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EFFECTS OF STILLAGE APPLICATION ON CANE AND SUGAR YIELDS AND JUICE QUALITY

University of Hawaii PH.D. 1984

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EFFECTS OF STILLAGE APPLICATION ON CANE AND SUGAR YIELDS AND JUICE QUALITY

A DISSERTATION SUBMITTED TO THE GRADUATE DIVISION OF THE
UNIVERSITY OF HAWAII IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY

IN AGRONOMY AND SOIL SCIENCE

DECEMBER 1984

By

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ABSTRACT

A sugarcane field experiment was carried out to evaluate the effects of a range of K rates (0-1920 Kg/ha) from cane juice stillage (residue from alcohol production) applied broadcast or in the furrow and KCl on cane and sugar yields and juice quality. Determination of soil pH, Al, Ca, Mg, K, Na, and P and analyses of N, P, K, Ca, and Mg in the +3 leaf, 3-6 sheaths, and 8-10 internodes were made throughout the crop. At harvest, yield of primary stalks and tillers were recorded, juice analyzed for Pol, brix, reducing sugars, fiber and ash, and total nutrient uptake determined.

Yields of cane and sugar increased up to 120 Kg K/ha from both stillage and KCl broadcast applications. At this K rate, soil K concentration at 15 days after application was 0.22 meq/100 g and +3 leaf, 3-6 sheath, and 8-10 internode K concentrations were 1.99 and 1.51, respectively, at 4 months and 0.98, 2.43, and 0.75, respectively, at 10 months of age. Since these soil and tissue K levels were associated with the highest statistical yields from K broadcast, it may be concluded that they are adequate for sugarcane growth. It was necessary to add approximately 100 m^3 of stillage to supply 120 Kg of K.

Rates of K from stillage up to 480 kg/ha appear to have no detrimental effects on cane and sugar yields. However, 960 and 1920 Kg K/ha from stillage increased cane, but decreased sugar yields and juice quality. These negative effects of high stillage rates on sugar yields seem to be related to the N added with stillage. Addition of dolomite with high stillage rates raised soil pH and increased stillage N mineralization resulting in lower plant N and higher juice quality.

Ripener (Polaris) application 10 weeks prior to harvest also lowered plant N and improved juice quality.

Stillage applied in the furrow immediately after planting at 240 Kg K/ha resulted in the highest yields. This was probably due to the increased germination, emergence and early growth rates observed in these treatments.

Soil pH, Ca, Mg, and especially K increased with stillage application while soil Al decreased, particularly at high stillage rates. Application of high stillage rates may induce Ca and Mg deficiencies because more K is added relative to Ca and Mg which leads to a high K/Ca + Mg ratio. Application of dolomite improved this ratio resulting in higher yields. Leaching of soil K increased with increasing stillage application rates.

Concentrations of Ca and Mg decreased whereas K increased in plant tissues with increasing K rates. Therefore, if high stillage rates are to be applied, soil Ca and Mg levels should be determined to predict possible deficiencies. The 3-6 sheaths and 8-10 internodes appeared to be the most sensitive to plant K, Ca, and Mg status. All three tissues were adequate for plant N.

A sugarcane yield response curve to K fertilization may be used to determine the amount of stillage K to be applied. In addition, since stillage N and K composition are highly variable, these should be determined to quantify the amounts of these nutrients supplied by stillage. If high amounts of stillage are to be applied for waste management, problems such as difficulty in cane ripening, lower juice quality and soil salinization should be considered. However, ripener application can overcome the delayed ripening and improve juice quality.

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INTRODUCTION

Alcohol production has been a commercial enterprise in Brazil for a relatively long time. However, it was not until 1973 when the world energy crisis started that Brazil established the goal of increasing alcohol production to replace increasing amounts of imported fossil fuels on which the country is heavily dependent. Since then, although this goal has been achieved gradually through government programs, significant problems have been encountered. These are related to disposal of the distillation residues from alcohol production, known as stillage, which have increased tremendously in volume.

The main crop utilized for alcohol production is sugarcane, since it is well adapted to the climates and soil types of Brazil. Because the cane fiber can be burned to produce the heat needed for distillation it produces a positive energy balance. Perhaps more importantly, a considerable infrastructure exists throughout the country for growing sugarcane and making alcohol from it.

While the basic process for making alcohol is well understood, a proper method for disposing of and/or utilizing the distillery residues (stillage) is still the subject of many studies. Therefore, this area has received increasing research effort in recent years. This is due to the fact that:

1. Stillage has a high biological oxygen demand (BOD) because of its high carbon content, which makes it a potential pollutant if dumped in rivers or lakes. Branco et al. (1980) have stated that two liters of stillage on the average, have the same water pollution potential as an individual's daily domestic sewage production.

2. Stillage is produced at the rate of 12.5 liters of stillage per liter of alcohol, although efforts have been made to reduce this stillage to alcohol ratio through improved yeast and fermentation techniques.

3. Stillage has an appreciable fertilizer value, especially as a source of K.

In Brazil, the alternative methods for stillage disposal or utilization that have been proposed are the following:

1. land disposal of untreated sitllage as a fertilizer
2. protein production through unicellular microorganisms
3. biogas production
4. evaporation of the stillage to a concentrated slurry and utilization of the concentrate as a fertilizer or animal feed
5. inceneration of the stillage and recovery of potassium.

Although all of these alternatives deserve close scrutiny, the most economical and suitable at present seems to be land disposal of untreated stillage as a fertilizer. In principle, stillage could be used to fertilize many different crops, but for reasons of economics and location, its sole use at present has been as a fertilizer for sugarcane.

There are two possible approaches to land disposal of untreated stillage as a fertilizer:

1. the waste management approach which aims at the disposal of the maximum amount of untreated stillage per unit of land with little or no undesirable effects on the crop to be grown, the characteristics of the soil, the quality of the groundwater and surface runoff

2. the soil fertility approach which aims to use the amount of stillage per unit of area required to supply the K needs for a growing crop, since K is the major nutrient in stillage.

The latter approach would maximize the use of stillage as a fertilizer whereas the former would maximize the use of land for disposal. There are very few studies on the waste management approach to stillage disposal.

Sugarcane was the crop of choice for this study because most, if not all, of the alcohol in the sugarbelt of Rio de Janeiro State is from sugarcane. In addition disposal of stillage appears to be economically feasible only to sugarcane fields which generally surround the alcohol processing plant due to the short hauling distances.

Stillage is a residue rich in potassium and organic matter, poor in phosphorus, and with appreciable nitrogen content. The composition of stillage is quite variable depending upon the raw material used for fermentation (cane juice or molasses), as well as on the fermentation conditions and distillation process (Almeida, 1962). Studies generally have shown that K from stillage or from inorganic fertilizer is equally effective in supplying the K requirements of crops. However, some authors have reported an "auxinic effect" of stillage, that is, plants fertilized with stillage have better growth than plants fertilized with inorganic fertilizers, even though the rates of inorganic nutrients applied were comparable in both materials.

Some studies with sugarcane show an increase in cane yields, but no increase in sugar yields with the use of stillage as a fertilizer, however, others have reported an increase in both cane and sugar yields. Stillage also has been reported to retard cane maturation when it is used as a fertilizer.

Recommended optimal stillage application rates appear to fall into the 30 to 50 m^3/ha range for cane molasses stillage and 80 to 200 m^3/ha for cane juice stillage, although as already mentioned, stillage composition is highly variable.

There appears to be no data on the downward movement of K in the soil profile, with application of various rates of stillage. In addition, no data were found on the effects of K from stillage on the cation balance, especially between Ca, Mg, and K. These are important relationships if the goal is to maximize the use of stillage as a K fertilizer.

This research had the following objectives:

1. to determine the effects of untreated stillage on cane and sugar yields and juice quality
2. to study the effects of stillage on nutrient concentration of sugarcane tissues and total nutrient uptake
3. to determine the degree of leaching of applied K in the soil profile
4. to determine the maximum disposal rate and optimum fertilization rate of stillage
5. to measure the effect of K from stillage on the balance between Ca, Mg, and K in the cane plant
6. to study the effect on cane yield of applying stillage broadcast and in the furrow
7. to study the use of ripeners with high stillage rates to improve juice quality.

LITERATURE REVIEW

Research regarding the possibility of land disposal of untreated stillage started in the early 1950's (Almeida et al., 1950, 1951; Almeida 1952, 1953). Since then, stillage has been identified as a promising fertilizer material, especially as a source of K.

Chemical Characteristics of Stillage

The chemical characteristics of stillage are quite variable, depending upon the fermentable substrate used (cane juice, molasses, or a combination of the two), fermentation conditions, and distillation procedure (Table 1). In addition, recent work related to stillage composition has shown that it also can change with time in the harvesting season (Bolsanello et al., 1980). In addition to these factors, possible variability in composition of the substrate may be due to climate and soil where the sugarcane is grown, and to varietal differences in uptake of nutrients, which also contribute to the high variability in stillage composition.

As mentioned earlier, stillage may be considered basically a K source, although its N content can also be considerable in some instances. The values for the C/N ratio shown in Table 1 indicate that N immobilization may or may not occur after stillage application to soil, since in two cases out of eight, the C/N ratio is above 20 (the critical value generally reported for occurrence of N immobilization).

The high K content of stillage in relation to Ca and Mg suggests that deficiencies of the two latter cations may be induced by application

Table 1. Chemical composition of stillage from various sources

Characteristic	HAWAII	BRAZIL							
		Molasses			Combined Cane Juice + Molasses		Cane Juice		
	HSPA[a]	Gloria[b]	UFRRJ[c]	Bols.[d]	Gloria[b]	Bols.[d]	Gloria[b]	UFRRJ[c]	Bols.[d]
pH		4.90	4.20	4.20	4.60	3.80	4.30	4.20	3.60
Electric Cond. (mmhos/cm)			18.00					4.90	5.20
COD[e] (O_2 g/l)			65.96					32.36	
Organic C (%)		1.90	2.00	1.72	1.20	1.36	0.60	1.00	0.91
Organic matter (%)		6.43		5.69	3.80	4.51	1.91		3.47
C/N		16.00	28.00	20.23	16.40	35.72	19.70	9.30	31.35
C/P		283.58	121.60	280.23	250.00	221.57	105.69	381.68	189.58
Ash (%)				1.73		0.98			0.54
N (Kg/m^3)	0.25	1.18	0.72	0.79	0.70	0.43	0.28	1.08	0.35
P_2O_5 (Kg/m^3)	0.26	0.15	0.38	0.14	0.11	0.14	0.13	0.06	0.11
K_2O (Kg/m^3)	12.77	7.83	4.57	5.50	4.57	2.61	1.22	1.74	1.15
Ca (Kg/m^3)	1.21	2.60	0.33	1.61	1.23	1.04	0.49	0.04	0.54
Mg (Kg/m^3)	0.67	0.60	0.27	0.61	0.40	0.31	0.13	0.03	0.18
Na (Kg/m^3)			0.13					0.04	
S (Kg/m^3)		2.13			1.25		0.20		
Fe (ppm)	24.00		74.00	119.74		129.70			110.05
Cu (ppm)	1.00			9.39		10.12			17.56
Zn (ppm)	1.00			3.09		2.38			2.28
Si (ppm)	334.00								
Mn (ppm)				11.06		5.50			9.66

[a] HSPA - Values are averages of 11 samples collected weekly for a period of 3 months at Puunene Sugar factory on Maui, Hawaii.

[b] Gloria - Values are averages of 21, 11, and 4 determinations of stillage from molasses, combined (cane juice + molasses) and cane juice, respectively, collected at Usina da Pedra, São Paulo State, Brazil (Gloria et al., 1973).

[c] UFRRJ - Values are determinations of stillage samples from molasses, and cane juice collected at Usina Queimado, Usina Outeiro, and Usina Victor Sense in Rio de Janeiro State, Brazil (Projeto UFRRJ - Depto. de Solos - FINEP, 1978-1979).

[d] Bolsanello - Values are averages of 8, 5, and 10 determinations of stillage from molasses, combined and cane juice, respectively, collected at several alcohol plants in the Rio de Janeiro State sugarbelt (Bolsanello et al., 1980).

[e] COD - Chemical Oxygen Demand.

of large quantities of stillage, especially if the soil is deficient or low in either of these two cations.

Effects of Stillage on the Chemical, Physical, and Biological Properties of Soils

Stillage has generally been reported to change chemical, physical, and biological properties of soils. The degree of change is in general related to the volume and composition of stillage applied, and soil type.

Chemical Properties

Soil pH and Al: Soil pH is reported to increase consistently after stillage application (Almeida et al., 1951). Mattiazzo (1977) found that 183 days after stillage application, the pH of an Entisol changed from 6.5 to 7.5 and that of an Oxisol from 5.2 to 6.6. Magro (1978) has also observed that stillage application leads to a systematic increase in soil pH during a sugarcane crop cycle. Other authors have reported similar increase in pH followed by a decrease in Al (Almeida, 1953; Ranzani, 1956; Briegger, 1977; Nunes, 1979). Rezende (1979) also observed a decrease in extractable soil Al and an increase in soil pH 15 days after stillage application. However, soil pH decreased later resulting in increased soil Al according to analyses done at 60 and 120 days after stillage application and there was no subsequent increase in soil pH. In general, the increases in soil pH were observed when stillage volumes greater than 100 m^3/ha were applied.

Almeida (1953) explained this increase in soil pH after stillage application as being a consequence of the increased microbial activity supported by the added organic matter. Asghar and Kanehiro (1977) have reported that the increase in soil pH after addition of sugarcane residues to soils is due to release of OH^- during the process of mineralization of N from organic matter. In addition, they also observed a reduction in levels of soil Mn as soil pH increased. However, Hoyt and Turner (1975) observed that levels of soil Al decreased with addition of alfalfa, in particular and also with sucrose and peat. They attributed these results to formation of complexes of soil Al with organic matter, since the greater part of decrease in soil Al occurred before the formation of appreciable amounts of NH_4^+ in the soil and the increase in soil pH. In fact, Mortensen (1963) observed that several organic matter compounds can complex metals such as Al by surface adsorption, chelation, and other reactions.

A possible cause of the decrease in soil Al and increase in soil pH is the large quantity of salts added to soil at high stillage rates. These salts increase base saturation of the soil, possibly by exchanging with H and Al in the soil exchange complex. It should be pointed out that K, which is the major nutrient in stillage, is used to displace extractable soil Al in laboratory determinations. As a result of the displacement of H and Al from the soil exchange complex and removal by leaching, soil pH should eventually increase while soil Al decreases. Further evidence for these reactions comes from the report that soil pH was noticeably increased only with stillage rates of 1600 m^3/ha (Projeto UFRRJ - Depto. de Solos - FINEP, 1978-1979). With such stillage rates the electrical conductivity of the soil saturation extract was about 7.95 mmhos/cm at 25°C.

Soil K, Ca, Mg, and Na: Since the major nutrient in stillage is K, stillage application thus results in a significant increase of soil K, and the magnitude of the increase will be related to the amount of stillage applied and its K concentration. On the other hand, Ca and Mg are added in smaller quantities, since their concentrations in stillage are also lower (Table 1). Concentrations of the three major cations in stillage vary, and since there is no apparent relationship among them, the K/Ca and K/Mg ratios will also vary which may lead to nutrient imbalances in the soil-plant system. When interpreting these ratios in stillage applications, one must be aware that concentrations in stillage are expressed either in percentage or Kg/m^3, whereas in soil their concentrations are expressed in meq/100g. Since the weight of a meq is 39, 20, and 12 mg for K, Ca, and Mg, respectively, their ratios can change considerably from stillage to soil. Therefore, it is wise to interpret elemental ratios in stillage on the soil basis rather than the concentration-in-stillage basis to assure that the effects in the soil are adequately accounted for.

Several studies have reported significant increases in exchangeable bases, especially K and to a smaller extent Ca and Mg as a consequence of applying stillage to the soil (Almeida et al., 1950; Brieger, 1977; Magro, 1978; Nunes, 1979). However, it has been reported that stillage application generally does not affect soil Na (Nunes, 1979). This is probably due to the relatively low Na content in stillage (Table 1). After addition of stillage to soils, Nunes (1979) observed that extractable soil Ca and Mg values increased to levels that exceeded the amounts of these nutrients added in stillage.

Soil N and P: While cations added in stillage are generally in inorganic form, most of the N and P is present in organic form. Studies have shown that all of the N present in stillage is generally present as organic N, and approximately 50% of this N is in the soluble fraction, probably as low molecular weight proteins or polypeptides. This material would probably mineralize very rapidly under optimum conditions. P is also found in organic form, and 30 to 80% of this P is generally present in soluble form as orthophosphate, which can also be mineralized with considerable speed (Projeto UFRRJ - Depto. de Solos - FINEP, 1981).

Although the amounts of N added to soil can be significant (Table 1), the direct contribution of stillage to soil P is generally quite small. There might be indirect effects on soil P due to increasing soil pH which decreases soil Al and increases P availability.

However, Gloria and Mattiazzo (1976), in a study of stillage added with fertilizer P observed that P was more available to plants in treatments that did not receive stillage than in those that received stillage, possibly due to P immobilization in the stillage treatments. According to the authors, the incubation period with stillage may not have been long enough for P initially immobilized to be released. Nunes (1979) also reported that the biological immobilization of P increased substantially with increasing stillage rates. Examination of the C/P ratios of stillage, reveals that P immobilization is very likely to occur following stillage application (Table 1), since mineralization will be the net effect when this ratio is less than 200 while immobilization predominates during the initial stages of decomposition when the C/P ratio of added organic matter is greater than approximately 300 (Alexander, 1975). However, Enwezor (1976) reported that a decrease of the C/P ratio increased initial P immobilization with several types of organic matter. However, P was then mineralized after 12 weeks of incubation. On the other hand, he observed that decreasing the C/N ratio, increased N mineralization. Ghoshal (1975) studied the chemical and biological fixation of P and observed that chemical P fixation occurred immediately after incubation, prior to the increase in soil microorganism population. The rate of biological fixation of P within a given time was related to the source of carbon. Addition of glucose caused a faster increase in the soil microorganism population than addition of cellulose and as a result there was a faster immobilization of both native and added P, with glucose addition. It should be pointed out that part of the sugar added with stillage is readily fermented, therefore, P immobilization is likely to occur because of the low P content of stillage.

According to Alexander (1965) addition of organic matter to soil will increase the soil microorganism population which will decompose organic material with the release of N and P. On the other hand, microorganisms will absorb nutrients from the soil solution for cell synthesis. Therefore, there will be a net increase in soil N and P if the microbial demand is lower than the amount of nutrient mineralized, otherwise nutrient immobilization will occur.

Mineralization or immobilization rates are influenced by several factors such as type of organic matter, C/N ratio and decomposition rate which is influenced mainly by soil temperature, moisture, and pH.

Therefore these microbiological processes may vary with location and time.

These results suggest that addition of stillage at higher rates, especially with high C content, can cause immobilization of P, especially in soil where P is limiting. If this shortage of P occurs at the beginning of a sugarcane crop when there is high demand for P yields may be decreased (Humbert, 1968).

Stillage can add appreciable amounts of N to soil; however, the length of time for it to become available to plants depends mainly on the C/N ratio, whereas the amount of N added depends on the N content of stillage. Other environmental factors such as temperature, soil moisture, aeration and soil pH will also govern the speed of mineralization.

When stillage with a C/N ratio of 40 was applied to soil there was a sharp increase in soil NH_4^+ in the first 3 weeks after stillage application and subsequently NH_4^+ remained relatively stable with a tendency to decrease up to the 15th week (Amaral Sobrinho, 1983). The level of NH_4^+ maintained in the soil increased with the quantity of stillage applied. On the other hand, NO_3^- decreased sharply in the first week after application of stillage, increased after the 7th week, then remained stable thereafter. The higher the stillage rate, the lower the NO_3^- level throughout the experiment. Amaral Sobrinho (1983) concluded that initially, especially in the first two weeks following stillage application, there was N immobilization which was followed later by release of N.

Other authors (Luisi, 1979; Nunes, 1979; Almeida et al., 1982) have also reported a decrease of NO_3^- in soil after application of stillage. This immobilization seems to occur only in the first 2 or 3 weeks after stillage application, which is the period when a significant part of the sugars added with stillage are readily fermented. Amaral Sobrinho (1983) reported that soil organic N increased in the first week following stillage application, which probably reflected the growth of the microbial population. Organic N then decreased gradually up to the 7th week, and remained constant thereafter. However, at 15 weeks after application, the levels of organic N were higher for all stillage treatments and the levels were related to stillage rates. These findings suggest that although part of the organic N added with stillage is readily released by microbial activity, the other part may remain in the soil for a longer period and then be released later to the crop. Delayed release of N could adversely affect the ripening of sugarcane (Humbert, 1968).

Soil CEC: Valsechi et al. (1954) reported that in addition to the increase in base saturation, there was also an increase in soil CEC with stillage application. Part of the increase may be due to an increase in organic matter, which would shift the zero point of charge (pH0) of the soil to lower pH values and increase CEC (Uehara, 1977). Veloso (1976) studying the cerrado soil from the Amazon region, reported that the major part of soil CEC is due to organic matter, and an increase of 1% in soil organic C would result in a CEC increase of 4 meq/100 g. However, the increase in soil pH as well as in salt concentration with stillage application may also contribute to the increase in soil CEC.

If we consider CEC of a soil as:

$CEC = S\sigma$

Where:

S = area (cm^2/gm)

σ = surface charge density ($e\ s\ u/cm^2$), and

$$\sigma = \left(\frac{2\ n\ E\ K\ T}{\pi}\right)^{1/2} \sinh z(1.15)\ (pH0 - pH)$$

Where:

n = electrolyte concentration ($ions/cm^2$)

E = dielectric constant of water

K = Boltzamann constant

T = absolute temperature

sinh = hyperbolic sine

z = counter-ion valence

pHO = zero point of charge

pH = soil pH

When adding stillage to a soil would increase n and pH, as already mentioned. Thus, the σ would become more negative and, therefore, the net result would be an increase in soil CEC.

Physical Properties

Almeida et al. (1950) reported that stillage application increases water-holding capacity of soils. In addition, stillage is reported to decrease the volume of run-off water and consequently the volume of soil lost by erosion (Cesar et al., 1954).

Ranzani (1956) also reported that total porosity and water holding capacity increased with stillage application. However, permeability was not appreciably modified.

Rezende (1979) studied the effects of stillage rates on physical properties on an alluvial soil from Campos, Rio de Janeiro State, Brazil, and observed that the osmotic potential of soil solution increased with stillage rate, mainly due to K, but water holding capacity and total porosity remained unchanged during a 120 day period.

Biological Properties

It has been reported that after stillage application the populations of fungi, actinomycetes, bacteria, and N-fixing bacteria (Bayerinckia and Azospirillium) increased significantly. This increase in the N-fixing bacteria is explained by the fact that nitrogen fixation consumes considerable amounts of chemical energy which is supplied by carbohydrates present in stillage. Stillage rates of 600 m^3/ha resulted in a significant increase in nitrogenase activity. If two applications of stillage were made each year at this rate, this nitrogenase activity would be equivalent to the fixation of 36 Kg N/ha/year (Projeto UFRRJ - Depto. de solos - FINEP, 1978-1979).

Almeida (1953), Carmargo (1954), and Caldas (1960) have also reported an increase in soil microorganism populations after addition of stillage, and the greatest growth was observed in fungi and bacteria populations, while actinomycetes were inhibited. However, this is often observed where N is not limiting and the actinomycete population is stimulated only when the simpler substrate has been decomposed (Waksman, 1932).

Effects of Stillage on Growth, Productivity, and Nutrient Uptake by Crops

Research showing the potential use of stillage as fertilizer probably started in the 1950's, since previously stillage was considered unsuited for use as a fertilizer because it was very acid (Almeida et al., 1950, 1951; Almeida, 1952, 1953). Since then, an increasing amount of research has been conducted, especially in relation to sugarcane fertilization, to develop appropriate techniques for the disposal of stillage.

Crop Growth and Nutrient Uptake

Ranzani et al. (1954) studied the effect on applying 1000 m^3/ha of either alone or with supplemental inorganic fertilizers on the growth and production of beans, cotton, corn, and sesame. They found that with the exception of corn, there was no significant difference between application of stillage alone and stillage with supplemental inorganic fertilizers. However, stillage alone and supplemented stillage produced much higher yields than inorganic fertilizers alone. It was found that 1000 m^3 of stillage supplied 470 Kg of N, 22 Kg of P, and 2573 Kg of K while the inorganic fertilizers supplied 80, 200, and 100 Kg/ha of N, P, and K, respectively. Thus the amounts of N and K from inorganic fertilizer were much lower than those supplied by stillage, but the amount of P from inorganic fertilizer was higher. Therefore, the difference in growth observed probably was due to this difference in the amounts of nutrients added. This type of experiment provides information on waste management of stillage rather than on its use to improve soil fertility.

