbert, 1962). This statement serves to stress upon the necessity of having adequate K available to utilize unassimilated N in the cane in order to bring about a stage of maturity where the reducing sugars are converted to sucrose.

In a field trial on a silty clay loam soil of Somalia, compared with the unfertilized controls, applying N alone, NP, NK and NPK increased cane yields by 92.9, 96.4, 99.2 and 105% respectively (Malik *et al.* 1993). As already mentionned, Rabindra *et al.* (1993) observed in 1988 at Karnataka in India that while cane yield with N only at 250 kg N ha^{-1} was 30-34 t ha^{-1}, application of NPK with K at 125 kg K ha^{-1} raised cane yield to 130-136 t ha^{-1}. Sugarcane tends to benefit most from single early K applications (Donaldson *et al.*, 1990; Rao and Subba-Rao, 1982). Split application either showed no promise (Sundara, 1985; Ng Kee Kwong *et al.*, 1994) or was uneconomic as the extra expenditure would not be offset by the increase in yield (Rao and Subba-Rao, 1982).

Effect of K on sugarcane quality

Improving cane quality is one of the most important means for maximising profitability in the sugarcane industry. It is indeed far more profitable to grind cane with a high percentage of recoverable sucrose as this will reduce the cost per unit tonne of sugar produced. In this respect juice quality is important as it determines the maximum sucrose yield. Unfortunately however sucrose content in cane is affected primarily by variety and climatic conditions and only in a relatively minor extent by the fertilizers applied. Though reports exist to indicate that K is capable of raising sugar yields without a concomitant increase in the yield of cane (see e.g. Dang and Verma, 1996), the majority of K fertilizer trials showed, as illustrated in **Table 2**, that a response to K in terms of cane yield was not accompanied by an increase of sucrose in the cane. Wood (1990) observed in South Africa that increasing the rate of K in the absence of a cane yield response had little effect on cane quality. Gulati *et al.* (1998) also observed in India that while K application in 2 equal splits (50% at sowing and 50% at end of monsoon) gave maximum cane yield and number of millable canes, juice quality was unaffected.

Most importantly, an excessive uptake of K from soil has been found to depress the recovery of sucrose during milling. As reviewed by Filho (1985), K has a tendency to increase sucrose solubility during sugar processing, thus maintaining a certain amount of sucrose in solution, one K^+ tying up one molecule of sucrose. Wood (1990) noted a significant depression in sucrose concentration of cane following an application of 183 kg K ha^{-1} in South Africa. Chapman (1980) observed in long term trials in Australia that 196 kg K ha^{-1} slightly decreased sucrose content in cane when compared to the no K treatment. A more vivid example of K lowering sucrose recovery is provided by Korndorfer (1990) who observed that vinasse (distillery slops) when applied at 120 m^3 ha^{-1} to a dark red dystrophic latosol in Brazil increased cane yield from 98 to 127 t ha^{-1} but decreased recoverable sucrose concentration in cane from 15.0 to 13.1%. Thus available data in the literature shows that K, in spite of its important role in sugarcane plant, must be kept just adequate to produce optimum yields and to regulate maturity so that maximum sugar is recovered from the millable stalks.

Concluding Remarks

Although the impact of K on sugar cane growth and yield is not as marked or visible as that of N, there is little doubt that K manuring has a significant positive bearing on the profitability of sugar cane industry. Considerable losses in cane and sugar production will occur even before any visible symptoms of K deficiency appear. The fact that a large amount of K is needed to drive N-stimulated growth towards maturity serves to show that K fertilization of sugarcane cannot be considered in isolation from the requirements of the sugarcane for other nutrients particularly N. Instead a balanced nutrition approach must be adopted if the optimum sugarcane yield and benefits from K fertilization are to be attained. Moreover since the response of sugarcane to K fertilization is dependent on the available K status of the soil the importance of a soil testing programme in K fertilizer recommendations cannot be overemphasized. K manuring should be aimed at maintaining an acceptable soil K status for the following ratoon crops in the cycle, as an excessive uptake of K by sugarcane has a detrimental impact on sucrose recovery during milling. There is indeed little value to add extra K fertilizer over and above that required to replace the offtake by the current sugarcane crop. Furthermore as sugarcane is a semi-perennial crop, K rates to be used must be decided on the basis of field response studies conducted over the entire sugarcane crop cycle.

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