Recently, it was reported that there was no difference in dry matter production or tissue K percentage in corn with K from either stillage or K_2SO_4. Nitrogen uptake was high during the first 30 days after planting in treatments with or without stillage, resulting in high N concentration in plant tissue ($\simeq$ 4% N) which was probably due to added inorganic N. From 30 to 60 days after germination, however, plant tissue N decreased drastically to levels below 1%. It was concluded that N in stillage, although of considerable quantity, apparently was not available for the entire 75-day period. Incubation studies showed an appreciable immobilization of N and P with increasing stillage rates (Projeto UFRRJ - Depto. de Solos - FINEP, 1978-1979).

Gloria et al. (1977) reported that cane productivity increased somewhat more with stillage than with the same amounts of nutrients supplied by inorganic fertilizer. Silva et al. (1977) reported benefits from stillage application included increased cane tonnage and reduced rates of inorganic fertilizer due to the nutrients supplied in stillage. Stupiello et al. (1977) also reported increased cane yield with stillage application. Magro (1978) observed an increase in cane yields with application of stillage, but cane growth was luxurious, cane lodged easily, and the stalks also broke easily. In addition, he reported that there is an increase in the percentage of flowering in varieties that flower. This increase in flowering may be due to the increased K levels, since some studies indicate that flowering is enhanced by K fertilization (Humbert, 1968).

Recommended Stillage Rates

Almeida (1952) summarized the information available at that time and recommended rates of 500 to 1000 m^3 of stillage/ha for sugarcane fertilization. The same conclusion was also reached by Lima (1953).

Later, Gomes (1957) suggested that 250 m^3/ha of stillage was an economical rate. More recently, Gloria and Magro (1976) reported that optimal stillage application rates are a function of soil fertility, among other parameters and rates appear to fall into the 30 to 50 m^3/ha range for stillage from molasses fermentation and the 80 to 200 m^3/ha range for stillage from cane juice fermentation. They reported that higher rates have undesirable effects on crops and increase yields only slightly.

Stupiello et al. (1977) also recommended stillage rates less than 42 m^3/ha to avoid detrimental effects of excessive nutrient application on cane juice quality. Similar observations were made by other authors (IAA - Planalsucar, 1974).

Branco et al. (1980) reported that large quantities of stillage may add excess salts to soil, therefore the ideal quantity of stillage as a fertilizer is a function of stillage composition and type of soil.

It should be noted that in recent years, researchers have been more careful in recommending stillage rates, and have considered the important factors of soil, stillage composition, and stillage type. However, since there still is a wide range of variability within the same stillage type, a better criteria would be the K content of stillage.

Cane and Sugar Yields and Juice Quality

Silva et al. (1977) observed that stillage application increased cane tonnage and reduced the requirement for inorganic fertilizers applied because of the nutrients contained in stillage. However, they reported stillage application reduced cane juice quality.

Stupiello et al. (1977) also reported increased cane yields with stillage application, but reduced juice quality. They observed that pol percent cane, brix, pol percent juice, and purity decreased whereas reducing sugars, and ash percent juice increased with increasing stillage rates.

Magro (1978) found that cane yields increased but sugar production remained essentially the same since there was a decrease in pol percent cane in the field that received stillage. He also pointed out that high rates of stillage delayed the ripening of cane.

Cesar et al. (1978) found that continuous application of stillage to a cane field lead to higher starch levels in cane juice, which interfered with the processing of sugar by reducing the filtration rate. In addition, the high level of K also reduced sugar recovery.

Branco et al. (1980) reported that among the major undesirable effects of stillage fertilization was the increase in ash content of cane. This increase was similar to that obtained with application of equivalent amounts of mineral fertilizers. Low stillage rates did not jeopardize sugar quality or industrial yield. On the other hand, increased ash content, which corresponds to increased potassium concentration, can improve the alcohol yield from fermentation when cane is used exclusively for alcohol production (Branco et al., 1980).

Although there have been many studies on the use of stillage as a fertilizer, none of them appears to be comprehensive, including an exploration of the nutritional and physiological changes in the sugarcane plant. No information was found in the literature reviewed which explained these relationships with stillage application.

As discussed earlier, considerable amounts of N are immobilized following stillage application and this immobilized N did not appear to be mineralized in 75 days (Amaral Sobrinho, 1983). This may imply that immobilized N can be released later in the crop season and if climatic conditions are appropriate growth will be stimulated, thereby increasing production of reducing sugars and consequently decreasing sucrose storage. Where cane is grown for 12 or 14 months, as in Brazil, it is standard practice to apply all the N fertilizer by the third or fourth month so the plant will be stressed for N for 3 to 4 months prior to harvest. This practice retards vegetative growth resulting in the accumulation of sucrose in the upper portions of the stalk, which improves juice quality (Clements, 1980).

Du Toit (1959) reported that N responses were more common and relatively higher in stubble than in plant cane. The effect of N on sucrose content of cane at harvest was small when applied as an early top dressing. Late top dressing significantly reduced sucrose content of the stalk.

Lakshmikantham (1974) found in India that increasing the level of N fertilization led to a significant depression in juice sucrose content. Application of phosphate or potash, individually or in combination to crops grown on normal soils where large quantities of nitrogeneous fertilizer had been applied, did not result in significant improvement in the sucrose content of juice. This may suggest that although stillage supplies relatively more K than N, the former may not overcome the detrimental effects of the latter, especially when high rates of stillage are applied.

Humbert (1968) reported that where fields are irrigated with mill water, the continuous supply of nitrogen and other nutrients makes it more difficult to properly ripen them. The irrigation intervals must be gradually lengthened in order to gradually convert a vigorously growing stalk to a ripening stalk where the reducing sugars are being converted to sucrose. This is due to the fact that the gradual water stress reduces vegetative growth to a larger extent than sucrose production and accumulation.

In addition to the detrimental effects of N, there is also the interaction between K, Ca, and Mg in the plant that should be considered since stillage adds relatively higher amounts of K in relation to Ca and Mg. Humbert (1968) reported that K application resulted in higher K levels and lower Ca and Mg levels in cane. Clements (1980) also showed that Ca and Mg concentrations of sheaths decreased with K fertilization.

Based on the results described above, it seems that a better understanding of the negative effects of stillage on ripening would result from studies of the effect of stillage on plant N which plays a key role in ripening. In addition, the balance among K, Ca, and Mg in the cane plant must be studied, since high stillage rates may produce imbalances.

Therefore, this comprehensive study involving stillage application and measurement of soil and tissue levels of nutrients at several times during the crop; as well as total nutrient uptake, cane, and sugar yields, and juice quality at harvest was undertaken in the hope of improving the understanding of these factors and their interrelationships.

MATERIALS AND METHODS

A sugarcane field experiment to study the effects of untreated stillage on cane and sugar yields was conducted at São João Sugar Company, Campos County, Rio de Janeiro State, Brazil.

Climate

Rainfall and temperature data for the experimental site are presented in Table 2. The climate is characterized by a hot, wet season and a cooler dry season.

Soil

Soil at the experimental site is classified as Udifluvent according to the U.S. Soil Taxonomy and as an Eutrophic Alluvial according to the Brazilian classification (Ramos, 1984). Some chemical and physical properties are shown in Table 3 and were determined according to the methods described by EMBRAPA (1979). It should be noted that the soil is relatively low in K. This soil was selected so that the response to K in stillage might be better evaluated and also because it represents soil on which a considerable area of sugarcane is grown.

Experimental Design

The 20 treatment combinations selected (Table 4) were set up in a randomized complete block design with 5 replications which gave a total of 100 plots.

Each plot had four rows 6.0 m long and 1.5 m apart for a plot size of 36 m^2. The center 3 m of the middle rows were harvested, leaving 1.5 m on each end as a border.

Table 2. Monthly average temperature and rainfall of the experimental site for 1980-1982

Year	1980		1981		1982	
Month	Average Temp °C	Rainfall (mm)	Average Temp °C	Rainfall (mm)	Average Temp °C	Rainfall (mm)
January	25.7	222.3	27.2	30.3	25.9	143.6
February	25.4	76.6	27.5	99.3	27.4	13.4
March	27.5	24.3	26.6	96.3	26.2	204.0
April	25.3	64.0	24.0	67.8	23.4	147.0
May	24.3	44.0	22.9	37.2	21.6	41.0
June	21.7	27.2	21.6	11.0	23.4	5.4
July	21.9	16.8	20.7	29.6	22.0	24.6
August	22.8	25.7	22.0	20.8	22.8	66.4
September	22.5	29.4	23.8	29.8	22.5	17.0
October	23.9	104.8	23.3	90.0	24.4	52.6
November	24.5	75.8	25.5	230.0	27.0	70.2
December	26.6	186.1	26.1	142.0	25.9	178.2

Table 3. Chemical and physical measurements of the Udifluvent of field experiment

Chemical Measurements													
Depth (cm)	pH (H_2O)	pH (KCl)	Exchangeable Bases Ca	Mg	K	Na	Sum	Exchangeable Acidity Al	H	Total	Effective CEC	Base Sat. (%)	Org. C (%)
			meq/100 g										
0-20	4.56	4.10	6.22	0.50	0.12	0.06	6.90	0.62	5.57	6.19	13.09	53	1.84
20-40	4.50	4.00	3.60	0.35	0.07	0.03	4.05	0.60	3.72	4.32	8.37	48	0.98
40-60	4.40	4.00	1.60	0.14	0.05	0.02	1.81	0.60	2.00	2.60	4.41	41	0.65

Physical Measurements								
Depth (cm)	Particle size distribution (%) Sand	Silt	Clay	Density (g/cm^3) Bulk	Real	Water content (% of whole soil) 1/3 atm	1 atm	15 atm
0-20	19	28	53	1.33	2.35	43.6	38.7	26.1
20-40	17	31	52	1.35	2.40	44.5	38.7	26.8
40-60	13	33	54	1.37	2.36	43.6	37.2	23.8

Table 4. Treatment combinations

K Sources	K rates (Kg K/ha)						
	0	60	120	240	480	960	1920
1. K from stillage broadcast	+[†]	+	+	+	+	+	+
2. K from KCl broadcast		+	+	+	+		
3. K from stillage in the furrow		+	+	+	+		
4. K from stillage broadcast + N				+			
5. K from stillage broadcast + ripener					+	+	
6. K from stillage broadcast + dolomite					+	+	

[†] Indicates the treatment combination included.

These treatment combinations were chosen after a preliminary greenhouse experiment with stillage using corn as an indicator crop.

The stillage used in this preliminary experiment was produced at the Food Science Pilot Plant at the University of Hawaii, using molasses from Oahu Sugar Company, Oahu, Hawaii. This stillage had the following analysis: pH - 4.9; P_2O_5 - 0.29 Kg/m^3; K_2O - 10.88 Kg/m^3; Ca - 0.45 Kg/m^3; Mg - 1.56 Kg/m^3; Na - 0.35 Kg/m^3; and S - 1.33 Kg/m^3.

The soil used in this experiment was an Ultisol of the Manana series which had low K content (0.10 meq/100 g) to allow evaluation of the response to K fertilization.

Results showed that generally there was no difference in K uptake or dry matter production by corn with K supplied either by stillage or KCl. It was also observed that increasing K rates from both sources (stillage or KCl) decreased Ca and Mg concentration of corn plants.

Soil and Plot Preparation

Initially the soil was leveled for furrow irrigation and then subsoiled and harrowed. The plots were then set out, staked, and a blanket application of dolomite was made at the rate of 2 tons/ha because soil Mg levels and soil pH were relatively low (Table 3).

Treatment Description and Preparation

Since stillage composition is highly variable (Table 1), the rates of stillage applied were calculated to supply the amounts of K shown in Table 4. The N added with stillage was determined for each plot and the average amount added for each K rate is shown in Table 5. Stillage treatments that received low amounts of stillage N were supplemented with fertilizer N as urea, and the amounts added are shown in Table 5.

Table 5. Amounts of stillage N (Kg/ha) added with stillage and supplemental fertilizer N added

K Levels	N Added (Kg/ha)		
(Kg/ha)	Stillage	Fertilizer N	Total N
0	0	170	170
60	15	155	170
120	30	140	170
240	60	110	170
480	120	50	170
960	240	0	240
1920	410	0	410

A description of each set of K source treatments shown in Table 4 follows:

1. K from Stillage Broadcast

Stillage to supply 0, 60, 120, 240, 480, 960, and 1920 Kg K/ha was broadcast on the soil surface and incorporated by harrowing before planting. The application of fertilizer N was made as urea according to the rates shown in Table 5. The application was split so that half was applied 15 days after planting and the other half at 60 days after planting. The N was applied as a band in the cane row.

2. K from KCl Broadcast

KCl rates were selected to supply 60, 120, 240, and 480 Kg K/ha KCl was broadcast on the soil surface and incorporated by harrowing so that K from stillage and from KCl could be compared under similar conditions. N was applied in a band in the cane row as urea at the rate of 170 Kg/ha which was split and the two half doses applied at 15 and 60 days after planting.

3. K from Stillage in the Furrow

In this set of treatments, stillage to supply K at rates of 60, 120, 240, and 480 Kg K/ha was applied in the furrow immediately after planting. The same N rates, application time, and placement described for stillage broadcast were used.

4. K from Stillage Broadcast + N

Stillage to supply 240 Kg K/ha was applied on the soil surface and incorporated by harrowing. In addition to the 110 Kg fertilizer N/ha added to this stillage level (Table 5), a supplement of 80 Kg fertilizer N/ha was applied so that the total N for this treatment was 250 Kg/ha.

This total amount of fertilizer N was also split into two applications and applied as described for the previous treatments.

5. K from Stillage Broadcast + Ripener

Application of stillage to supply 480 and 970 Kg/ K/ha and addition of fertilizer N followed the same procedures previously described for stillage broadcast (treatment set 1). Ten weeks prior to harvest, these treatments received 4 Kg/ha of Polaris (Diphosphonodiethylglycine), applied in water solution over the top of the canopy.

6. K from Stillage Broadcast + Dolomite

Before the application of stillage, these treatments received an application of dolomite at the rate of 6 tons/ha, in addition to the 2 tons added during soil preparaiton as previously mentioned (total of 8 tons/ha), which was then incorporated into the soil by harrowing. Application of stillage to supply 480 and 960 Kg K/ha and supplemental N fertilizer were applied by the same methods used for stillage broadcast described above (K source treatment set 1).

Type and Composition of Stillage

Stillage used in this sugarcane field experiment was from sugarcane juice fermentation. As already mentioned, stillage composition is highly variable; therefore, each batch of stillage was analyzed for N and K, since these were the main nutrients to be controlled in this study. N and K content of five batches of stillages are shown below:

Batch no.	N (Kg/m^3)	K (Kg/m^3)
1	0.64	2.02
2	0.49	1.20
3	0.34	1.70
4	0.24	0.96
5	0.30	1.50

The average composition of this sugarcane juice stillage from Sao Joao Sugar Company is the following:

C	C/N	N	P_2O_5	K_2O	Ca	Mg
%	Kg/m^3					
1.20	33.2	0.38	0.02	1.48	0.40	0.29

P and Micronutrient Fertilization

After furrows were cut, treble superphosphate (180 Kg P_2O_5/ha), $ZnSO_4$ (30 Kg $ZnSO_4$/ha) and Borax (10 Kg Borax/ha) were applied by hand below the seed at planting in all plots.

Planting

Three-eye seedpieces of sugarcane stalks, variety CB 45-3 which is an important commercial variety grown in Brazil, previously treated with Benlate (Benomyl (methyl-1-butylcarbomoyl)-2-benzimidazolecarbamate)) solution (1 Kg of active product per 1600 l. of water) were hand planted on November 1, 1980, with 10 buds per linear meter. The seed pieces were covered manually with 5 cm of soil and the experiment was irrigated shortly afterward.

Irrigation

Plots were irrigated when water tension in the soil reached 1.2 atm, determined by mercury manometer tensiometers installed at depths of 25 and 50 cm from the soil surface (Souza et al., 1977). There were three tensiometers installed at random in each replication. The volume of water applied was approximately equivalent to 1.2 times pan evaporation measured by a Class A evaporation pan. Irrigation was discontinued 2 months prior to harvest.

Measurements during the Experiment

Soil

Soil samples were collected at 15 days, 4 months, 7 months, and 10 months after planting, and also at harvest. Each sample consisted of four subsamples taken 1.5 m apart from between the two harvest rows. For treatments that received stillage and KCl broadcast, the subsamples were taken at 30 cm from the stool. For treatments that received stillage in the furrow, the subsamples were taken between the rows, 10 cm from the stool. Samples were taken at three depths: 0-20, 20-40, and 40-60 cm from the soil surface. The four subsamples for each depth were composited into one sample per depth, air dried, sieved, and analyzed for pH, Al, Ca, Mg, K, Na, and P by methods given later.

Plant

Plant samples were taken at 4, 7, and 10 months after planting and at harvesting. These samples were collected from one of the first stools in the border area adjacent to the harvesting area in the middle row.

At 4, 7, and 10 months after planting and at harvest, a +3 leaf (leaf nos. 3 or 4 in the crop log system) was collected from each of three stalks in the stools adjacent to each end of the harvest rows (four per plot); therefore, 12 +3 leaves were collected from each plot. The middle third of each leaf was taken, the midrib removed, and blades dried in a forced draft oven at 70°C for 7 days then ground in a laboratory Wiley-mill to pass a 20 mesh sieve (Galo et al., 1962). These samples were then analyzed for N, P, K, Ca, and Mg by methods given later.

At 4 and 10 months after planting, crop log samples and 8 to 10 internode samples were taken. For this purpose, one entire stalk was taken from the same stool sampled for the +3 leaves, totaling four stalks per plot. Crop log samples consisted of blades and sheaths 3, 4, 5, and 6 (counting the rolled spindle as leaf no. 1) from each stalk. Leaf sheath fresh weight (weight of 16 sheaths/plot) was recorded, sheaths were chopped into small pieces, and dried at 70°C in a forced draft oven for moisture determination. Sheath moisture was expressed in percent fresh weight. The middle third of each leaf blade was removed and the midribs stripped off. The 5th internode below the last green sheath was collected at the 10 month sampling, the middle third separated, and sliced.

Leaf blade and 5th internode samples were then dried as described for the sheath samples. Dried sheath, leaf blade, and 5th internode samples were ground in a laboratory Wiley-mill to pass a 20-mesh sieve for nutrient analysis. Sheath samples were analyzed for Ca, Mg, K, and P; blades for N; and 5th internodes for P (Clements, 1980).

The 8-10 internode samples were collected from the same stalks used for the crop log samples. These samples consisted of the middle third of internodes 8, 9, and 10 which are the internodes immediately below the leaf sheaths 8, 9, and 10 with the crop log numbering system. After separating the internodes from the stalks, several slices taken from the center of each internodes dried at 70°C, and ground in a laboratory Wiley-mill to pass a 20-mesh sieve for analysis of N, P, K, Ca, Mg, and K.

At harvest, four entire stalks were taken, one from each stool adjacent to the ends of each harvest row. The entire stalks were chopped with a forage chopper and the chopped material collected in a bucket. The material was mixed thoroughly and a subsample of 500 g taken, placed in a paper bag, and dried at 70°C. Fresh and dried weights were recorded and percent dry matter determined. These samples were then ground in a laboratory Wiley-mill and analyzed for N, P, K, Ca, and Mg.

Measurements at Harvest

Yields

Cane was harvested on February 1-10, 1982 at 15 months of age. All stalks from the harvesting area (center 3 m of the two middle rows) were cut by hand and classified into primaries and suckers, and the number of stalks in each class recorded. Primaries are the sugarcane stalks that emerged up to 6 months after planting and suckers were those stalks that emerged thereafter.

Ten primary stalks from a plot were then taken at random and split into two parts, (1) top internodes (nos. 1 to 13) and (2) bottom internodes (below 13). Internode no. 1 is the internode immediately below leaf no. 1 according to the crop-log numbering system. Fresh weights of both parts were recorded and the juice quality of the top and bottom internodes was determined.

Ten suckers from a plot were also taken at random and the top part separated from the bottom as described for primaries. Both parts were weighed and juice quality was determined only in the bottom part.

The remaining primaries and suckers in each plot were then separated into top and bottom sections and the weights of both parts were recorded for the two classes of stalks.

Chemical Analyses

Soil

The methods used for soil analyses are those recommended for Brazil's soils and are described in the manual of Methods of Soil Analysis, edited by the National Soil Survey and Conservation Services, EMBRAPA, 1979.

Soil pH: Soil pH was determined on a 1: 2.5 soil: water paste after 1 hour equilibration using a Beckman phasar I pH meter with a glass electrode.

Soil P, K, Na: P, K, and Na were extracted with the North Carolina double acid extractant (Black et al., 1965). A 10 g (oven dried basis) soil sample was shaken for 5 minutes with 100 ml of a 0.05 N HCl + 0.025 N H_2SO_4 solution and allowed to equilibrate overnight. The 50 ml aliquot pipetted from the supernatant was divided into two parts: 5 ml for P analysis, and 45 ml for K and Na analyses.

P was determined by the Ascorbic Acid Method (Watanabe et al., 1965) using a Micronal spectrophotometer with wavelength set at 882 mμ. K and Na were determined with a Micronal flame photometer.

Soil Ca, Mg, Al: A 10 g (oven dried basis) soil sample was shaken for 5 minutes with 100 ml of 1 N KCl and allowed to equilibrate overnight. Two 25 ml aliquots were pipetted from the supernatant. One was used for Ca and Mg determination and the other for Al determination.

Ca and Mg were determined either by the EDTA method using Eriochrome Black T as the indicator for determination of Ca + Mg and then Calcon as the indicator for determination of Ca, as described by Black et al. (1965) or by using Varian Techtron Atomic Absorption Spectrophotometer model AA-5. Al was Determined by titration with 0.025 N NaOH using Bromothymol Blue as the indicator.

Plant

The +3 leaf samples and total plant samples were digested with nitric:perchloric acid. Ca, Mg, and K in the digest were determined using a Varian Techtron Atomic Absorption spectrophotometer model AA-5, according to the recommendations of Sarruge and Haag (1974). P was determined colorimetrically with the molybdate vanadate solution and the color intensity was measured with a Micronal spectrophotometer. N was determined after digestion with sulfuric acid according to the Microkjeldahl procedure with titration of the distillate with 0.05 N H_2SO_4 using Bromocresol Green and Methyl Red as the mixed indicator.

Crop log and 8 to 10 internode samples were analyzed for P, K, Ca, Mg, S, Si, Na, Cl, Al, Mn, Cu, Zn, and Fe by the X-ray fluorescence technique using an X-ray Quantometer Model 72000 supplied by Applied Research Laboratories. N was digested with sulfuric acid and then determined with an Auto Analyzer according to the method described by Schuman et al. (1973).

Stillage

Stillage was analyzed for N, P, and K, according to the method of Gloria et al. (1976). A 5 ml sample of stillage was digested with

10 ml of a sulfuric acid solution containing 300 ml H_2SO_4, 54 g Na_2SO_4, and 9 g Na_2SiO_3 per liter on a micro-kjeldahl digestion block. After digestion, N was determined by titration of the distillate with 0.05 N H_2SO_4 using Bromocresol Green and Methyl Red as the mixed indicator. P was determined colorimetrically using the Molybdate Vanadate method and a Micronal spectrophotometer set at 420 mμ, while K was determined using a Micronal flame photometer.

Ca and Mg in stillage were analyzed according to the method described by Rodella (1976). A 10 ml stillage sample was digested with 10 ml concentrated nitric acid on a digestion block. Ca and Mg were then determined by the EDTA titration method using Eriochrome Black T as an indicator for the determination of Ca + Mg together and then Calcon as an indicator for the determination of Ca alone (Black et al., 1965.

Determination of Cane Quality

Sugarcane stalk samples collected at harvest were chopped into fine aggregates in a forage chopper, the material collected in a bowl and after the material was mixed, a 500 g sample was taken. This sample was poured into the cage of a Codistil Hydraulic Press and pressed at 250 Kg/cm^2 for 1 minute and the juice collected (Pereira, 1977).

Juice was filtered and analyzed for Brix % juice using a Bausch and Lomb refractometer. Pol % juice was determined in the juice after clarification with dry lead acetate and filtration using a Schmidt and Haensch saccharimeter Model Saccharomat III.

The press residue was then weighed, dried in a convection oven at 85°C and reweighed.

Fiber % cane was determined with the formula:

$$\text{Fiber \% cane} = \frac{100 \times PR - PD \times B}{5\ (100 - B)} \tag{1}$$

Where:

PR = weight of press residue

PD = weight of dried residue

B = Brix % juice.

Pol % cane was determined with the formula:

$$\text{Pol \% cane} = P \times \frac{(1 - \text{fiber \% cane})}{100} \tag{2}$$

Where P = Pol % juice

Juice purity was calculated with the formula:

$$\text{Juice purity} = \frac{\text{Pol \% juice} \times 100}{\text{Brix \% juice}} \tag{3}$$

Total sugars % juice and reducing sugars % juice were determined by the Lane-Eynon method, as described by Meade (1981). For the analysis of total sugars, a 25 ml sample of juice was treated with 5 ml of concentrated HCl, heated to 65°C, to invert all sugars to reducing sugars. Following this, the solution was neutralized with a 20% solution of NaOH. Reducing sugars in both determinations were measured by titration with Fehling's solution using Methylene Blue as the indicator.

Total sugars % cane and reducing sugars % cane were then calculated by the following formula:

$$\text{TS \% cane} = \text{TS \% juice}\ \frac{(1 - \text{fiber \% cane})}{100} \tag{4}$$

Where: TS % cane = total sugars % cane

TS % juice = total sugars % juice

$$\text{RS \% cane} = \text{RS \% juice} \; \frac{(1 - \text{fiber \% cane})}{100} \qquad (5)$$

Where: RS % cane = reducing sugar % cane

RS % juice = reducing sugar % juice

Statistical Analyses

Statistical analyses of the data included analyses of variance, Duncan's Multiple Range Test, Waller-Duncan K-ratio Test, and correlation and regression techniques, which were carried out on an IBM 370 computer at the University of Hawaii Computer Center Using the Statistical Analyses Stem (SAS) package (SAS Institute, Inc., 1979).

EFFECTS OF STILLAGE APPLICATION ON CANE AND POL (SUGAR) YIELDS AND JUICE QUALITY

Effects of Stillage Application on Cane and Pol Yields

Cane Yields

Generally, there was a significant increase in total yield of cane with increasing K rates from stillage broadcast and in the furrow, and from KCl (Table 6). However, there was a drop in total cane yields with the highest stillage rate although it was not significant (Figure 1). This yield increase is mainly a response to K fertilization, since comparable yield increases occurred with applications of KCl.

The total yield of cane increased up to the 960 Kg K/ha rate from stillage broadcast while the yield of primaries increased only up to 480 Kg K/ha and then started to drop (Figure 1). However, the yield of tillers generally increased with increasing K rates from stillage and the largest incremental increase was from 480 to 960 Kg K/ha stillage broadcast, which caused the total yield of cane to increase in spite of the decrease in primaries.

This decrease in yield of primaries with increasing stillage may be due to nutrient imbalance, especially in relation to Mg. As will be discussed later, stillage decreased tissue Mg levels, but the Mg concentration was above critical level. However, those samples were taken when the crop was 4 months old and the crop may have suffered from Mg deficiency at earlier stages of growth, when the root system was relatively small and probably exploiting mainly the 0-20 cm soil

Table 6. Effects of K from stillage, KCl, and stillage with dolomite and ripener on cane and Pol yields[†]

K Rates	Cane Yield (T/ha)			Pol Yield (T/ha)		
(Kg/ha)	Primary	Tillers	Total	Primary	Tillers	Total
			K from stillage broadcast			
0	108.94	30.16	139.10	15.45	2.13	17.58
60	115.04	32.22	147.26	16.47	2.08	18.56
120	125.25	35.71	160.96	19.18	2.72	21.90
240	126.59	38.65	165.24	18.21	2.95	21.16
480	129.95	39.03	168.97	18.03	2.59	20.62
960	123.93	48.79	172.72	16.37	3.60	19.97
1920	117.68	50.66	168.34	15.21	3.65	18.86
MSD[††]	9.37	10.02	12.38	2.43	1.31	2.78
			K from KCl broadcast			
0	108.94	30.16	139.10	15.45	2.13	17.58
60	120.11	32.44	152.55	17.45	2.31	19.76
120	125.45	44.39	169.84	18.32	3.33	21.64
240	130.02	36.22	166.24	18.91	2.58	21.49
480	132.06	42.11	174.17	19.36	3.38	22.74
MSD	6.98	9.30	7.80	1.88	ns	2.54
			K from stillage in the furrow			
0	108.94	30.16	139.10	15.45	2.13	17.58
60	117.13	29.22	146.35	16.41	2.02	18.43
120	127.40	29.57	156.97	18.54	2.16	20.70
240	145.35	40.32	185.67	20.82	3.05	23.87
480	139.48	43.15	182.63	19.77	3.27	23.04
MSD	13.25	10.73	15.39	2.68	ns	2.78
			K from stillage broadcast + N			
240	125.72	38.38	164.10	16.99	3.01	20.00
			K from stillage broadcast + ripener			
480	128.18	24.73	152.91	19.77	2.48	22.26
960	125.93	28.93	154.85	18.52	3.14	21.67
			K from stillage broadcast + dolomite			
480	138.70	39.14	177.84	19.55	2.92	22.47
960	132.11	24.47	156.58	18.92	1.75	20.66

[†] Values are means of five replicates.

[††] MDS = Minimum Significant Difference ($P \leqslant 0.05$) from the Waller-Duncan Multiple Range Test.

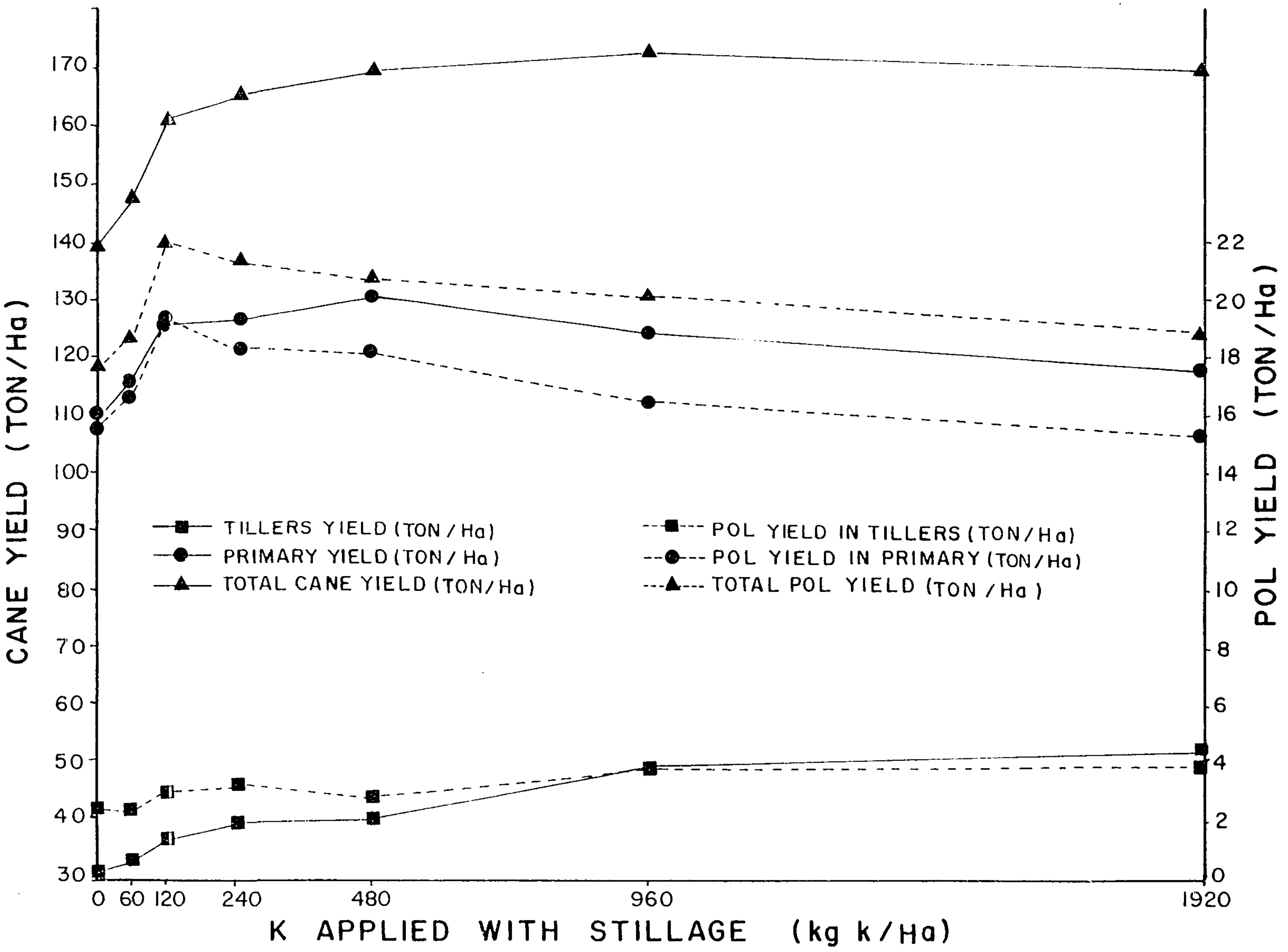

Figure 1. Effect of K from stillage broadcast on cane and Pol yields from primary cane and tillers.

soil layer where the Mg/K ratio was 1.35 and 2.22 for the 960 and 1920 Kg K/ha rates, respectively (Table 17). McColloch et al. (1957) reported that when the soil Mg/K ratio was less than 2, additional Mg was required to prevent deficiency from developing in citrus. In this study, at 4 months, Mg had leached out of the 0-20 cm layer and accumulated in the deeper layer (Figure 17) whereas K leached down and did not seem to have accumulated in the deeper layers (Figure 9). Therefore, there was a higher Mg/K ratio in these soil layers (20-40 and 40-60 cm) that may have favored Mg uptake by the crop. These favorable uptake conditions due to the Mg/K ratio plus the fact that the crop root system was probably exploiting Mg in the soil at depths of 40-60 cm at 4 months, may have contributed to the higher tissue Mg concentrations observed then. Also stillage treatments that received additional dolomite had a higher cane yield of primary stalks at comparable K rates than the stillage treatments that did not receive dolomite (Table 6). Therefore, the highest stillage treatment which may be considered a high fertility treatment, since it received the highest N and K rates, could have shown the yield potential of the experimental site, but probably did not do so because of nutrient imbalance. The electrical conductivity (Ec) of a saturation extract of the 15-day sample from this treatment was 3.00 mhos/cm which is below the Ec for a saline soil (Ferreira, 1980) and therefore excessive salt was not likely to have limited yields.

Tiller yields generally increased with increasing K levels, and the higher the K rate, the higher the tiller yields (Table 6). The yield of tillers was highest for the two highest K rates from broadcast stillage, where the largest drop in yield of primaries was observed. This was probably due to the fact that these treatments had large amounts of residual K and stillage N which apparently was mineralized throughout the cropping period. This N supply may then have favored tiller growth.

Clements (1980) concluded from a nitrogen and potassium factorial experiment that maximum yields of cane and Pol were achieved with the highest levels of N (600 lb/acre) and K (750 lb/acre) fertilizer. However, his fertilizer application may not have caused serious nutrient imbalance since N and K were applied in split applications. However, he pointed out that there was a decrease in Ca and Mg in plant tissues with higher K rates as was observed in the present study. The single K application in the present study caused a sharp increase in K/Mg and K/Ca ratios which combined with the small root systems of young cane made Ca and Mg uptake more difficult, and as a consequence a nutrient imbalance may have occurred in the early growth stages.

Pol (sugar) Yield

Pol is the polariscopic determination of the amount of sucrose in juice at a constant temperature based on the ability of sugars to rotate the plane of polarized light. Since it is highly correlated with the amount of sucrose, and easy to determine, it is the usual measurement taken to estimate sugar yields.

Pol differs from sugar in that it is the actual measure of sucrose in the stalks while sugar is the amount of sucrose recovered in the milling process. Therefore, Pol is not affected by factory recovery.

Total Pol yields increased with application of stillage broadcast up to 120 Kg/ha, then decreased at the rate of about 0.5 ton/ha with the next three rates and dropped 1.11 ton/ha at the highest rate (Figure 1).

Although cane yields of primaries increased up to 480 Kg K/ha from stillage broadcast, the yields of Pol from primaries increased only up to 120 Kg K/ha, then decreased thereafter (Figure 1).

Pol yield of tillers increased with increasing K rates to the maximum yield at 1920 Kg K/ha, but tons of Pol were relatively low compared to that of primaries. Therefore, total Pol yield did not change appreciably from the yield of primaries (Table 6; Figure 1).

Increased cane yields and decreased in sugar yields with stillage application have been reported by other authors (Stupiello et al., 1977; Magro, 1978). However, in the present study there was an increase in both cane and Pol yields with stillage rates up to 120 Kg K/ha. According to the composition of stillage used in this experiment, approximately 100 m^3 of stillage/ha was applied to supply 120 Kg K/ha which is in agreement with the rate of stillage fertilization recommended by Gloria and Magro (1976) for optimal cane juice quality. From a waste management point of view, it appears that rates of cane juice stillage up to 480 Kg K/ha can be applied broadcast without causing a significant drop in sugar yields (Table 6). At this stillage rate, only 50 Kg of supplemental fertilizer N was required whereas at the 120 Kg K/ha stillage rate, 140 Kg of fertilizer was required (Table 5).

Pol yields for the stillage broadcast treatment decreased at rates greater than 120 Kg K/ha whereas those of the KCl treatments remained generally constant even at rates greater than 120 Kg K/ha (Table 6). The only difference between treatments is the amount of fertilizer N added with stillage. Therefore, this suggests that slow mineralization of part of the N added with stillage may have caused the drop in Pol yield in the stillage broadcast treatment.

Regression Equations for Yield of Cane and Pol of Primary Stalks, Tillers, and Total Stalks from Broadcast Application of Stillage

Regression equations which describe cane and sugar yields from application of stillage broadcast with all rates (0 to 1920 Kg K/ha) are shown in Table 7. In general, the equations for total cane and Pol yields and cane and Pol yields of primary stalks include the square root terms with positive coefficients and linear terms with negative coefficients. This is probably due to the fact that cane and Pol yields increased with increasing stillage K rates. However, the incremental increase in cane yield was smaller for the higher K rates while with Pol, yields decreased with K rates higher than 120 Kg K/ha (Figure 1).

The equations for cane and Pol yields of tillers also included the square root term with positive coefficients for the same reasons discussed for primaries. However, the coefficients for the square root terms were smaller for the tillers than for the primaries, indicating that the incremental yield increases were larger for the former than the latter. In addition, the coefficients for the linear terms for the tillers were positive.

Table 7. Regression equations describing the effect of added K from stillage broadcast on cane and Pol yields of primaries, tillers and total stalks (Figure 1)†

Total cane yield = $137.864 + 2.159\ K^{1/2} - 0.032\ K$
$R^2 = 0.46$***

Total Pol yield = $17.339 + 0.448\ K^{1/2} - 0.014\ K$
$R^2 = 0.30$**

Primary stalk cane yield = $107.589 + 1.929\ K^{1/2} - 0.048\ K$
$R^2 = 0.33$**

Primary stalk Pol yield = $15.227 + 0.424\ K^{1/2} - 0.015\ K$
$R^2 = 0.39$**

Tiller cane yield = $30.275 + 0.229\ K^{1/2} + 0.016\ K$
$R^2 = 0.51$****

Tiller Pol yield = $2.112 + 0.023\ K^{1/2} + 0.001\ K$
$R^2 = 0.31$**

†n = 35
*Significant at 5% level.
**Significant at 1% level.
***Significant at .1% level.
****Significant at .01% level.
ns = Nonsignificant
K = applied K.

Effects of K Sources and Application Methods on Yield of Cane and Pol

Germination and emergence of cane was faster and growth rates were higher for stillage applied in the furrow than in the broadcast or KCl treatments. Measurements taken at 3.5 months of age (Table 8) showed that cane height was significantly greater in the furrow stillage treatments than for the other K treatments at comparable K rates. A similar increase was also observed at the highest K level for stillage broadcast; however, this initial rapid growth did not result in high yields probably due to nutrient imbalance as discussed previously. The increased growth is probably related to the activity of soil microorganisms that fermented sugars added with stillage, thereby raising soil temperature around the seed-pieces which consequently germinated more rapidly. Also, the organic acids produced by microbiological activity may have softened the sugarcane buds and hastened germination. In addition, organic matter in stillage added to the furrow may have increased the retention of nutrients as well as the water holding capacity of the soil near the seed-piece and enhanced initial growth. Furrow placement of this organic matter concentrated it there, whereas broadcasting the same amount of organic matter over a larger area followed by incorporation diluted it. It is important to point out that this higher initial growth apparently resulted in higher cane yields of primary and total stalks.

The effects of sources and methods of application of K were evaluated by averaging yields over K rates of 60 to 480 Kg/ha. Average cane yields for primaries, tillers, and total stalks were not significantly different for the stillage broadcast or KCl treatments

Table 8. Effect of K sources and application methods on the height of sugarcane at 3.5 months of age[†]

K rates (Kg/ha)	Cane Height (m)
K from stillage broadcast	
60	2.08
120	2.16
240	2.08
480	2.24
K from KCl broadcast	
60	2.00
120	2.30
240	2.08
480	2.18
K from stillage in the furrow	
60	2.34
120	2.34
240	2.52
480	2.46
Average for K from stillage broadcast	2.14 a[††]
Average for K from KCl	2.14 a
Average for K from stillage in furrow	2.42 b[††]

[†] Means of 10 values.

[††] Numbers followed by the same letters are not significantly different at the 5% level.

(Table 9). However, total yield of cane was slightly but not significantly higher for KCl than for stillage broadcast treatments, mainly because cane yields of tillers in the 120 to 480 Kg K/ha KCl treatments were variable and were generally higher than the tiller yields of stillage broadcast treatments.

There was no significant increase in cane yield for stillage broadcast or KCl, between 120 and 480 Kg K/ha (Figure 2; Table 6). In fact, data in Table 20 in the section on tissue K show that K concentrations in 3-6 sheaths and 8-10 internodes for these treatments were generally above critical levels, 2.25 and 1.00% K, respectively, at 4 months of age and 2.25 and 0.70 - 0.80%, respectively, at 10 months of age (Samuels, 1969). In addition, soil K for the 120 Kg K/ha treatment at 15 days was 0.22 and 0.25 meq K/100 g soil, respectively, for stillage and KCl treatments, which are reported to be levels above which no response to K fertilization is expected (Locsin et al., 1956).

Total Pol yield was significantly higher for the KCl treatment than for the stillage broadcast treatment (Table 9). This is due to the fact that above 120 Kg K/ha, Pol yield decreased in the stillage broadcast treatments, but increased in the KCl treatments (Table 6; Figure 2). As previously discussed, this may have been due to the N added with stillage. It was observed that at levels of K greater than 120 Kg/ha, the higher the K rate and the more N applied, the larger the drop in Pol yields. This result is consistent with data of Clements (1980) which showed that cane quality declines when cane is not stressed for nutrients, especially N, near harvest.

Table 9. Effect of (60, 120, 240 and 480 Kg K/ha) application from stillage broadcast and in the furrow and KCl on cane and Pol yields[†]

Treatment	Primaries	Tillers	Total
		Cane yield (ton/ha)	
Stillage broadcast	126.91 a[†]	36.40 a	160.01 a
KCl broadcast	124.21 a	38.79 a	165.70 ab
Stillage in the furrow	132.34 b[†]	35.57 a	167.91 b
		Pol yield (ton/ha)	
Stillage broadcast	17.97 b	2.59 a	20.56 b
KCl broadcast	18.51 ab	2.90 a	21.41 a
Stillage in the furrow	18.89 a	2.63 a	21.51 a

[†] Values are means of five replicates.

[††] Numbers in the same column followed by the same letters are not significantly different at the 5% level.

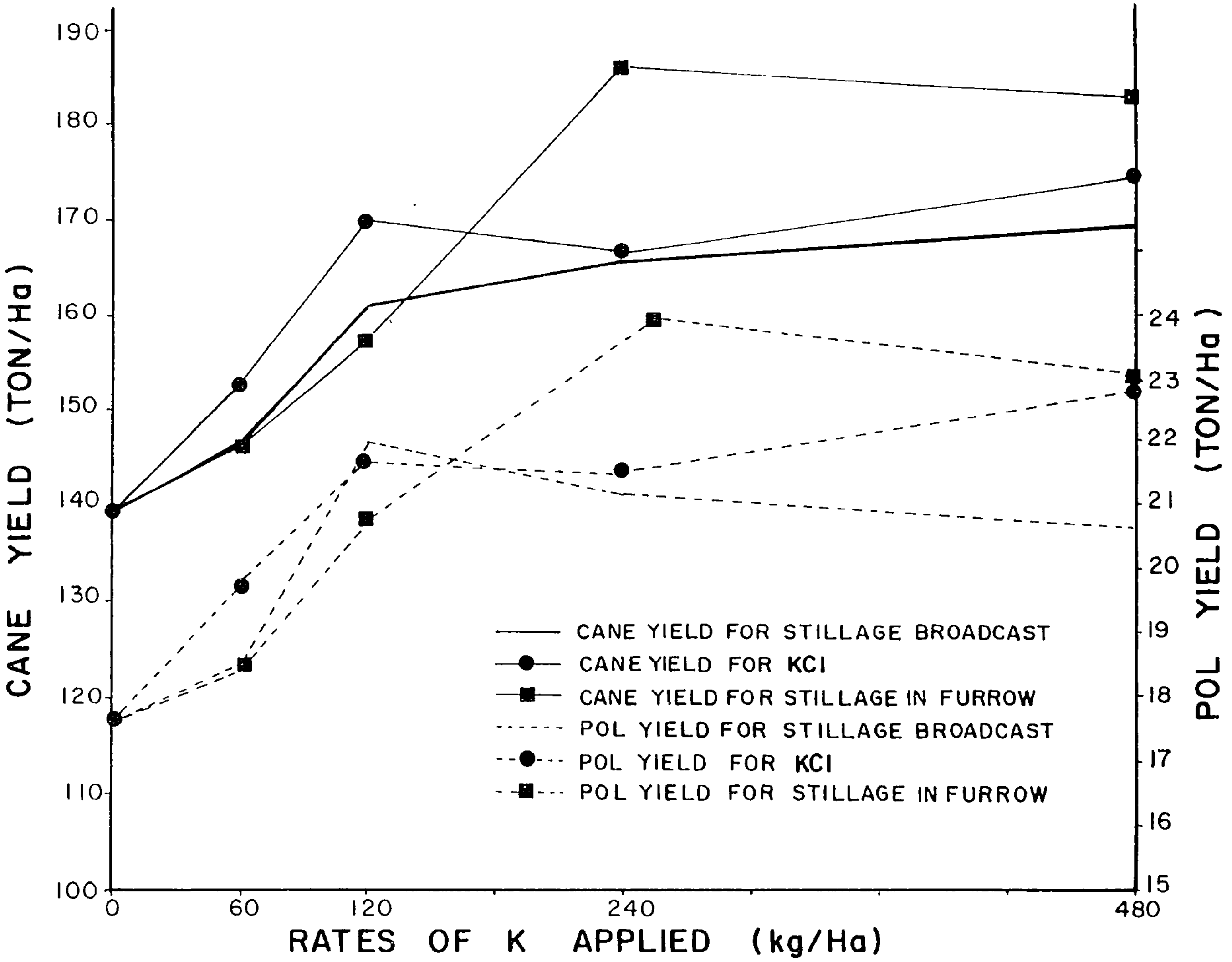

Figure 2. Effect of K from stillage broadcast and in the furrow and KCl on cane and Pol yields.

Average cane yields of primary stalks from stillage applied in the furrow were significantly higher than those from the stillage broadcast or KCl treatments (Table 8). However, yields of tillers from the three K sources were not significantly different. Total cane yield was significantly higher for stillage in the furrow than for stillage broadcast, but was not significantly different from that of KCl treatments (Table 9). As already explained, the variable and higher yields of tillers in the 120 to 480 Kg K/ha rates for the KCl treatments raised the total yield for the KCl treatment, which otherwise would have been similar to that for the stillage broadcast treatment, as is the yield of primaries.

Total cane yield for the furrow stillage treatment increased significantly up to the 240 Kg K/ha rate, whereas in the KCl and stillage broadcast treatments this level was 120 Kg K/ha. Only the 240 Kg K/ha rate of the stillage in the furrow treatment had 3-6 sheath and 8-10 internode K concentrations above the critical levels (2.25% for 3-6 sheaths and 1.00% for 8-10 internodes) at 4 months. However, at 10 months these critical levels were met by the 120 Kg K/ha rate. A possible explanation for this change is that the initially high growth rate discussed above may have resulted in lower tissue K levels because 120 Kg K/ha did not supply sufficient K to meet the plant's requirements. However, later in the crop cycle when these effects of added organic matter diminished, growth rates for these treatments may have decreased and the lower K rate, that is, 120 Kg K/ha, supplied adequate K for plant growth.

Total Pol yields for the stillage in the furrow treatments increased with increasing K rates (Table 6), which were similar to the response of total yields of cane (Figure 1). Although the average total Pol yield for stillage in the furrow was significantly greater than that for stillage broadcast (Table 9), it was not different from the average total yield of the KCl treatments. Total Pol yields for 60 and 120 Kg K/ha for furrow stillage treatments were lower than the Pol yields for stillage broadcast and KCl treatments at the same K rates. However, at 240 and 480 Kg K/ha, stillage in the furrow had higher total Pol yields than those of comparable KCl and stillage broadcast treatments. In fact, 240 Kg K/ha from stillage in the furrow gave the highest Pol yield for this experiment (Table 6).

These results suggest that stillage can replace KCl as a K source and be applied either in the furrow or broadcast at planting. Branco et al. (1980) reported that furrow application of stillage was the most widely-used method in Brazil, but is hindered by the need to dilute the stillage and the difficulty of accurately controlling the rate of application. However, the present results have shown that undiluted stillage can be applied in the furrow at planting with better results than broadcast application. It appears to be important to base the rate of application on the K concentration of the stillage and also to obtain some measure of the amount of N added with stillage so that the required fertilizer N can be appropriately reduced.

The response to stillage application may be different in a ratoon crop, especially for furrow application. Therefore, more research is necessary to determine the effectiveness of furrow application of stillage on ratoon crops. Also, the soil type and soil fertility level should be taken into account since it is known that some soil types are able to accept high stillage rates without adverse effects. However, soil studies are too incomplete to allow conclusions to be drawn about the effects of stillage (Branco et al., 1980).

Regression Equations for Predicting Total Yield of Cane and Pol from various K Sources

Regression equations for yields of cane and sugar (Pol), for the curves shown in Figure 2 are presented in Table 10.

The best fitting models included linear and square root terms because as may be noted, there was generally an increase in total Pol or total cane yield with the first K rates and thereafter yields either decreased or increased slightly.

Effects of Dolomite on Cane and Pol Yields

Dolomite application significantly increased cane yields of primary stalks and decreased the yield of tillers relative to those of stillage broadcast treatments (Table 11). The low tiller yield for the 960 Kg K/ha + dolomite treatment is due to the unusually low tiller yields of two replicates which were included in the calculations. Therefore, the discussion will be limited to the primary stalks only.

Both cane and Pol average yields of primary stalks increased significantly with dolomite application (Table 11). The magnitude of the increase was 6.67 and 11.86%, for primary stalk cane and Pol yield, respectively. The magnitude of the increase with dolomite application was similar for the two K rates, 8.75 and 8.80 ton/ha of

Table 10. Regression equations describing the effect of added K from stillage broadcast and in the furrow, and KCl on total cane and Pol yield (Figure 2)†

K from stillage broadcast

Cane yield = $138.815 + 0.505\ K^{1/2} + 0.130$
$R^2 = 0.58$***

Pol yield = $14.480 + 0.132\ K^{1/2} + 0.183\ K$
$R^2 = 0.42$**

K from KCl broadcast

Cane yield = $138.586 + 2.807\ K^{1/2} - 0.052\ K$
$R^2 = 0.61$***

Pol yield = $17.533 + 0.434\ K^{1/2} - 0.012\ K$
$R^2 = 0.74$****

K from stillage in the furrow

Cane yield = $139.340 - 3.558\ K^{1/2} + 0.5803\ K$
$R^2 = 0.61$***

Pol yield = $17.577 - 0.456\ K^{1/2} + 0.079\ K$
$R^2 = 0.68$****

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†n = 25
*Significant at 5% level.
**Significant at 1% level.
***Significant at .1% level.
****Significant at .01% level.
ns = Nonsignificant
K = applied K.

Table 11. Effects of application of dolomite on cane and Pol yields[†]

Treatment	Primaries	Tillers	Total
	Cane yield (ton/ha)		
480 Kg K/ha SB[††]	129.95	39.03	168.97
960 Kg K/ha SB	123.93	48.79	172.72
480 Kg K/ha SB + dolomite	138.70	39.14	177.84
960 Kg K/ha SB + dolomite	132.11	24.14	156.58
Average for K SB	126.94 b[†††]	43.91 a[†††]	170.84 a
Average for K SB + dolomite	135.40 a	31.81 b	156.21 a
	Pol yield (ton/ha)		
480 Kg K/ha SB	18.03	2.59	20.62
960 Kg K/ha SB	16.37	3.60	19.97
480 Kg K/ha SB + dolomite	19.55	2.92	22.47
960 Kg K/ha SB + dolomite	18.92	1.75	20.66
Average for SB K	17.20 b	3.10 b	20.30 a
Average for SB K + dolomite	19.24 a	2.33 a	21.57 a

[†] Means of 10 values.

[††] SB = Stillage Broadcast.

[†††] Numbers in the same column followed by the same letters are not significantly different at the 5% level.

primary stalk cane for the 480 and 960 Kg K/ha stillage rates, respectively.

As K rates increased from 480 to 960 Kg K/ha, there was a decrease in primary stalk cane yield of 4.60% and 4.75% for treatments without and with dolomite, respectively. This was a similar decrease even though overall yields were higher for the dolomite treatments (Table 11). However, Pol yield of primary stalks decreased 9.22 and 3.22%, as K rates increased from 480 to 960 Kg K/ha for treatments without and with dolomite, respectively. These differences suggest that dolomite application improved juice quality, especially with 960 Kg K/ha, as will be discussed later (Table 13).

This improvement in juice quality was probably due to the accelerated rate of N mineralization with dolomite application as will be discussed later. This fact may be responsible in part, for the higher cane yields of primary stalks, since more N was available during the early stages of growth when it is most needed, especially for 15-month old cane (Humbert, 1968). In addition, a better balance of nutrients also may have contributed to the improved yields with dolomite application. The imbalance between K, Ca, and Mg previously discussed caused yields to decrease. Therefore, application of dolomite improved (decreased) the soil K/Ca + Mg ratio and allowed greater Ca and Mg uptake by sugarcane with a resultant increase in cane and Pol yields (Table 11). The Ca + Mg concentrations in tissues of plants which did not receive dolomite were very near the critical levels, especially at 4 months. Therefore, Ca and Mg deficiencies may have been induced by the high rates of K in the soil prior to 4 months.

Effects of a Ripener on Cane and Sugar Yields

Total cane yield decreased (9.90%) with ripener application (Table 12). The decrease was due to the fact that although cane yields of primary stalks were not affected, the cane yield of tillers decreased significantly with ripener application (Table 12). On the other hand, total Pol yield of primary stalks was increased significantly (8.20%) by the ripener (Table 12). Pol yield of tillers was not affected by the ripener (Table 12) because pol percent cane increased (Table 13), but cane yield of tillers decreased.

Ripener application (Polaris) usually stops cane growth because it blocks N metabolism and then N limits growth (Clements, 1980). In the present study, as mentioned in the Materials and Methods section, cane at harvest was topped and then weighed. Since the growth rate of primary stalks probably was low at harvest, yields of primaries were not affected by ripener. Tillers were probably growing more rapidly so yields were more drastically decreased by the application of ripener.

However, total Pol yield increased significantly with ripener application (Table 12). These results suggest that a ripener can be beneficial in fields where ripening problems are experienced due to application of high stillage rates. The fact that Pol yields can be increased in fields that receive high stillage rates by application of a chemical ripener (Polaris), supports the contention that ripening problems related to high rates of stillage are mainly caused by delayed release of N due to mineralization of organic N.

The present experiment was harvested in the middle of the rainy season so environmental conditions were also unfavorable for ripening

Table 12. Effects of application of a ripener (Polaris) on cane and Pol yields[†]

Treatment	Primaries	Tillers	Total
	Cane yield (ton/ha)		
480 Kg K/ha SB[††]	129.95	39.03	168.97
960 Kg K/ha SB	123.93	48.79	172.72
480 Kg K/ha SB + ripener	128.18	24.73	152.91
960 Kg K/ha SB + ripener	125.93	28.93	154.85
Average for K SB	126.94 a[†††]	43.91 a	170.85 a
Average for K SB + ripener	127.05 a	26.83 b[†††]	153.88 b
	Pol yield (ton/ha)		
480 Kg K/ha SB	18.03	2.59	20.62
960 Kg K/ha SB	16.37	3.60	19.97
480 Kg K/ha SB + ripener	19.77	2.48	22.26
960 Kg K/ha SB + ripener	18.52	3.14	21.67
Average for K SB	17.20 b	3.10 a	20.30 a
Average for K SB + ripener	19.15 a	2.81 a	21.96 b

[†] Means of 10 values.

[††] SB = Stillage Broadcast.

[†††] Numbers in the same column followed by the same letters are not significantly different at the 5% level.

Table 13. Effects of K from stillage, KCl, stillage with dolomite and stillage with ripener on juice quality[†]

K Rates (kg/ha)	Primaries			Tillers		
	Brix % Juice	Pol % Juice	Purity	Brix % Juice	Pol % Juice	Purity
			K from stillage broadcast			
0	18.46	16.36	88.60	12.68	7.68	60.57
60	18.80	16.16	85.95	12.00	7.25	60.42
120	19.86	17.34	87.33	13.18	8.33	63.20
240	18.72	16.29	87.03	13.00	8.37	64.38
480	18.30	15.90	86.89	12.00	7.31	60.92
960	17.68	14.92	84.51	12.44	8.11	65.19
1920	17.32	14.10	81.45	12.60	8.33	66.11
MSD[††]	1.30	1.20	3.74	ns	ns	ns
			K from KCl broadcast			
0	18.46	16.36	88.60	12.68	7.68	60.57
60	18.82	16.39	85.95	13.02	8.00	61.44
120	18.66	16.28	87.33	12.94	8.23	63.60
240	19.32	16.74	87.03	12.42	7.69	61.92
480	18.78	16.44	86.89	13.30	8.87	66.69
MSD	ns	ns	ns	ns	ns	ns
			K from stillage in the furrow			
0	18.46	16.36	88.60	12.68	7.68	60.57
60	18.44	15.97	86.61	12.36	7.58	61.32
120	18.46	15.92	86.24	13.20	8.13	61.59
240	18.40	16.16	87.83	13.02	8.41	64.59
480	18.48	15.94	86.26	12.90	8.17	63.33
MSD	ns	ns	ns	ns	ns	ns
			K from stillage broadcast + N			
240	17.74	15.19	85.63	12.90	8.52	66.05
			K from stillage broadcast + ripener			
480	19.56	17.44	89.16	14.92	11.01	73.79
960	19.04	16.57	87.03	15.80	11.96	75.70
			K from stillage broadcast + dolomite			
480	18.30	15.74	86.01	12.76	8.21	64.34
960	18.76	15.86	84.54	12.28	7.69	62.62

[†] Values are means of five replicates.

[††] MSD = Minimum Significant Difference ($P \leqslant 0.05$) from the Waller-Duncan Multiple Range Test

by withholding water, a normal practice in Hawaii. Therefore, conditions were probably ideal for improving sugar yields by application of Polaris. Pan et al. (1977) reported that the effect of any chemical ripener varies with the sugarcane variety and the condition of the cane at the time of spraying. Several authors have reported that Polaris is effective when adverse ripening conditions occur (Azzi et al., 1977; Nickell et al., 1982).

Effects of Stillage Application on Juice Quality

Brix, Pol, and Purity

Increasing stillage rates initially increased brix, Pol, and purity (Figure 3) up to 120 Kg K/ha from stillage broadcast. Thereafter all three variables decreased.

This increase in brix and Pol of primary stalks was observed only at 120 Kg K/ha, and therefore may not be attributed to the effect of K on juice quality since treatments with higher rates of K, including the KCl treatments (Table 13) did not show any further increase in juice quality although there were trends for maximum values at 240 Kg K/ha in both the KCl and stillage broadcast treatments.

Although there was a decrease in brix of primary stalks with increasing K rate from stillage broadcast, it was not statistically different from the control even at the highest K rate (Table 13). Brix for the 480 to 1920 Kg K/ha treatments was also not significantly lower than the highest brix reading for the 60 to 240 Kg K/ha treatments. On the other hand, Pol and purity decreased significantly from the control plot only at the two highest stillage rates (960 and 1920 Kg K/ha), which further supports the suggestion made previously

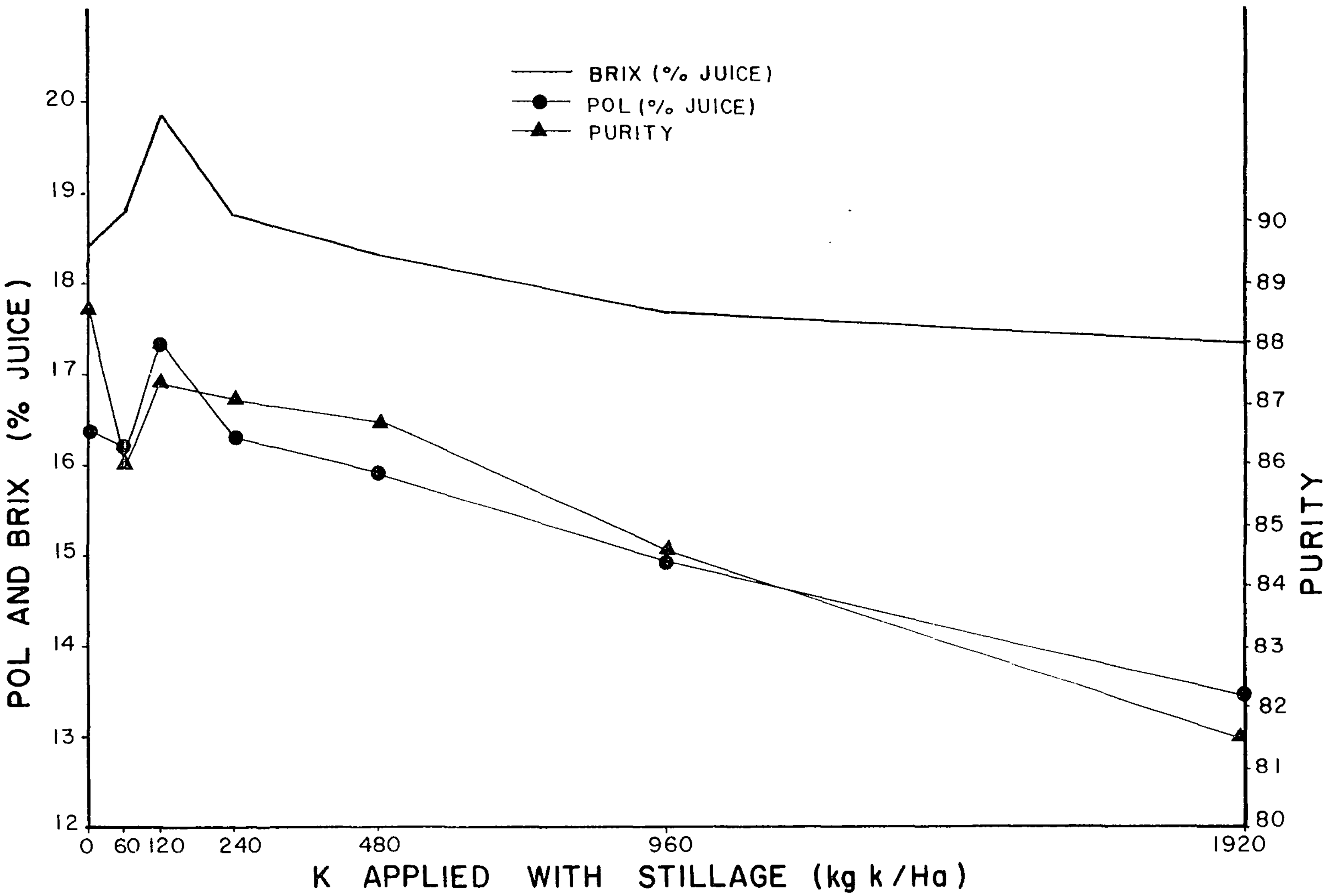

Figure 3. Effect of K rates from stillage broadcast on Pol, brix, and purity of juice from primary stalks.

that cane juice stillage can be applied broadcast or in the furrow up to rates of 480 Kg K/ha without detrimental effects on cane yields or juice quality. However, high rates are not recommended since they have been shown to have detrimental effects on cane yields and juice quality.

It is interesting to compare the brix and purity of stillage broadcast at 240 Kg K/ha with the stillage broadcast + N treatment at the same K rate. The brix, Pol, and purity also decreased with the additional N which appears to support the suggestion that the decrease in quality with stillage application is largely related to excess N. Clements (1970) stated that as far as quality is concerned, there is an element of risk in applying large amounts of N but much less risk in applying large amounts of K. This is in agreement with the probable conclusion in this experiment that the drop in quality with high stillage rates is more closely related to high N than to high K applications.

Juice quality of the tillers was not significantly affected by K rates from stillage broadcast in the furrow or KCl (Table 13), but the overall quality was low mainly because tillers were immature.

Reducing Sugars, Fiber, and Ash

Reducing sugars of mature internodes were significantly higher only for the highest stillage rate (1920 Kg K/ha) compared to the control. This is further indication that plants were still actually growing in the high stillage treatment (Table 14). These findings are further supported by the fact that the lowest fiber content occurred in this same treatment (Table 14). In addition, reducing sugars for the immature internodes for this treatment were the highest

Table 14. Effects of K from stillage, KCl, stillage with dolomite, and stillage with ripener (Polaris) on juice quality of primary stalks[†]

K Rates (Kg/ha)	Pol % Cane	Reducing Sugars % Juice	Total Sugars % Cane	Reducing Sugars % Juice 1-13 Int.	Ash % Juice	Fiber % Cane
K from stillage broadcast						
0	14.19	0.51	15.68	2.64	0.42	11.52
60	14.33	0.51	15.35	2.77	0.48	11.37
120	15.31	0.43	16.63	2.94	0.48	11.54
240	14.43	0.41	15.81	2.97	0.53	11.24
480	13.82	0.45	15.08	3.05	0.54	10.80
960	13.22	0.52	14.77	3.09	0.65	10.72
1920	12.95	0.74	13.71	3.28	0.70	10.71
MSD[††]	0.94	0.11	1.11	0.57	0.12	0.74
K from KCl broadcast						
0	14.19	0.51	15.68	2.64	0.42	11.52
60	14.54	0.48	15.75	2.64	0.43	11.31
120	14.61	0.49	15.55	2.78	0.55	11.26
240	14.57	0.42	16.14	2.74	0.56	11.29
480	14.67	0.48	15.88	2.82	0.55	11.12
MSD	ns	ns	ns	ns	ns	ns
K from stillage in the furrow						
0	14.19	0.51	15.68	2.64	0.42	11.52
60	14.03	0.51	15.22	2.83	0.48	11.11
120	14.56	0.46	15.22	2.72	0.50	10.94
240	14.34	0.45	15.22	2.82	0.51	11.31
480	14.20	0.62	15.50	2.67	0.58	11.14
MSD	ns	ns	ns	ns	0.10	ns
K from stillage broadcast + N						
240	13.52	0.56	14.66	3.11	0.51	10.94
K from stillage broadcast + ripener						
480	15.41	0.35	16.14	2.17	0.59	11.50
960	14.69	0.33	15.60	2.42	0.56	11.35
K from stillage broadcast + dolomite						
480	14.09	0.39	15.25	2.71	0.55	10.82
960	14.32	0.31	15.90	2.72	0.62	11.07

[†] Values are means of five replicates.

[††] MSD = Minimum Significant Difference ($P \leq 0.05$) from the Waller-Duncan Multiple Range Test.

found and were significantly greater than those of the control (Table 14).

Total sugars also declined significantly at the two highest K rates of stillage broadcast. This indicates that sugar was used for growth instead of being accumulated in the stalk so quality was lowered.

Ash generally increased with increasing stillage rates, but was significantly higher than the control only at the two highest K rates. However, the same pattern was also observed with the KCl and stillage in the furrow treatments. Cesar et al. (1978) found the same results in a stillage experiment on sugarcane.

This low purity and high ash content of juice from the highest K rates of the stillage broadcast treatment will not affect the recovery of sucrose, but will create problems for boilinghouse operations. If the K content of juice is too high it becomes even higher when water is evaporated off so that KCl crystallizes and blocks the holes of the centrifuge by becoming wedged among the large sucrose crystals thereby making it very difficult to remove the molasses. This is another detrimental consequence of applying high stillage rates in addition to the reduction in Pol yield.

Effect of Dolomite on Juice Quality

Application of dolomite with stillage caused a small but nonsignificant increase in brix and Pol (Table 15). However, it resulted in a significant reduction of reducing sugars in mature as well as immature internodes of primary stalks. This may be due to the increased rate of mineralization of stillage N that resulted in

Table 15. Effect of stillage and dolomite on juice quality of primary stalks[†]

Treatment	Brix	Pol	Purity	Reducing Sugars (% juice)	
	(% juice)	(% juice)		Mature Int.	Immature Int.
480 Kg K/ha SB[††]	18.30	15.90	86.89	0.45	3.05
960 Kg K/ha SB	17.68	14.92	84.51	0.52	3.09
480 Kg K/ha SB + dolomite	18.30	15.74	86.01	0.39	2.71
960 Kg K/ha SB + dolomite	18.76	15.86	84.54	0.31	2.72
Average for K SB	17.99 a[†††]	15.41 a	85.70 a	0.45 a	3.07 a
Average for K SB + dolomite	18.53 a	15.80 a	85.27 a	0.32 b	2.72b[†††]

[†] Means of 10 values.

[††] SB = Stillage Broadcast.

[†††] Numbers in the same column followed by the same letters are not significantly different at the 5% level.

higher tissue N in the beginning of the crop, but lower N at the end of the crop. The low N at harvest restricted growth and improved juice quality even though environmental conditions may have favored growth at harvest.

These results suggest that if the rate of mineralization of stillage N can be increased early in the crop, there will probably be less adverse effects from high rates of stillage on sugar yields. It should be pointed out that dolomite was applied only with 480 and 960 Kg K/ha in this experiment.

Effect of Ripener (Polaris) on Juice Quality

In addition to increasing Pol yields of primary stalks, application of Polaris increased overall juice quality (Table 16). This increase in juice quality by the ripener further supports the suggestion that N added with stillage is the main problem with ripening cane that has received high rates of stillage.

Ripener application significantly increased brix and Pol, and also increased juice purity, although this was not significantly in the primary stalks (Table 16). On the other hand, ripener significantly decreased reducing sugars in the mature and immature internodes of primary stalks, which probably indicates growth reduction and sugar accumulation in the primaries. Brix, Pol and purity were significantly increased by ripener in tillers. Juice quality of tillers improved somewhat more than juice quality of primaries (Table 16). This is probably due to the more vigorous growth of the tillers and their low accumulation of sucrose. The application of ripener decreased their growth rate resulting in a relatively large accumulation of sugar.

Table 16. Effect of two stillage rates (480 and 960 Kg K/ha) and ripener (Polaris) application on juice quality[†]

Treatment	Brix	Pol	Purity	Reducing Sugars (% juice)	
	(% juice)	(% juice)		Mature Int.	Immature Int.
Primary cane					
480 Kg K/ha SB[††]	18.30	15.90	86.89	0.45	3.05
960 Kg K/ha SB	17.68	14.92	84.51	0.52	3.09
480 Kg K/ha SB	19.56	17.44	89.16	0.35	2.17
969 Kg K/ha SB + ripener	19.04	16.57	83.03	0.33	2.42
Average for K SB	17.99 b[†††]	15.41 b	81.70 a[†††]	0.48 b	2.84 b
Average for K SB + ripener	19.30 a	17.01 a	88.14 a	0.34 a	2.04 a
Tillers					
480 Kg K/ha SB	12.00	7.31	60.92		
960 Kg K/ha SB	12.44	8.11	65.19		
480 Kg K/ha SP + ripener	14.92	11.01	73.79		
960 Kg K/ha SB + ripener	15.80	11.96	75.70		
Average for K SB	12.22 b	7.71 b	62.93 b		
Average for K SB + ripener	15.36 a	11.48 a	74.61 a		

[†] Means of 10 values.

[††] SB = Stillage broadcast.

[†††] Numbers in the same column followed by the same letters are not significantly different at the 5% level.

These findings are in agreement with those of other authors (Azzi et al., 1977; McCatty et al., 1980) who have also described the benefits of Polaris application on sugar quality.

EFFECTS OF STILLAGE APPLICATION ON SOIL CHEMICAL PROPERTIES

Soil pH

Soil pH generally increased during first 120 days after application of stillage either broadcast or in the furrow and the increase in pH per m^3 of stillage added was relatively larger for lower rates than for higher rates of stillage probably due to the soils buffer capacity (Table 17; Figure 4). The increase in soil pH observed for the control treatment between 15 and 120 days after applying the treatments was due to application of dolomite immediately before the treatments (see Materials and Methods - soil preparation). Some of the pH increase stillage treatments during this period was also due to the effects of dolomite.

The observed increase in soil pH is in agreement with the results of many other studies (Almeida et al., 1951; Ranzani, 1956; Mattiazzo, 1977; Nunes, 1979; Lima, 1980). They explained this increase in soil pH as a consequence of mineralization of organic N added with stillage which in turn produced NH_4^+ and raised soil pH. According to Asghar and Kanehiro (1977) the reactions responsible for this pH increase would be the following:

$$R - NH_2^{\dagger} + HOH \xrightarrow[\text{hydrolysis}]{\text{enzymatic}} R - OH + NH_3 + \text{energy} \qquad (6)$$

$$NH_3 + HOH \rightleftarrows NH_4OH \rightleftarrows NH_4^+ + OH^- \qquad (7)$$

Recent studies (Amaral Sobrinho, 1983) have shown that mineralization of organic N with production of NH_4^+ and NO_2^- increases with

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[†] Organic N added with organic matter.

Table 17. The effects of K rates from stillage and KCl, and dolomite on soil exchangeable cations and Al and soil pH before and after cropping[†]

K Rates (Kg/ha)	Exchangeable Cations						Exch. Al		Soil pH	
	15 days			450 days			15 Days	450 Days	15 Days	450 Days
	Ca	Mg	K	Ca	Mg	K				
	(meq/100 g)									
				K from stillage broadcast						
0	6.62	0.57	0.12	5.35	0.48	0.09	0.78	0.59	4.62	4.90
60	6.67	0.75	0.18	5.39	0.51	0.12	0.74	0.58	4.62	5.04
120	6.95	1.05	0.22	5.48	0.64	0.14	0.58	0.45	4.86	5.14
240	7.18	1.21	0.31	5.74	0.66	0.16	0.46	0.33	4.96	5.24
480	7.26	1.32	0.44	5.87	0.75	0.18	0.42	0.30	5.04	5.30
960	7.32	1.47	0.66	5.89	0.94	0.24	0.34	0.24	5.14	5.32
1920	7.49	1.65	1.22	5.93	1.01	0.42	0.32	0.23	5.26	5.38
MSD[††]	ns	0.16	0.17	ns	0.11	0.06	0.13	0.10	0.28	0.22
				K from KCl broadcast						
0	6.62	0.57	0.12	5.35	0.48	0.09	0.78	0.59	4.62	4.90
60	6.29	0.58	0.18	5.10	0.51	0.10	0.67	0.57	4.64	4.96
120	6.32	0.68	0.25	5.12	0.54	0.13	0.58	0.42	4.86	5.10
240	6.40	0.62	0.36	5.12	0.47	0.14	0.64	0.50	4.74	5.16
480	6.30	0.64	0.48	4.89	0.45	0.16	0.66	0.52	4.60	5.04
MSD	ns	ns	0.10	ns	ns	0.06	0.15	0.14	ns	ns
				K from stillage in the furrow						
0	6.62	0.57	0.12	5.35	0.48	0.09	0.78	0.58	4.62	4.90
60	6.72	0.78	0.33	4.74	0.40	0.11	0.62	0.53	4.60	5.00
120	6.98	1.08	0.41	4.98	0.52	0.12	0.54	0.52	4.82	5.04
240	7.06	1.14	0.51	5.28	0.59	0.13	0.48	0.47	4.94	5.08
480	7.26	1.26	0.73	5.36	0.65	0.15	0.44	0.50	5.08	5.16
MSD	0.53	0.14	0.15	ns	0.10	ns	0.13	0.10	0.24	0.20
				K from stillage broadcast + dolomite						
480	7.53	1.88	0.46	6.43	1.25	0.15	0.20	0.14	5.26	5.64
960	8.08	1.96	0.69	6.66	1.27	0.21	0.18	0.12	5.42	5.72

[†] Values are means of five replicates.

[††] MSD = Minimum Significant Difference ($P < 0.05$) from the Waller-Duncan Multiple Range Test.

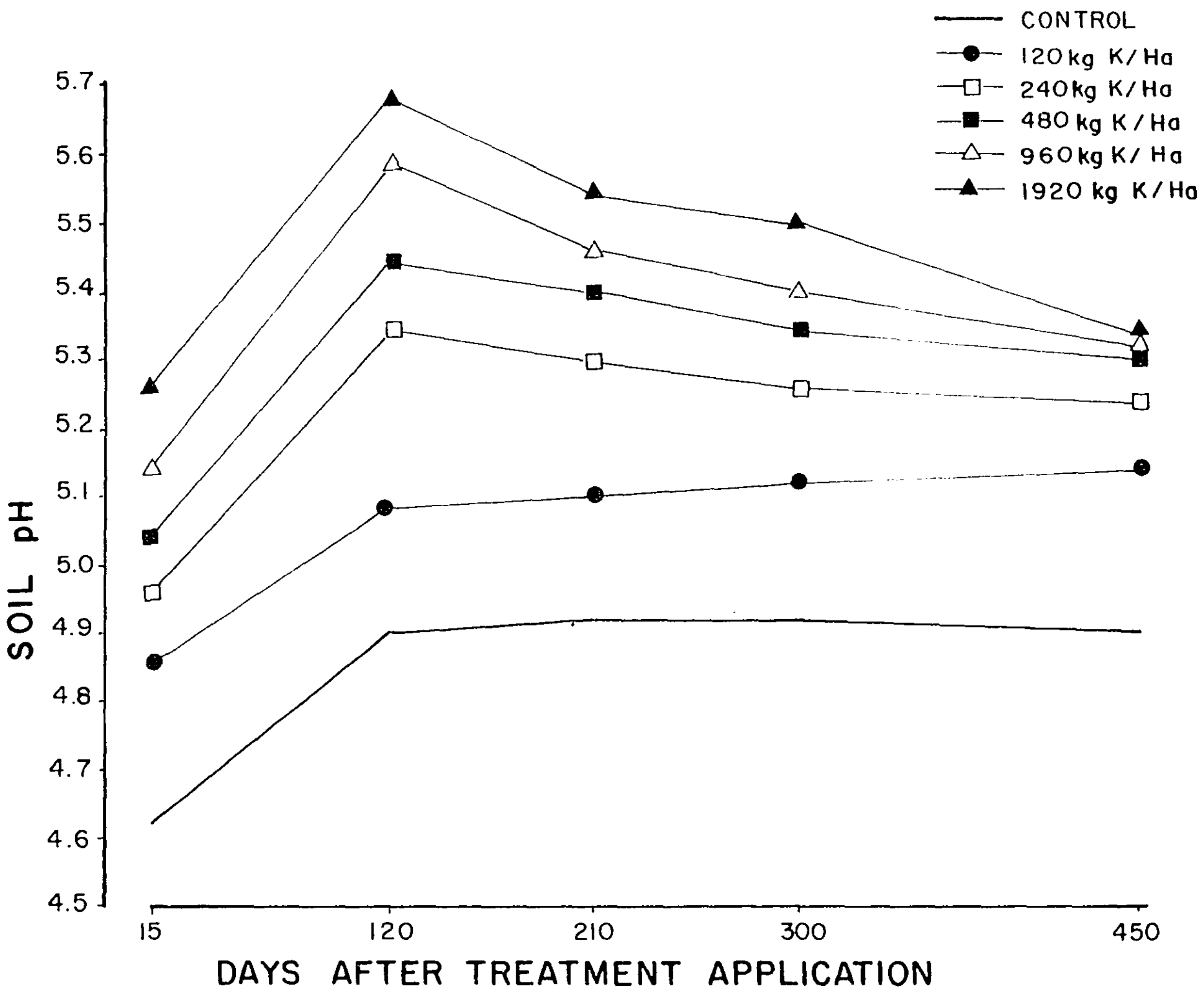

Figure 4. Changes in soil pH during the crop at the 0-20 cm depth with increasing stillage broadcast rates.

increasing stillage rates. This author also observed that the redox potential of soil decreased with increasing rates of stillage due to the O_2 demand of microorganisms. Therefore, the reducing processes responsible for the production of NH_4^+ and NO_2^-, especially NO_2^-, with the consumption of H^+, also should contribute to raising soil pH. The decrease in soil pH thereafter may be due in part to oxidative processes, such as nitrification which release H^+.

Stillage also adds other basic cations such as Ca and Mg in addition to K to the soil, as will be discussed later. Although these are present in low concentrations in stillage, the total quantities added to soil, particularly with high stillage rates, can be sizeable, and therefore, may also contribute to the increase in soil pH. Asghar and Kanehiro (1977) also reported that the addition of basic cations added with organic residues raised soil pH.

A comparison of soil pH from treatments that received 120 and 480 Kg K/ha from KCl and stillage (Figure 5) reveals that pH for stillage treatments were consistently higher than those for KCl treatments throughout the period of the experiment. It should be noted that the higher rate of KCl caused a marked decrease in soil pH relative to the other treatments. Stillage either broadcast or in the furrow had a similar effect on soil pH (Table 17). The dolomite application made to all plots prior to application of treatments probably accounts for much of the increase in pH in the KCl treatments and for part of the increase from stillage in the 15 to 120 day period. Thereafter pH decreased slightly for the 480 Kg K/ha stillage treatment, and then as with 120 Kg K from KCl, remained stable with a

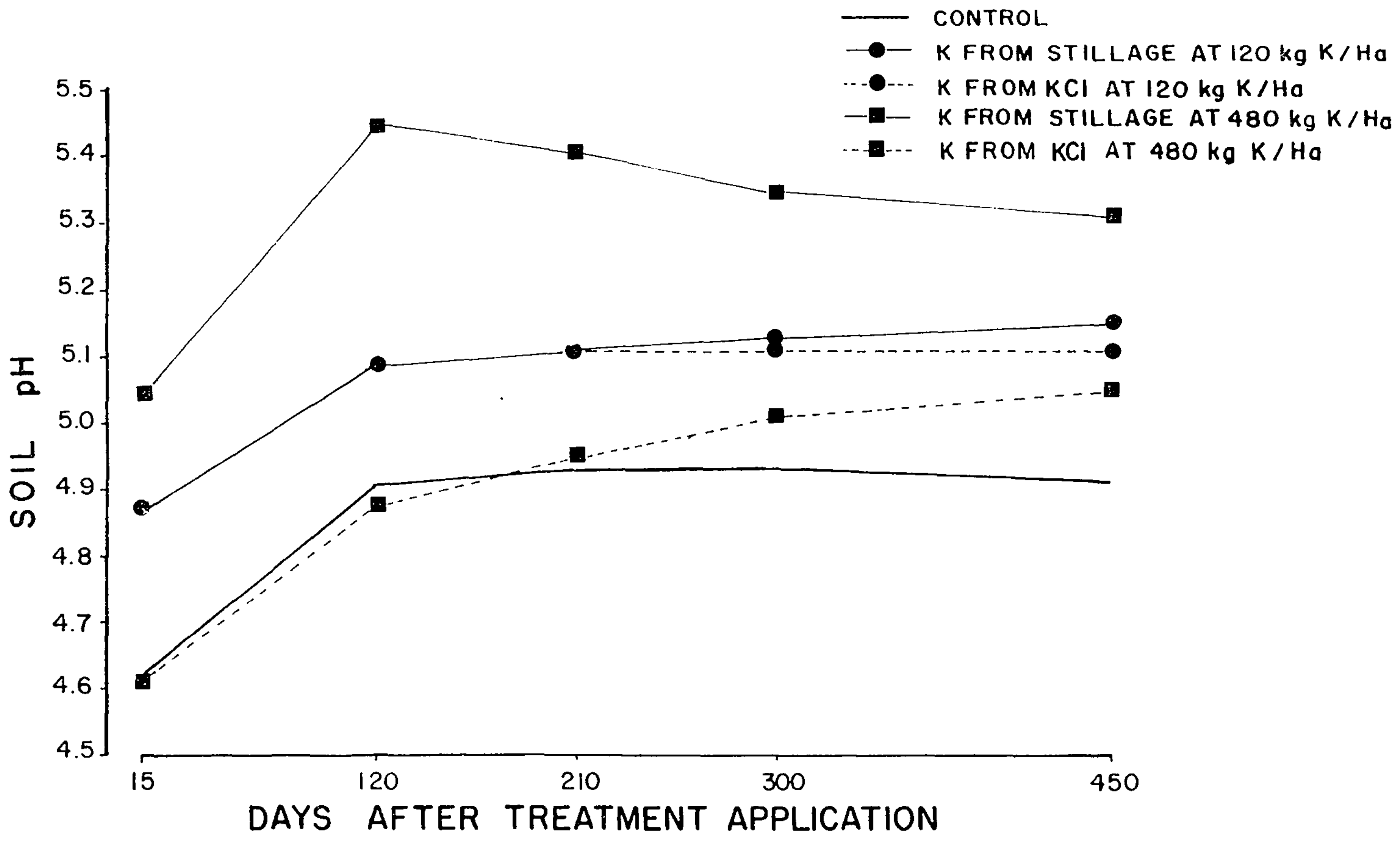

Figure 5. Changes in soil pH during the crop at the 0-20 cm depth with stillage and KCl broadcast applications.

tendency to decrease. Soil pH increased slightly in the other two treatments throughout the crop.

In the treatments that received additional dolomite, soil pH increased more than in those that did not receive it (Table 17).

This increase in soil pH can benefit crop growth, especially in acid soil, since it may increase the availability of nutrients such as P which is frequently limiting in tropical soils.

Soil Al

Stillage application either broadcast or in the furrow caused a significant decrease in extractable soil Al (Table 17), and the larger the stillage rate, the larger the decrease in extractable Al (Figure 6). This effect of stillage on soil Al was mainly due to the increase in soil pH discussed previously. Since KCl treatments did not cause a significant change in soil pH they also did not have any consistent effect on soil Al (Table 17). Further evidence is provided by the results of the dolomite treatments that caused a greater increase in soil pH and a larger decrease in soil Al than stillage treatments alone (Table 17). This relationship between soil pH and soil Al is well established.

The drop in soil Al in the control treatment was due to the initial dolomite application; therefore, the difference between the control and stillage broadcast and in the furrow treatments was mainly due to the effect of stillage (Figure 6).

The initial drop in extractable soil Al for all treatments was followed by an increase, with no change or a slight increase for the rest of the crop. However, it is important to note that the Al level

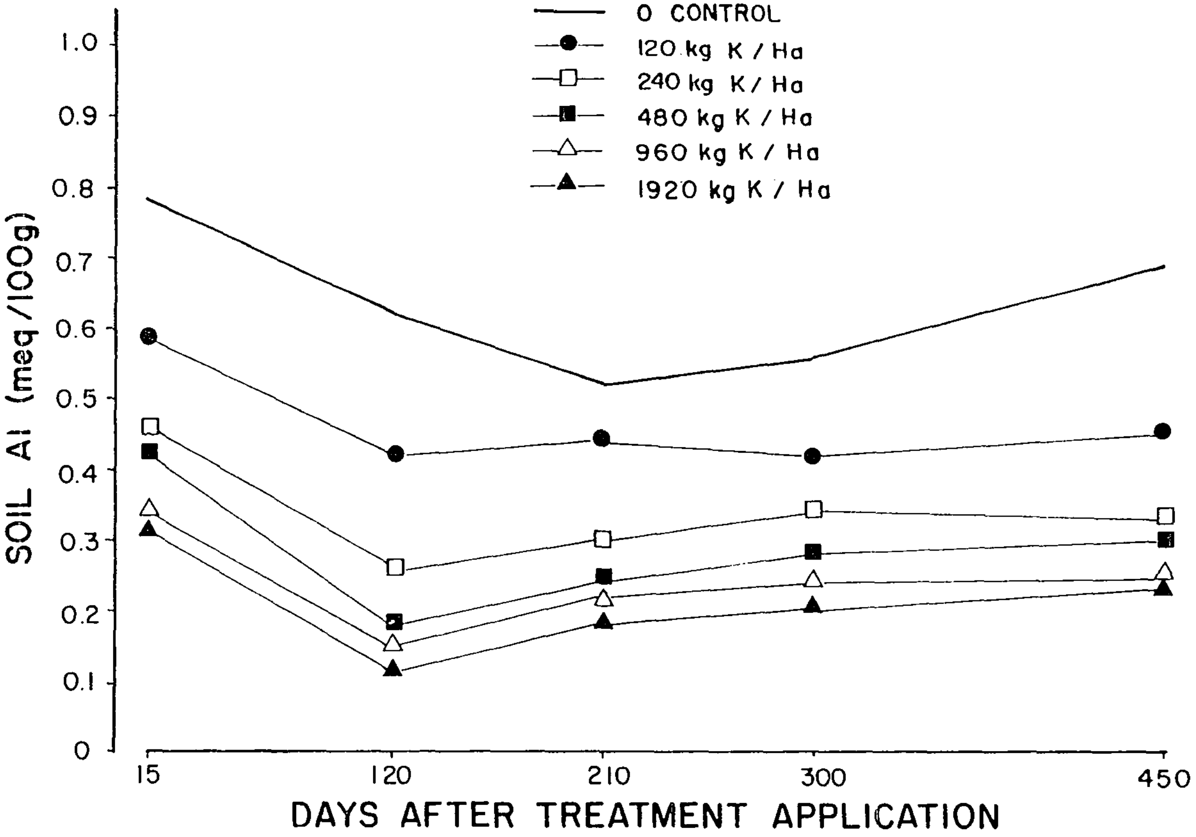

Figure 6. Al content of soil during the sugarcane crop at the 0-20 cm depth with increasing stillage broadcast rates.

for stillage broadcast or in the furrow treatments remained somewhat lower than those for KCl treatments (Figure 7; Table 17). The concentration of soil Al after the initial drop due to dolomite, decreased slightly for KCl treatments, whereas in those that received stillage, Al remained nearly constant, but was consistently lower than Al in the KCl treatments (Figure 7).

Although it is possible for K to exchange with H and Al on the exchange complex, thus lowering pH and raising Al content, this was not observed. If this exchange occurred, then over time Al and H would leach down and soil pH would increase in the upper soil layers. Perhaps soil Al was too low for this exchange to take place. However, this may occur at very high rates of stillage, but it could not be evaluated in the present study.

These findings are in agreement with those of other studies (Nunes, 1979; Rezende, 1979) and suggest an additional benefit of stillage application especially on soil where Al, Mn or other metal toxicities are likely to occur and limit crop growth. Asghar and Kanehiro (1977) reported reduced levels of soil Mn with the addition of sugarcane residue to soil. However, if either or both soil type or stillage source had been different, the results of this study may have been different.

Soil K

K is the cation of major interest in this study since it is the main element in stillage. Increasing K rates from stillage broadcast and in the furrow or KCl resulted in significant increases in soil K content (Figure 8) especially at the 0-20 cm depth (Table 18). The

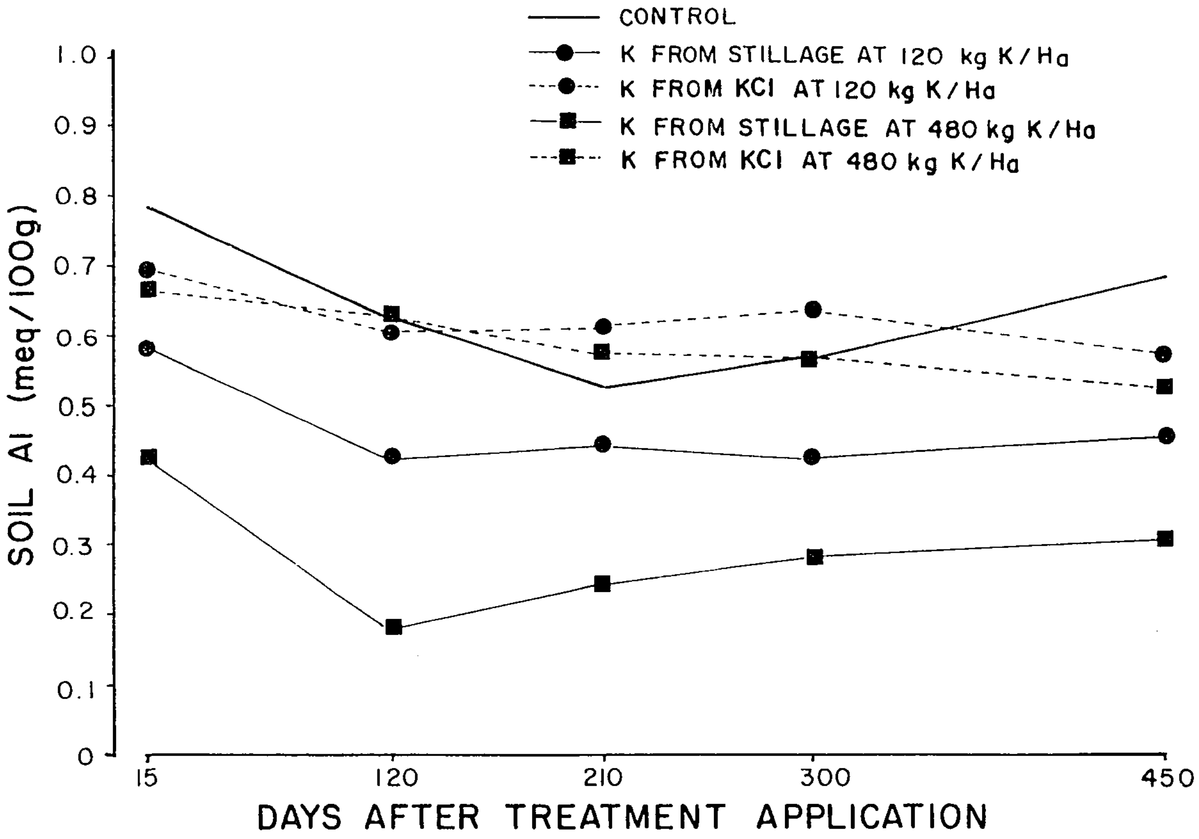

Figure 7. Changes in soil Al during the sugarcane crop at the 0-20 cm depth with stillage and KCl broadcast application.

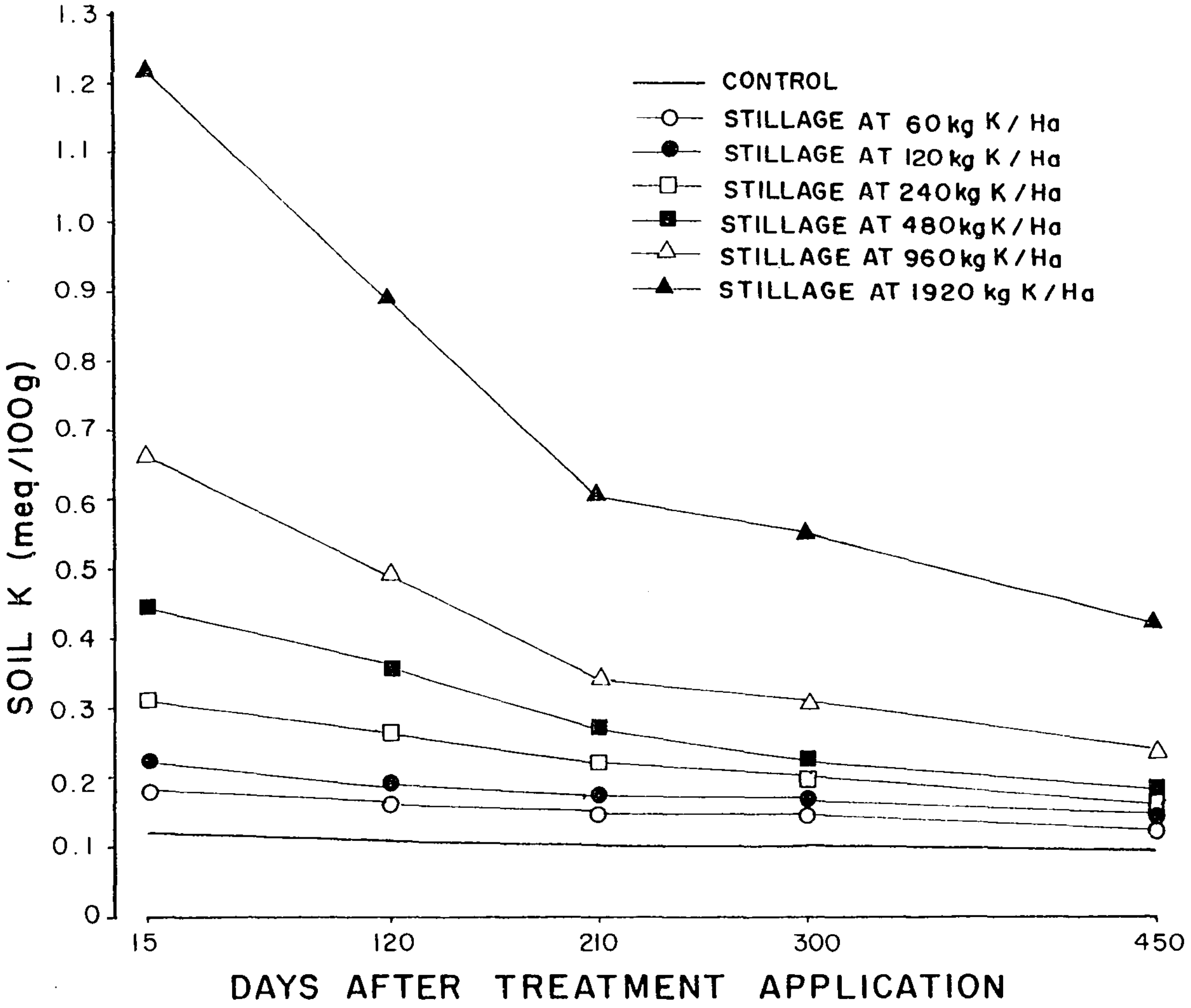

Figure 8. Changes in soil K during the crop at the 0-20 cm depth with increasing stillage broadcast rates.

Table 18. Exchangeable soil K at 3 depths at 15 and 450 days after application of K with stillage[†]

K Rates (Kg/ha)	Exchangeable K (meq/100 g)					
	15 days			450 days		
	Depth (cm)			Depth (cm)		
	0-20	20-40	40-60	0-20	20-40	40-60
	K from stillage broadcast					
0	0.12	0.07	0.05	0.09	0.05	0.03
60	0.18	0.08	0.05	0.12	0.06	0.04
120	0.22	0.09	0.05	0.14	0.09	0.05
240	0.31	0.11	0.07	0.16	0.10	0.07
480	0.44	0.13	0.09	0.18	0.11	0.08
960	0.66	0.27	0.16	0.24	0.13	0.11
1920	1.22	0.53	0.24	0.42	0.21	0.16
MSD[††]	0.17	0.06	0.04	0.06	0.05	0.04
	K from stillage in the furrow					
0	0.12	0.07	0.05	0.09	0.05	0.03
60	0.33	0.09	0.08	0.11	0.05	0.03
120	0.41	0.13	0.10	0.12	0.06	0.04
240	0.51	0.15	0.12	0.13	0.07	0.05
480	0.73	0.24	0.16	0.15	0.08	0.06
MSD	0.15	0.06	0.05	ns	ns	ns

[†] Values are means of five replicates.

[††] MSD = Minimum Significant Difference ($P \leqslant 0.05$) from the Waller-Duncan Multiple Range Test.

levels of K in the 20-40 and 40-60 cm depth were also significantly increased by the application of the two highest stillage broadcast rates (960 and 1920 Kg K/ha) (Table 18). This is probably due to the fact that the large volume of stillage added to supply these K rates may have percolated down in the soil profile and raised K concentration at these depths. However, it is interesting to observe the sharp drop in soil K concentration with time, especially at high stillage rates (Figure 8) which is due to leaching of K in the soil profile.

Stillage applied in the furrow resulted initially in higher soil K concentration than when it was broadcast for the same K rates (Table 17). This is due to the fact that stillage applied to the furrow was concentrated in a smaller volume of soil than in the broadcast application, which resulted in higher soil K concentrations. In addition, these higher K concentration in the furrow percolated into the soil profile, causing K levels in the 20-40 and 40-60 cm layers to be higher for stillage in the furrow than for stillage broadcast (Table 18).

In an attempt to estimate the leaching of K from the 0-60 cm soil layer, the levels of K from each sample depth (0-20, 20-40, and 40-60 cm) at 15 and 450 days were transformed from meq/100 g to Kg/ha. This was done by multiplying the value of meq/100 by the respective bulk density and by the respective soil volume. The values obtained were then added to total K uptake by the crop and this value called K recovery (Table 19). Subtracting K recovery from K measured in the soil at 15 days resulted in the values for K balance.

Table 19. Relationship between applied and recovered K from stillage broadcast

K Rates (Kg/ha)	Exchangeable K[a]					
	Sampling Time					
	15 days			450 days		
	Depth (cm)			Depth (cm)		
	0-20	20-40	40-60	0-20	20-40	40-60
A. Exchangeable K in Kg/ha						
0	125	75	53	93	53	32
60	187	84	53	125	63	43
120	228	95	53	145	95	54
240	322	116	75	166	105	75
480	456	137	96	187	116	86
960	685	284	171	249	137	118
1920	1266	558	257	436	221	171

B. K Balance - difference between added and recovered K

K Rates (Kg/ha)	Exch. K[b] 450 days 0-60 cm	Total K Uptake by Sugarcane	Total K[c] Recovery	Exch. K[b] 15 days 0-60 cm	K[d] Balance
0	178	171	349	253	+ 96
60	231	191	422	324	+ 98
120	294	224	518	376	+142
240	346	269	615	513	+102
480	389	293	682	689	- 7
960	504	347	851	1140	-289
1920	828	397	1225	2081	-856

[a] These values were obtained by multiplying the values for stillage broadcast in Table 18 in meq/100 g by the soil volume for each depth by the respective bulk density (Table 2).

[b] Exch. K at 15 and 450 days for 0-60 cm obtained by adding the K content of the 0-20, 20-40, and 40-60 cm depth in part A.

[c] Total K recovery is the sum of K uptake by sugarcane and K measured in the soil at the end of the crop.

[d] K balance is the calculated difference between K measured at 15 days and total K recovery; where + indicates that more K was recovered than was measured by soil analysis at 15 days and - indicates that K was apparently lost from the 0-60 cm layer.

The difference in soil K concentration between 15 and 450 days for the lower stillage rates (0 to 240 Kg K/ha) may be due essentially to K uptake by the crop. Data in Table 19 show that for these first four stillage rates the K balance was positive, which indicates that total K uptake plus K measured in the 0-60 cm soil layer at the end of the experiment (450-day sample) was greater than the K measured in this soil layer at the beginning of the experiment (15-day sample). This may suggest that either the root systems have extracted K from beyond the 60 cm depth of the soil profile or the method used to determine soil K extracted less K than the amount that was available for sugarcane. Cordeiro et al. (1977) studied K-lime relations in soil in which sugarcane was grown by means of ^{85}Rb labeling techniques and reported that K extracted by the 0.05 N H_2SO_4 method or by the method of Pratt and Hunter (0.1 N H_2SO_4) underestimated soil K that was actually available to sugarcane.

There appears to have been an actual loss of K from this 0-60 cm layer for the highest K treatments (480, 960 and 1920 Kg K/ha) because the K balance for these rates was negative (Table 19). Since clay present in this soil is composed mainly of Kaolinite and iron and aluminum hydroxides, it does not have the ability to fix or supply K. Therefore, it may be concluded that this negative K balance actually indicates cation loss through leaching.

Results in Figure 9 and Table 18 suggest that K leached from the 0-20 cm depth, for the highest K rates did not accumulate in the 20-40 and 40-60 cm depths. This conclusion was based on the fact that the K content at all depths was always lower than that for the previous

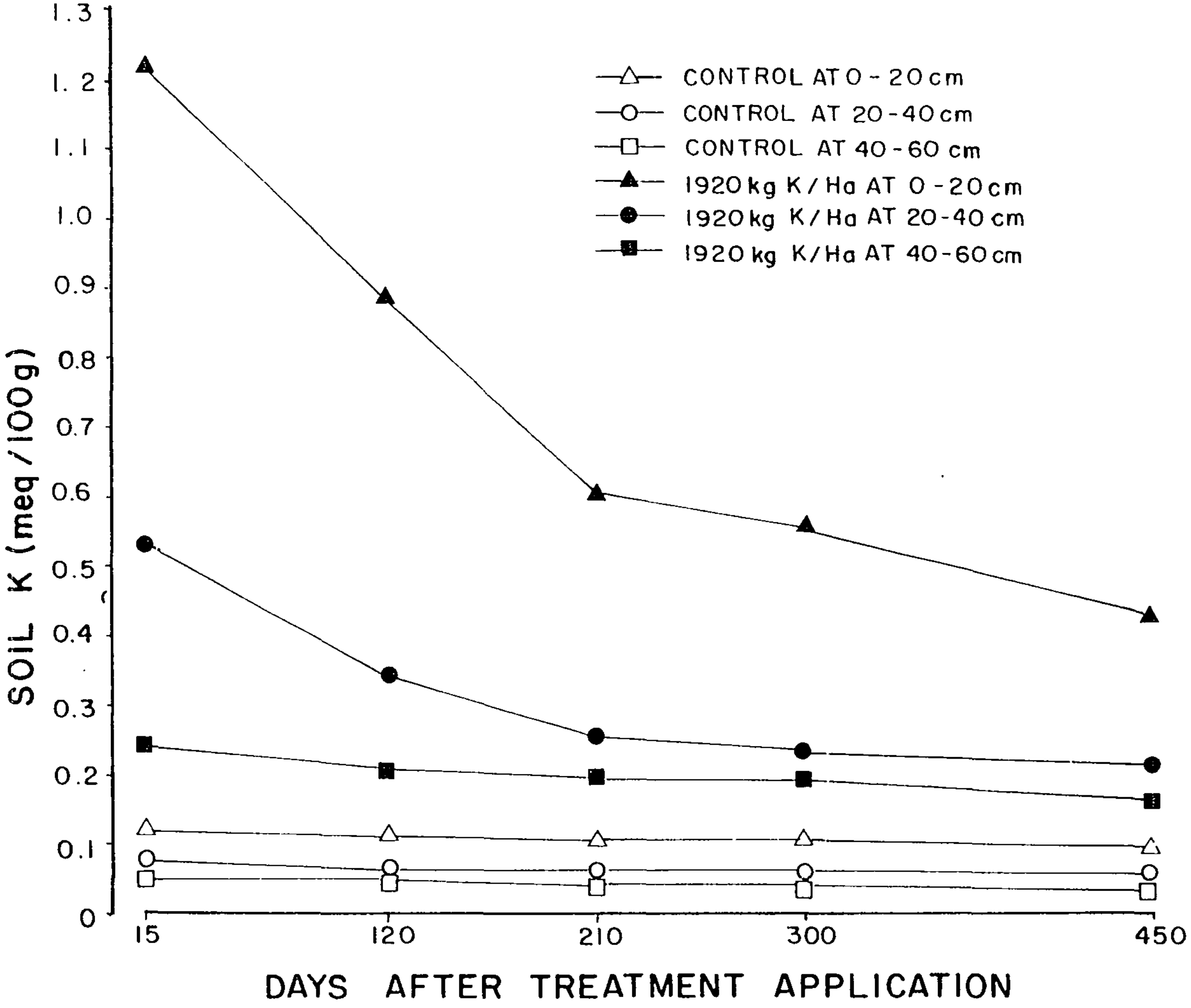

Figure 9. Changes in soil K during the crop at 3 depths with application of the highest stillage broadcast rate (1920 Kg K/ha).

sample throughout the duration of the crop (Figure 9). In addition, the K content of these three depths was lower at the end of the crop (450 days) than at the beginning (15 days) for all K rates (Table 18). One possible explanation is that K leached out at about the same rate from all depths, thus it did not accumulate at any depth. In fact, CEC decreased in the following order: 0-20 > 20-40 > 40-60 cm (Table 2), and therefore, the rate of leaching would be expected to follow the reverse order.

Based on total K uptake (Table 19) and the rates of applied K, the percentage of added K taken up by the crop is 33.0, 44.0, 40.8, 25.4, 18.3, and 11.8% for stillage K rates of 60, 120, 240, 480, 960, and 1920 Kg K/ha, respectively. To make these estimates it was assumed that the same amount of native soil K taken up by the control treatment was also taken up by the crop in the other treatments. Therefore, it may be concluded that with the application of K up to 240 Kg/ha, there is good recovery of added K, but thereafter recovery decrease with increasing K applied. However, it should be pointed out that generally the higher the rate of added K, the higher the K concentration remaining in the three depths at the end of the crop for all treatments (Table 18). These findings show that although there was loss of K by leaching at high stillage rates, substantial amounts of residual K remained in the soil. Nunes (1979) also observed that although there was increased leaching of K with increasing stillage rates, there was always a higher soil K content relative to the control at the end of the experiment than at the beginning.

Bittencourt et al. (1977) showed that the clay fraction (predominantly Kaolinite and hydrated Fe and Al oxides) of most of the soils of São Paulo State is highly selective for Ca and Mg, rather than K. Cordeiro (1978) in a review of the interactions among Ca, K, and Mg in the soil-plant system pointed out that clay in tropical soils absorbs cations selectively, i.e., Ca > Mg > K. In fact, the results shown in Figures 8, 12, and 15 for K, Ca, and Mg, respectively, appear to indicate that the order of leaching was K > Mg > Ca.

The soil used in this study has an effective CEC of 13.09 meq/ 100 g and a base saturation of 53%. Ca represents 90% of the exchangeable bases for the 0-20 cm depth, 89% and 88% for the 20-40 and 40-60 cm depths, respectively. Therefore, this high concentration of Ca ions probably competed with K for exchange sites. Since tropical clays have a higher affinity for Ca than for K, the latter would be more susceptible to leaching. Miyada et al. (1977) studied the leaching of K in several soils in Brazil, including three soils with CEC's of approximately 22, 12, and 10 meq/100 g and base saturations (BS) of 56, 89, and 18%, respectively. He found that the greatest loss of applied K through leaching was in the soil with CEC = 22 meq/100 g, BS = 56%, followed by the soil with CEC = 10 meq/100 g, BS = 18% and the smallest was by the soil with CEC = 12 meq/100 g, BS = 89%. They were not able to explain the great loss of K in the soil with CEC = 22 meq/100 g, except that its K content was higher than the others. Franco and Medina (1960) observed that all applied K had moved from the soil surface to depths greater than 1 meter 4 years after K fertilizer application.

Leaching of K from KCl in the present study was a little greater than that from stillage (Figure 10) especially between 15 and 210 days after treatment application. At the end of the experiment, soil K levels remained slightly and significantly higher in stillage treatments. The higher initial leaching rate of K from KCl than from stillage may be due to the fact that the organic matter added with stillage raised soil CEC and thereby decreased leaching of cations. However, after a period of time, this organic matter probably decomposed, releasing the K adsorbed to it and allowing it to leach out.

Although soil K from stillage in the furrow was higher than stillage broadcast initially, the reverse was observed at the end of the experiment possibly due to the greater amount of leaching of stillage in the furrow caused by application of irrigation water in the furrow (Table 18).

Dolomite appears to enhance the leaching of K in soil since K levels in soil that received dolomite were slightly lower than those that did not receive dolomite (Figure 11). It is interesting to observe that at 15 days, soil K levels were higher for the dolomite treatments, then they decreased at the 120 days and remained lower than K from the treatments without dolomite for the rest of the crop. This pattern of K decrease (Figure 11) may be due to increased microbiological activity. Thus, the rate of decomposition of organic matter at the higher pH resulted in release and leaching of K that may have been initially adsorbed on organic colloidal surfaces. Cordeiro et al. (1977) stated that the use of lime decreased the availability of soil K to sugarcane in direct proportion to the level of

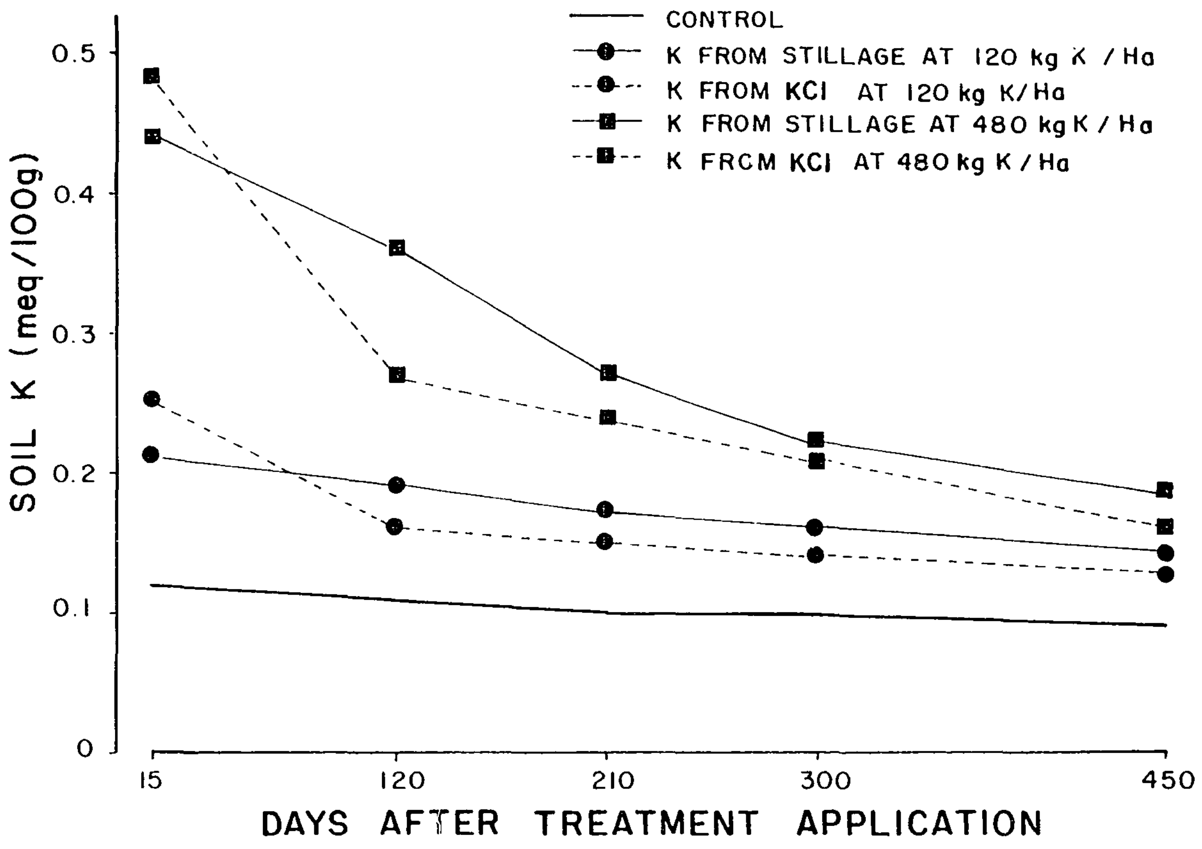

Figure 10. Changes in soil K during the crop at the 0-20 cm depth with stillage and KCl broadcast application.

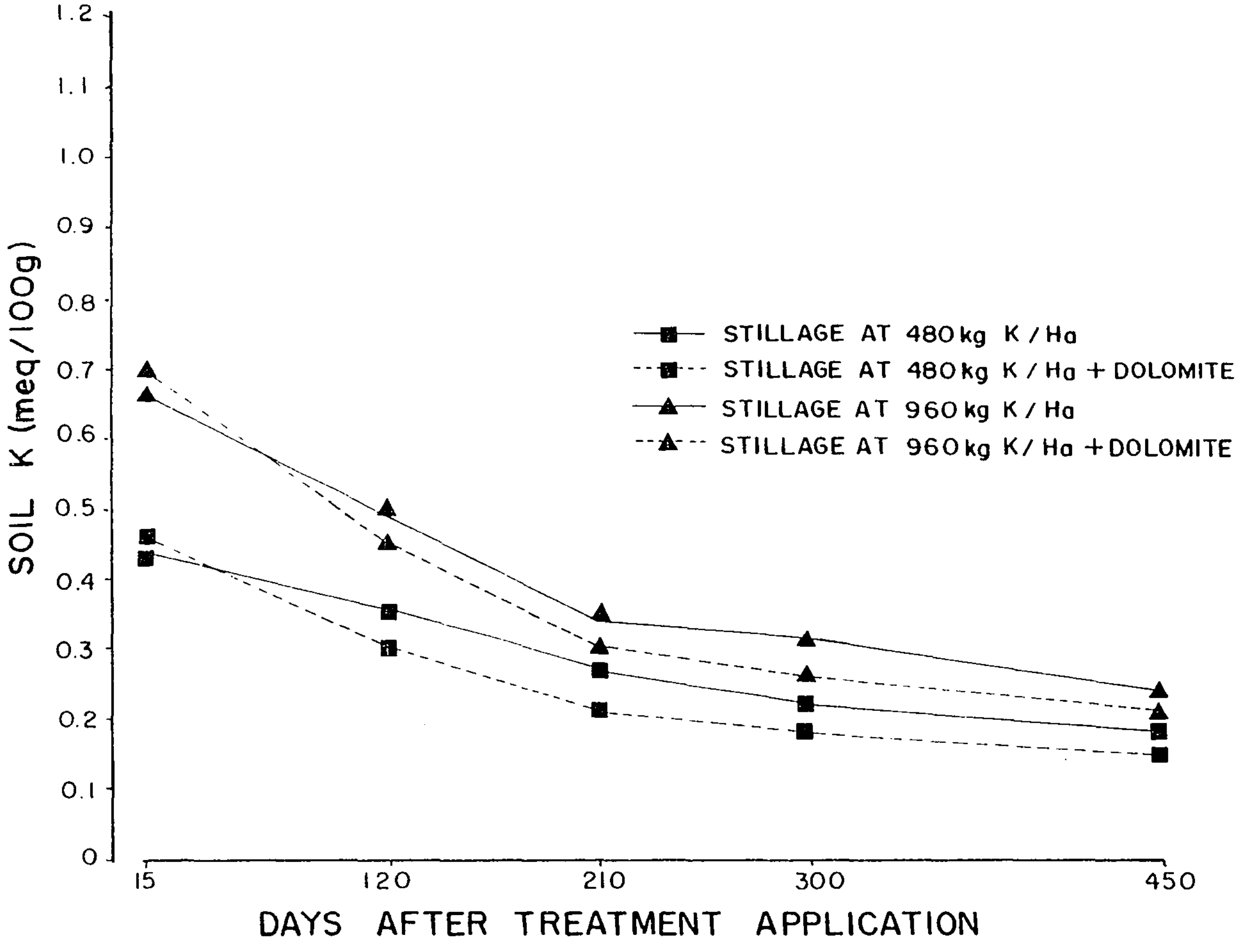

Figure 11. The effects of dolomite application on changes in soil K from stillage broadcast during the crop at the 0-20 cm depth.

lime applied in some soils but not in others. This decrease would be due to competition of Ca and Mg with K for the exchange sites on the soil clay, resulting in loss of K through leaching. Orlando Filho et al. (1977) found that the exchangeable K content of soils that received lime was always lower than that in soils that had not been limed.

Soil K in Relation to Cane and Sugar Yields

As previously discussed, cane and sugar yields increased with increasing soil K from stillage application.

The maximum statistical cane and sugar yield which is the yield obtained with the lowest rate of applied K that is not statistically different from the highest yield (480 Kg K/ha) was obtained with the 120 Kg K/ha stillage rate (Figures 12 and 13; Table 6). It should be pointed out that K rates of 960 and 1920 Kg K/ha do not represent yield response to K only since these stillage rates also provided higher N than the lower stillage rates (Table 5).

With this stillage rate, soil K concentration was 0.22 meq/100 g (86 ppm) at 15 days (Table 16), which is reported to be a level above which no response to K fertilization is expected with sugarcane (Locsin et al., 1956). The 15-day sample was chosen because this sample was taken immediately after stillage application and indicates soil K concentration at planting which would be comparable to a regular soil analysis.

Orlando Filho et al.(1981) reported a critical level of 91 ppm for soil K (0.23 meq/100 g) based on yield response of sugarcane to K fertilization on several Brazilian soils. Geus (1967) also reported

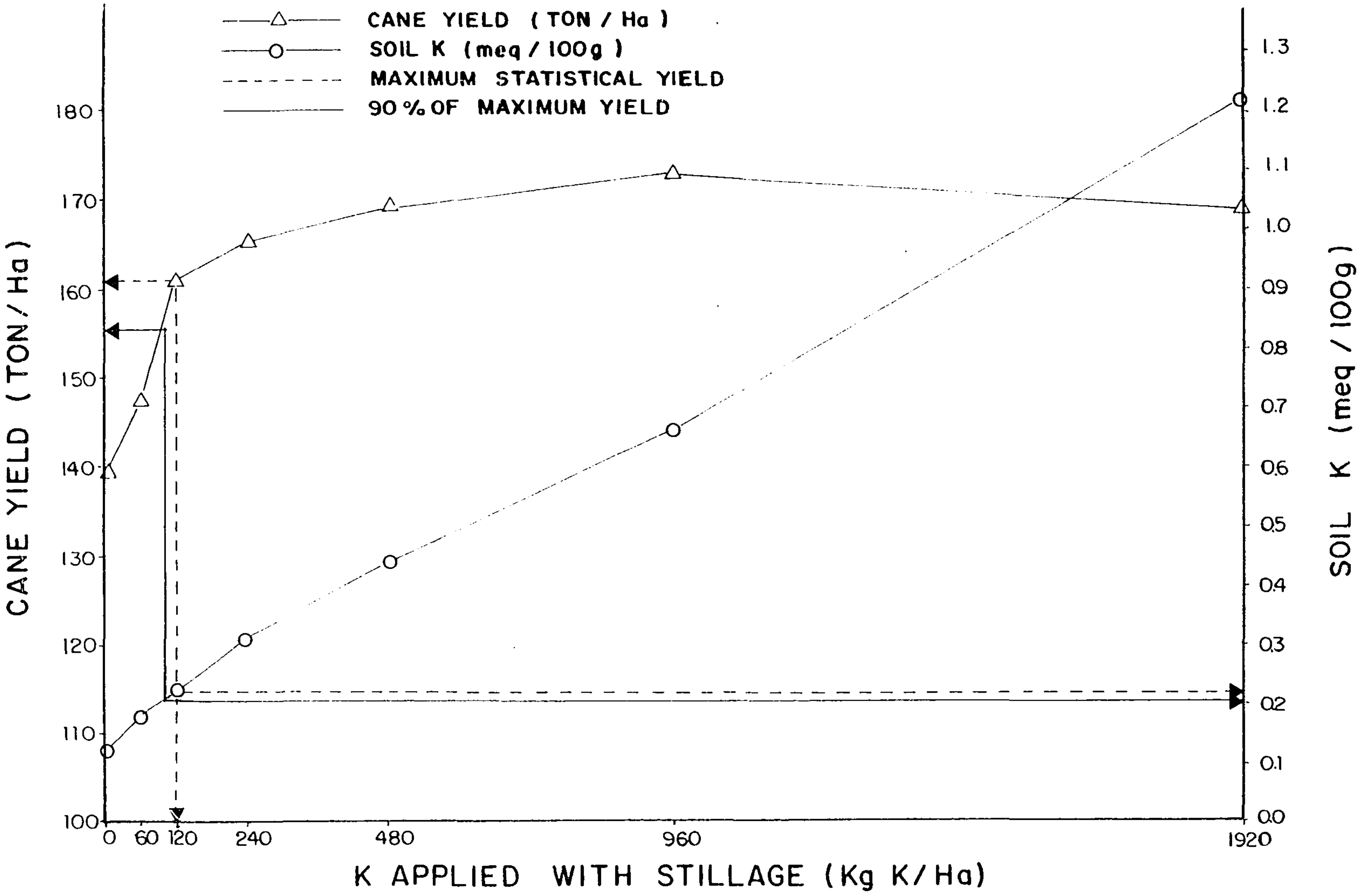

Figure 12. Relationship between applied K, cane yield, and soil K.

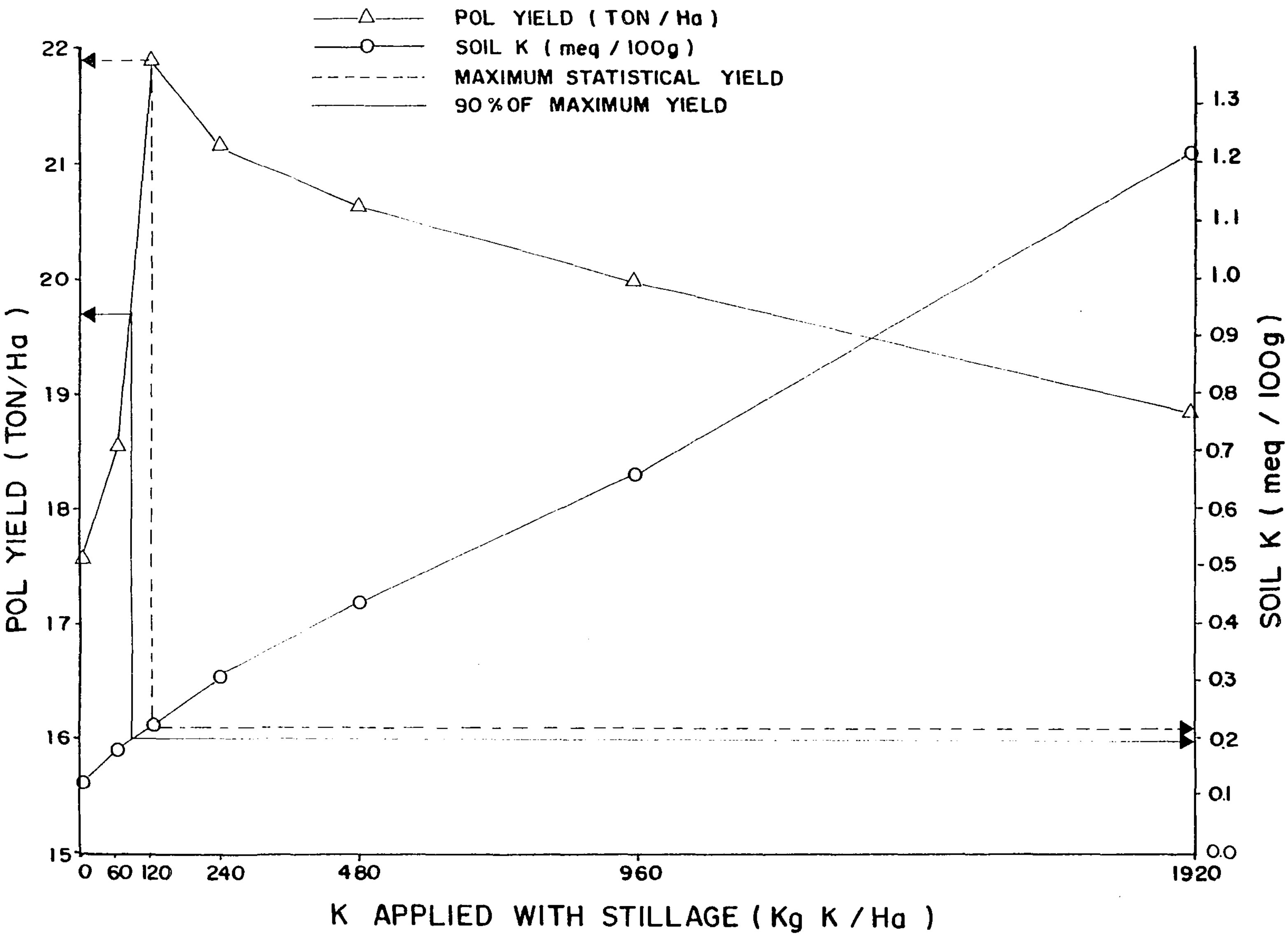

Figure 13. Relationship between applied K, Pol yield, and soil K.

several critical soil K levels for sugarcane: 100 ppm for Hawaii, 66 to 75 ppm for Trinidad, 78 ppm for Australia, and 125 ppm for Barbados. These levels agree very closely with the values determined in the present study.

More recently, Orlando Filho (1982) suggested a critical soil K level of 80 ppm for production of 90% of maximum sugarcane yield. In the present study, value of approximately 0.20 meq K/100 g (78 ppm) was found necessary to produce 90% of the maximum yields of cane and sugar (Figures 12 and 13). This is in close agreement with the reported critical levels.

These results suggest that soil analysis, together with a yield response curve for sugarcane to K fertilization, can be used to determine the amount of K from stillage to be applied to supply optimum K to sugarcane. However, if higher amounts of stillage are to be applied (disposal of excess stillage) other factors such as salinization of the soil and decreased sugar yields must be considered in establishing the upper limit of application rates.

Soil Ca

Soil Ca at 15 days after treatment increased in proportion to the amount of stillage applied broadcast or in the furrow (Figure 14), although this increase was not significant (Table 17). The addition of KCl also did not change soil Ca at 15 days (Table 17). These results are in agreement with those of many other studies (Almeida, 1952; Briegger, 1977; Magro, 1978; Nunes, 1979).

The Ca content of stillage alone may not account for the increase in soil Ca. One possible explanation is that sugars added with

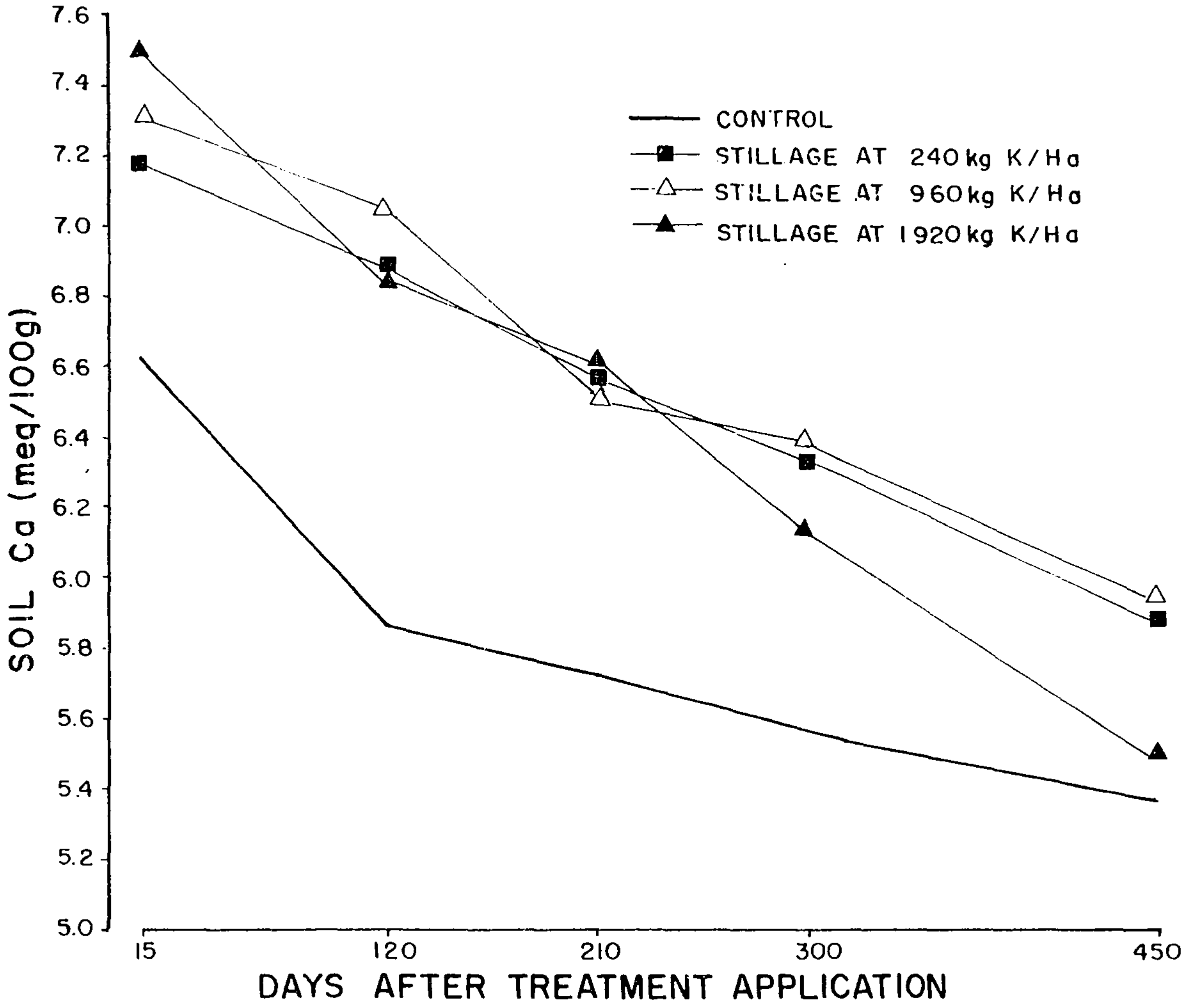

Figure 14. Changes in soil Ca during the crop at the 0-20 cm depth with increasing stillage broadcast rates.

stillage provided energy for soil microorganisms which multiplied and released CO_2 that likely formed H_2CO_3 which can solubilize added dolomite. This high microbiological activity especially in the first 2 weeks after stillage application (Amaral Sobrinho, 1983) may have contributed to the formation of H_2CO_3 in the soil micro environment through the reactions:

$$CO_2^{\dagger} + H_2O \rightleftarrows H_2 + CO_3^{=} \rightleftarrows H^+ + HCO_3^- \qquad (8)$$

According to Amaral Sobrinho (1983) quantities of CO_2 evolved reached approximately 400, 550, 600, and 650 mg CO_2/g of soil for stillage rates of 100, 200, 400, and 800 m^3/ha, respectively. Some studies also showed that microbial activity after addition of stillage can solubilize P from rock phosphate (Projeto UFRRJ - Dep. Solos - FINEP, 1981). In addition, the initial pH of stillage was low, and also contributed to the solubilization of dolomite.

Soil Ca decreased with time, and the largest decrease occurred at the highest stillage rate (Figure 14). The decrease in Ca content between the 15- and 450-day sample from the 0-20 cm depth was 1.27, 1.39, and 2.05 meq/100 g of soil with stillage rates of 0, 960 and 1920 Kg K/ha, respectively. This suggests that relatively high amounts of Ca leach out of the soil only when very high rates of stillage are applied.

Soil Ca at the 0-20 cm depth decreased for the control and 1920 Kg K/ha treatments while Ca increased at the 20-40 cm depth for these two treatments at 120 days (Figure 15). However, the increase

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[†] liberated by microorganisms.

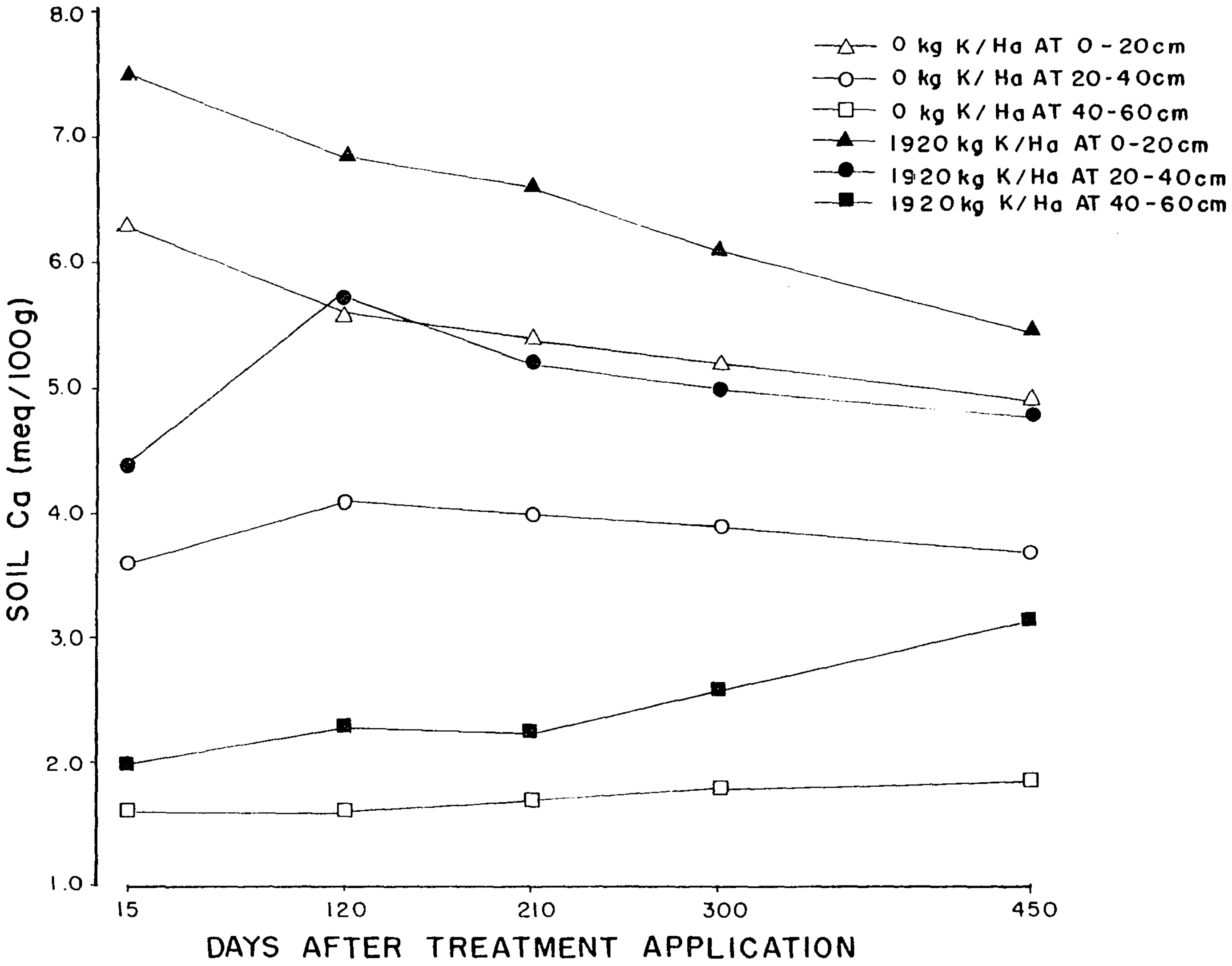

Figure 15. Changes in soil Ca during the crop at the 3 depths with application of the highest stillage broadcast rate (1920 Kg K/ha).

in soil Ca in the 20-40 cm depth was much larger for the 1920 Kg K/ha stillage treatment than for the control. Furthermore, the decrease in soil Ca in the 20-40 cm depth was accompanied by a comparable Ca increase in the 40-60 cm depth after 210 days. High stillage rates appear to increase leaching of Ca. The accumulation of Ca compared to the lack of accumulation of K in lower depths may also support the findings of Bittencourt et al. (1977) that the clay fraction in this soil has a higher affinity for Ca over K.

Nunes (1979), studying the effects of stillage rates on leaching of soil nutrients, found that even low rates of stillage caused leaching of Ca and Mg from soil columns. However, he used soil which had a lower CEC than the soil used in the present experiment, which probably favored leaching.

It seems that the source of K had no effect on Ca leaching (Figure 16). For the 120 and 480 Kg K/ha treatments, the rates of Ca leached out of the 0-20 cm depth were 1.20 and 1.38 meq/100 g, respectively, for stillage treatments and 1.20 and 1.40 meq/100 g, respectively, for KCl treatments during the cropping period. It should be noted that soil Ca in the stillage treatments was somewhat higher than that in KCl treatments because Ca was added with stillage and also probably due to solubilization of dolomite.

These results suggest that for soils low in Ca, high rates of stillage can cause nutrient imbalance with possible consequences on crop growth and yields.

Soil Mg

Increasing stillage rates either broadcast or in the furrow significantly increased soil Mg levels (Table 17; Figure 17), but addition of KCl did not have any significant effect on soil Mg concentration in

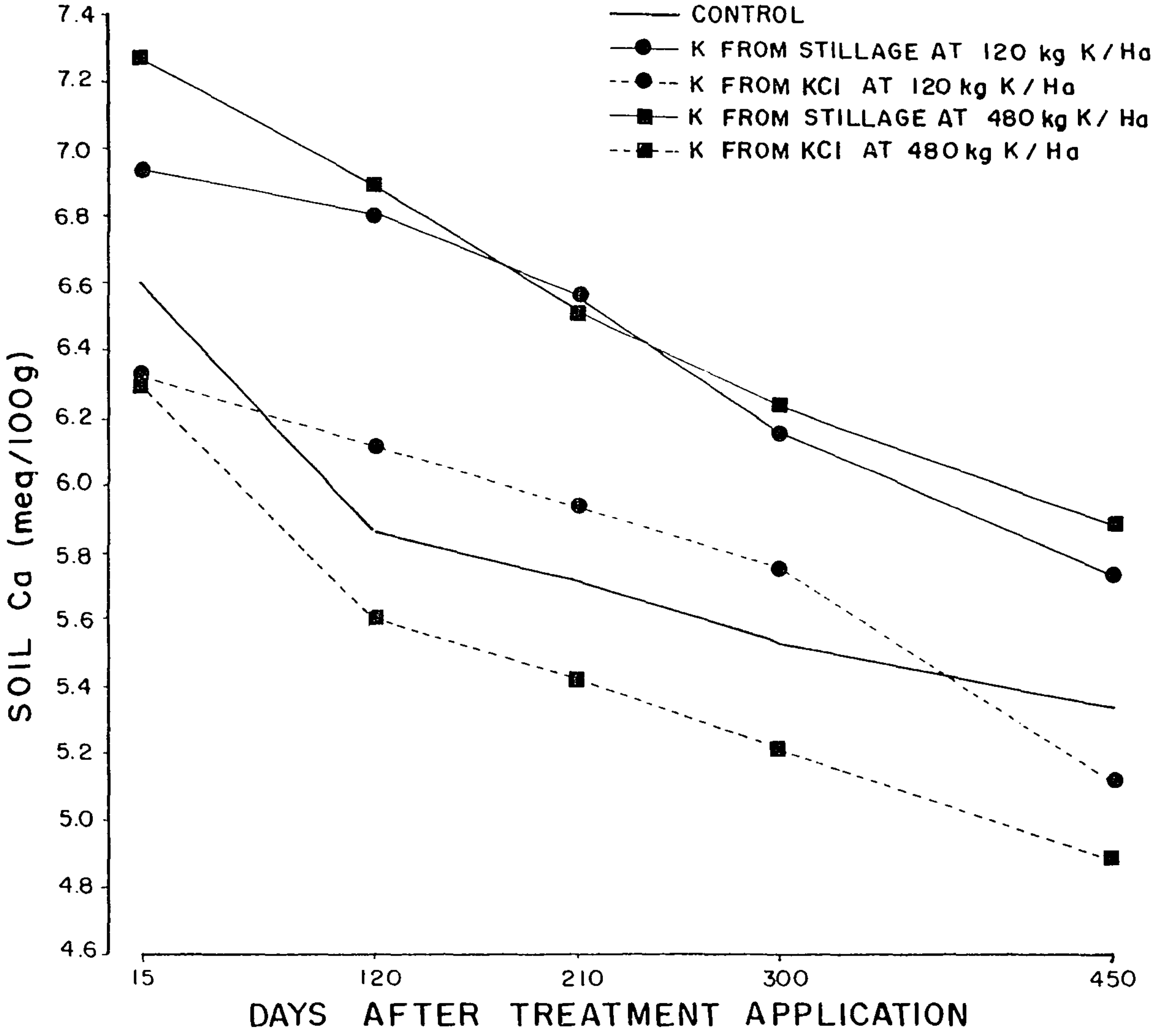

Figure 16. Changes in soil Ca during the crop at the 0-20 cm depth with stillage and KCl broadcast application.

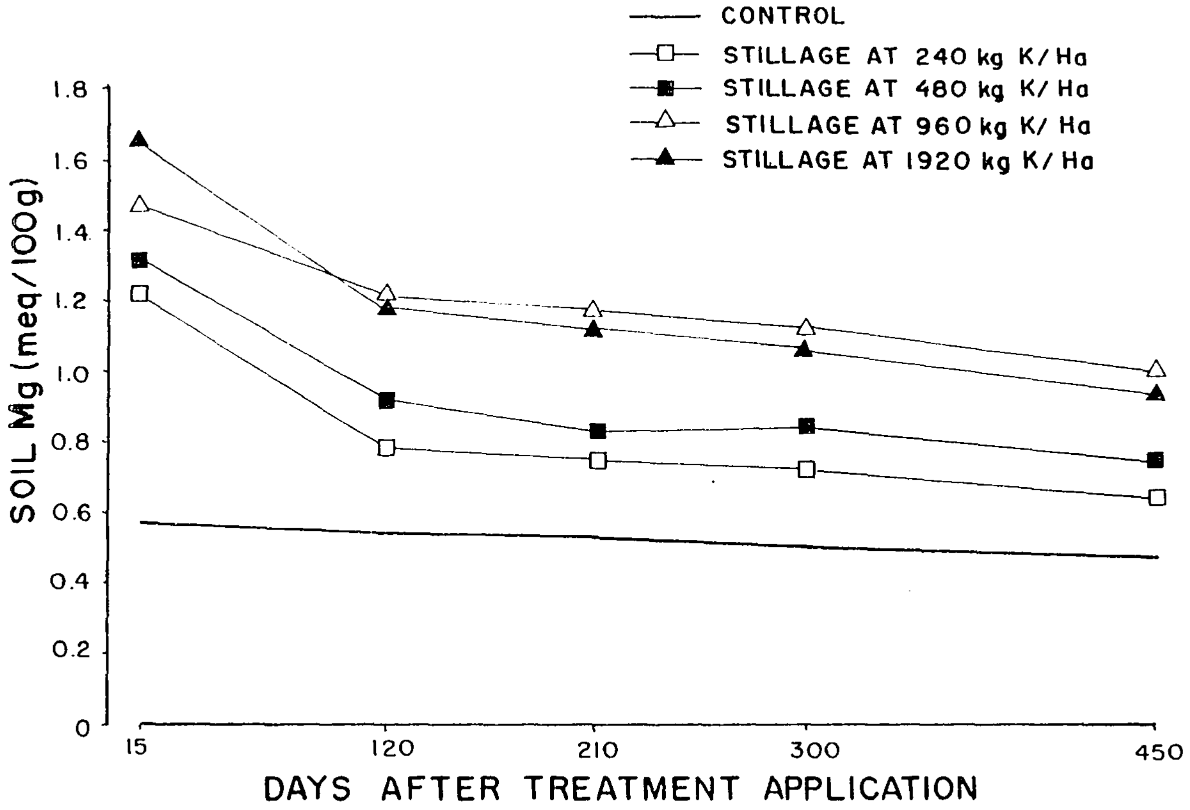

Figure 17. Changes in soil Mg during the crop at the 0-20 cm depth with increasing stillage broadcast rates.

the first sample (Figure 18). Similar results have also been reported by other researchers (Almeida, 1952; Brigger, 1977; Magro, 1978; Nunes, 1979). The difference observed in soil Mg between the stillage and KCl treatments is due to the Mg added in stillage to the soil.

As previously discussed for Ca, the Mg added in stillage alone may not be sufficient to account for the increase in soil Mg. The additional Mg was probably supplied by solubilization of dolomite as a result of microbiological activity since dolomite contains Ca and Mg.

However, Nunes (1979) found in a pot study of the effects of addition of stillage alone on levels of soil nutrients, that increases in soil Ca and Mg exceeded the levels added in stillage. He was unable to find any explanation for these results.

The curves in Figure 17 suggest that Mg decreased with time, and apparently the large drop was with the highest stillage rate. The differences in Mg content between the 15- and 450-day samples were 0.09, 0.55, 0.57, 0.60, and 0.71 meq/100 g of soil, for K rates from stillage broadcast of 0, 240, 480, 960, and 1920 Kg K/ha, respectively. If the total amounts leached are related to the total amounts of Ca and Mg in soil, it is apparent that relatively larger amounts of Mg were lost in relation to Ca. The leaching losses for Ca, Mg, and K during the 450-day period for the 1920 Kg K/ha stillage rate from the 0-20 cm depth was 20.8, 39.0, and 65.5%, respectively, of the amount of the cation present in the 15-day sample. However, it should be mentioned that even though total uptake was not considered it would not materially change the relative order of the leaching losses of these cations. These findings give further support to the suggestion made in the section on soil K that the susceptibility to leaching appeared

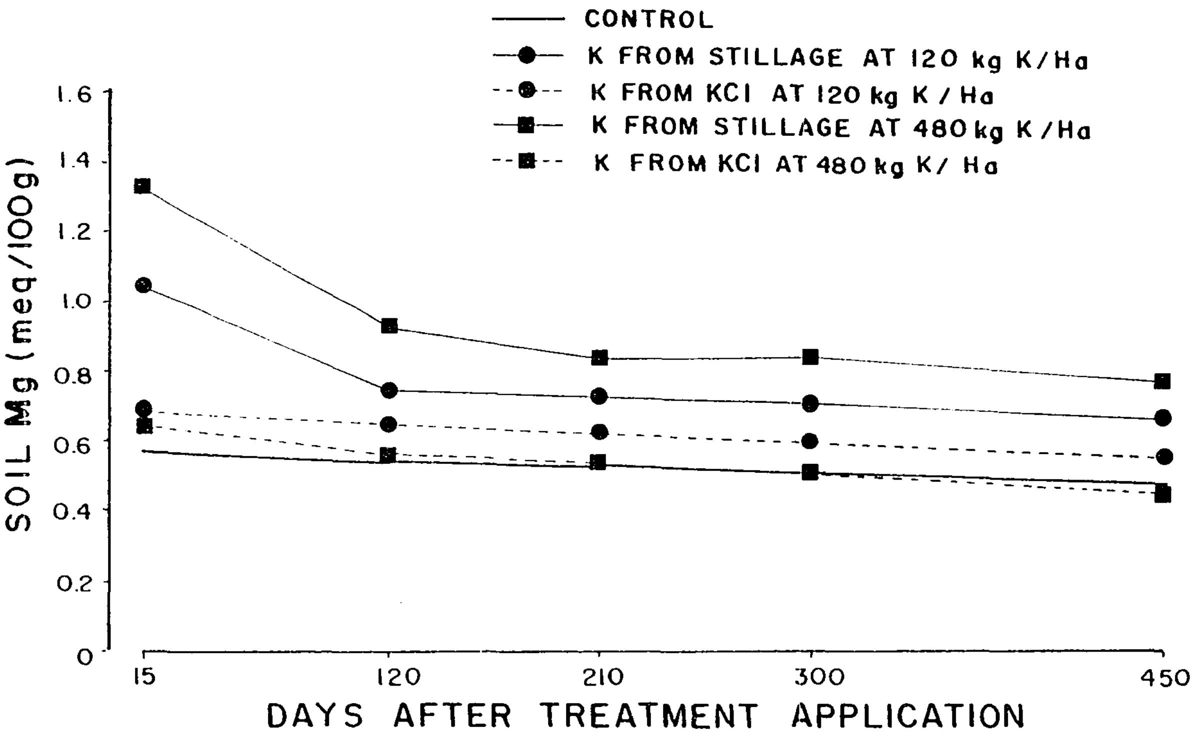

Figure 18. Changes in soil Mg during the crop at the 0-20 cm depth with stillage and KCl broadcast application.

to be in the order K > Mg > Ca. Nunes (1979) also reported that proportionately more Mg than Ca was lost by leaching following stillage application. Hossner et al. (1970) observed that Ca and Mg contents of soils were decreased by application of high rates of K. Cordeiro (1978) stated that there is a predominance of Ca over Mg in the competition for negative charges of the soil exchange complex. Therefore, this would imply that Mg is more susceptible to leaching than Ca.

Leaching of Mg is illustrated in Figure 19 by the decrease in soil Mg from the 0-20 cm depth with an increase in soil Mg at depths of 20-40 and 40-60 cm. These results indicate that Mg was leached out of the 0-20 cm layer and accumulated in the lower layers, as was also observed for Ca, but not for K.

It is interesting to observe Figure 18 that there was greater leaching of Mg in the stillage treatments than in the KCl treatments. For the 120 and 480 Kg K/ha treatments the quantities of Mg leached from the 0-20 cm depth were 0.49 and 0.57 meq/100 g for stillage and 0.14 and 0.19 meq/100 g for the KCl treatments, respectively. On the other hand, there appears to be no difference in the amount of Ca lost by leaching from the KCl and stillage treatments (Table 17). However, it should be pointed out that soil Mg levels at the end of the crop were generally higher for stillage than for KCl treatments (Table 17). These results seem to indicate that although stillage added Mg to the soil, a large percentage of it appears to be lost through leaching from the 0-20 cm layer. The high Ca saturation of this soil (90% of total exchangeable bases) may be interfering in this nutrient balance since, as already mentioned, there seems to be a higher affinity by the clay

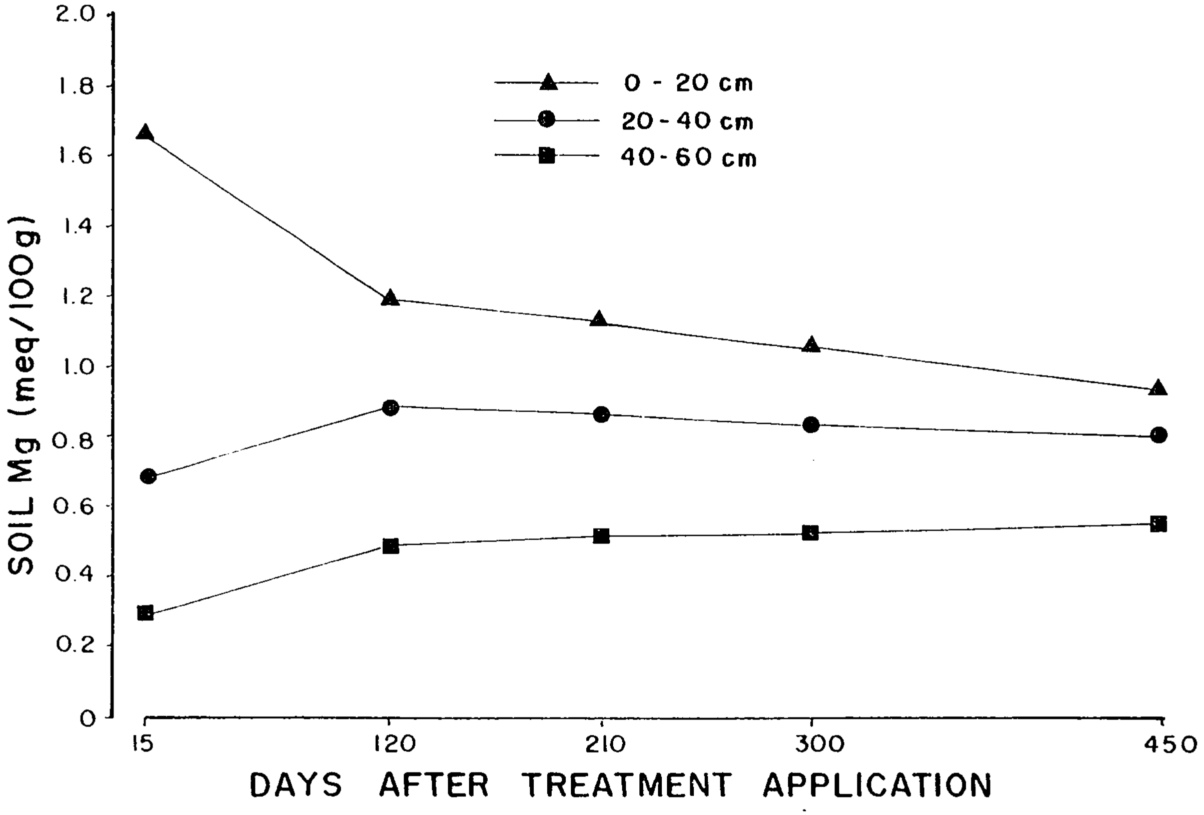

Figure 19. Changes in soil Mg during the crop at 3 depths with application of the highest stillage broadcast rate (1920 Kg K/ha).

to absorb Ca than Mg. Also the lower amounts of leaching of K in the stillage treatments resulted in higher soil K concentration which may have competed with Mg, thereby increasing its leaching rate.

It should be pointed out that dolomite treatments had higher soil Mg levels which may provide a more favorable balance for these cations, and may in turn favor crop growth.

Soil P and Soil Na

Data for soil P and soil Na were not presented since there were no significant differences in their levels. This would be expected since their concentrations in stillage are very low. These findings are in agreement with those of other studies on stillage (Almeida, 1952; Brieger, 1977; Nunes, 1979).

EFFECTS OF STILLAGE APPLICATION ON NUTRIENT CONCENTRATION OF INDICATOR TISSUES

Different tissues are used to evaluate the nutritional status of sugarcane in different countries. In Brazil the tissue most commonly used is the +3 leaf whereas in Hawaii it is leaf blades and sheaths 3, 4, 5, and 6 (Clements's Crop Log). Therefore, both groups of tissues were used in this study. In addition, the 8, 9, and 10 internodes were sampled since it is known to be a very sensitive tissue for certain nutrients (Humbert, 1968).

K Concentration and Total Uptake

Increasing levels of K from either stillage broadcast or in the furrow, or KCl, resulted in significant increases in the K concentration of +3 leaf, 3-6 sheath, and 8-10 internode samples collected at 4 and 10 months of age. The total uptake of K was also significantly increased (Table 20).

It is interesting to observe in Table 20 that K concentrations of the +3 leaf and 8-10 internodes dropped from the 4-month to 10-month sample, with K from stillage broadcast or in the furrow or KCl. K in the +3 leaf from the control treatment remained the same. The larger decrease in K concentration at the higher rates of K may have reflected the decrease in soil K which was also larger for the higher rates of K as discussed previously.

According to Samuels (1969) age has an effect on nutrient concentration of sugarcane, but supply of nutrient also has a marked effect on nutrient concentration and uptake. However, he reported that K

Table 20. Effects of K from stillage, KCl, and stillage plus dolomite on K concentrations of tissues[†]

K rates (Kg/ha)	Age in Months at Sampling						
	4			10			15
	+3 leaf %	3-6 sheaths %	8-10 int. %	+3 leaf %	3-6 sheaths %	8-10 int. %	Total uptake (Kg/ha)
				K from stillage broadcast			
0	0.91	1.29	0.57	0.91	1.66	0.44	171.4
60	0.98	1.53	0.72	0.96	2.28	0.57	190.8
120	1.12	1.99	1.51	0.98	2.43	0.75	224.5
240	1.19	2.44	1.97	1.04	2.63	1.10	265.9
480	1.28	2.62	2.26	1.06	2.79	1.45	293.4
960	1.32	3.25	2.99	1.10	3.16	1.96	347.6
1920	1.36	3.46	3.81	1.18	3.45	2.28	397.4
MSD[††]	0.15	0.21	0.18	0.12	0.18	0.17	37.6
				K from KCl broadcast			
0	0.91	1.29	0.57	0.91	1.66	0.44	171.4
60	1.02	1.60	0.69	0.95	2.06	0.54	197.9
120	1.12	2.26	1.29	1.01	2.59	0.97	252.6
240	1.16	2.37	1.56	1.04	2.65	1.30	255.8
480	1.28	2.60	1.87	1.07	2.74	1.38	301.6
MSD	0.10	0.14	0.14	0.10	0.17	0.12	36.5
				K from stillage in the furrow			
0	0.91	1.29	0.57	0.91	1.66	0.44	171.4
60	1.10	1.68	0.68	0.93	2.14	0.61	195.8
120	1.12	1.93	0.94	0.94	2.27	0.78	212.3
240	1.15	2.25	1.35	0.97	2.53	1.10	287.7
480	1.21	2.65	2.07	1.02	2.74	1.37	334.4
MSD	0.09	0.14	0.15	0.07	0.21	0.14	31.2
				K from stillage broadcast + dolomite			
480	1.25	2.72	2.26	1.04	2.89	1.46	297.2
960	1.28	3.04	2.84	1.07	3.05	1.57	286.7

[†] Values are means of five replicates.

[††] MSD = Minimum Significant Difference ($P \leq 0.05$) from the Waller-Duncan Multiple Range Test.

concentration in sugarcane tissues decreased until the cane is 15 months old for irrigated crops, and then increased near maturity. Clements (1980), on the other hand, showed that as the plant ages, its sheath moisture tends to drop while at the same time the total amount of K in the plant continues to increase. Hence, K concentration in sheaths rises near maturity.

The concentration of K in the +3 leaf and 8-10 internodes decreased with age, but 3-6 sheath K concentration increased, especially with 0 to 480 Kg K/ha (Table 20). In addition, the magnitude of the increase was larger for the 0, 60, and 120 Kg K/ha than for the 240 and 480 Kg K/ha rates (Table 20). These differences in the patterns of K concentration in the +3 leaf, 3-6 sheahts, and 8-10 internodes may be explained on the bases of the water status of the plant.

Concentration of K in the sheaths is known to be affected by moisture level. The sheaths are very sensitive to changes in water status of the plant and for this reason are used as an indicator tissue for plant moisture (Clements, 1980). Generally percent sheath moisture increases with increasing K rates from either stillage or KCl,at 4 and 10 months of age (Table 21). This relationship between K fertilization and water status has been reported by Humbert (1968). Clements (1980) also pointed out that one of the effects of K deficiency is lowering the moisture content of the plant. However, percent sheath moisture was lower at 10 months than at 4 months of age in all K rates (Table 21). Although sheath moisture decreases with age in this case, age alone may not have accounted for the drop because very dry weather caused irrigation to be inadequate prior to

Table 21. Changes in percent sheath moisture with increasing rates of K[†]

K rates (Kg K/ha)	Sheath Moisture (%)	
	4 months	10 months
	K from stillage	
0	81.5	75.6
60	82.3	76.0
120	83.1	76.0
240	83.5	76.3
480	83.8	77.0
960	83.7	78.6
1920	84.1	78.2
MSD[††]	2.0	2.3
	K from KCl	
0	81.5	75.6
60	80.6	74.8
120	82.5	74.3
240	83.2	75.5
480	83.1	76.9
MSD	2.0	2.3

[†] Values are means of five replicates.

[††] MSD = Minimum Significant Difference ($P \leqslant 0.05$) from the Waller-Duncan Multiple Range Test.

the 10-month sample (Table 2). The resulting water stress probably contributed to the decrease in sheath moisture between 4 and 10 months. Therefore, 3-6 sheath K concentration may have increased due to this water stress, especially in the lower K rates (Table 20) where sheath moisture was lower (Table 21) and growth may have been somewhat more reduced. Clements (1980) has reported that K concentration of sheaths increases strikingly during a drought, first, because with reduced growth K accumulates and, second, because with reduced moisture the apparent K concentration rises.

These relationships between sheath K and moisture limit its use for assessing the K level in plants under unirrigated conditions, since a water deficit can cause an increase in sheath K levels resulting in misleading interpretations. The concentration of K in the 8-10 internodes and +3 leaf appears to be less sensitive to small changes in water status of the plant, and therefore from this standpoint would appear to be better for assessing plant K levels under unirrigated conditions.

Increasing levels of stillage broadcast resulted in increasing tissue K concentrations, although the incremental increase in K concentration decrease at the higher rates of stillage (Figures 20 and 21). The effects of added K are largely linear for 3-6 sheath and 8-10 internode K concentrations at the lower K rates; however, at the highest K rates tissue K increases more gradually. Therefore, regression equations describing these relationships include the square root of applied K (Table 22). Cane yield responses to applied K were similar to responses observed in tissue K (Figure 21), although the response was generally linear only for the first two K increments, thereafter

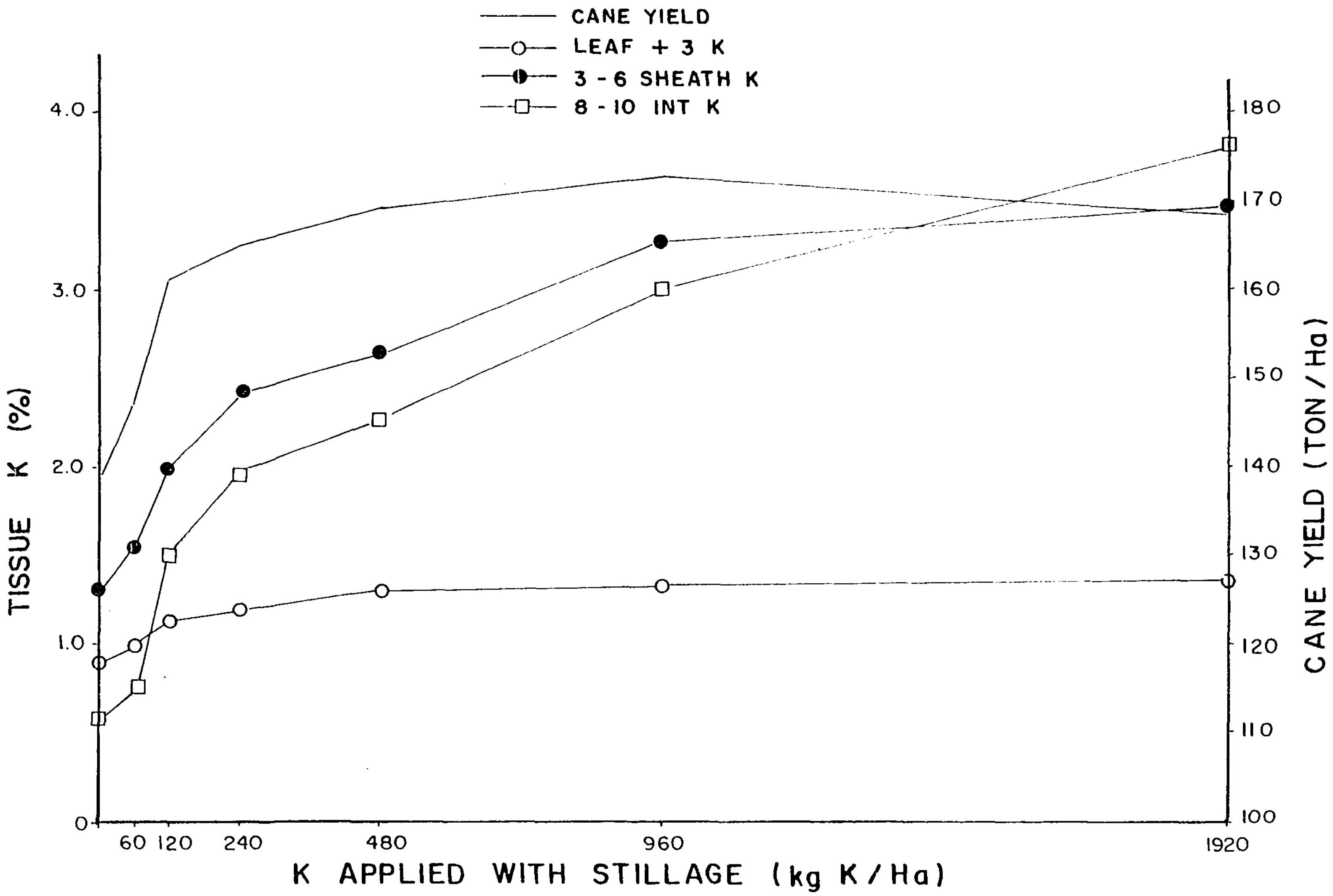

Figure 20. Effect of stillage broadcast rates on K concentrations in sugarcane tissues at 4 months of age and total cane yields.

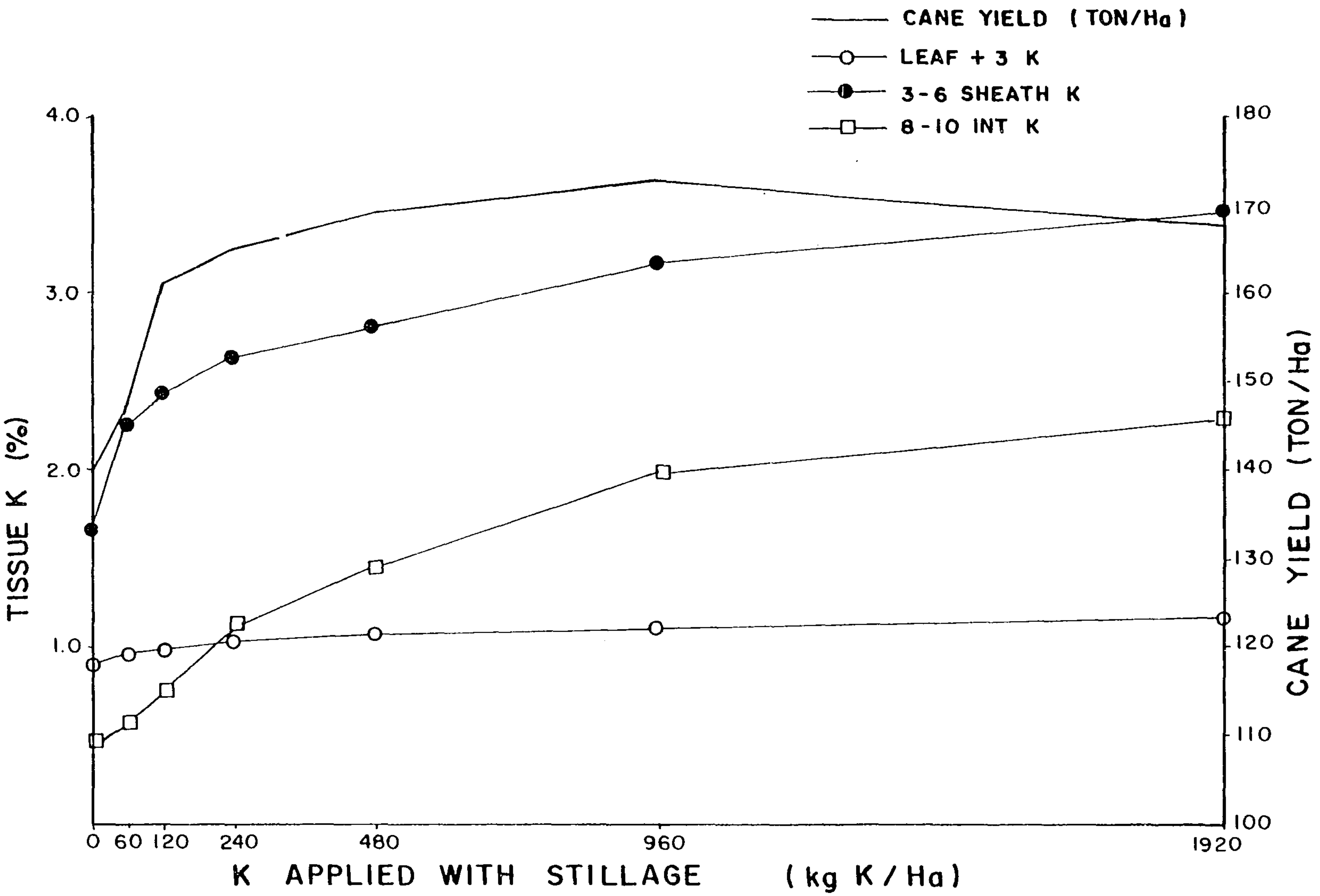

Figure 21. Effect of stillage broadcast rates on K concentrations in sugarcane tissues at 10 months of age and total cane yields.

Table 22. Regression equation describing the effect of added K from stillage broadcast on cane yield and K concentration in tissues of 4- and 10-month old sugarcane[†]

4-month old sugarcane (Figure 20)

+3 leaf K = $0.0884 + 0.023\ K^{1/2} - 0.0003\ K$
$R^2 = 0.81^{****}$

3-6 sheath K = $1.190 + 0.072\ K^{1/2}$
$R^2 = 0.90^{****}$

8-10 int. K = $0.443 + 0.086\ K^{1/2}$
$R^2 = 0.94^{****}$

10-month old sugarcane (Figure 21)

+3 leaf K = $0.919 + 0.006\ K^{1/2}$
$R^2 = 0.59^{****}$

3-6 sheath K = $1.121 + 0.066\ K^{1/2} - 0.001\ K$
$R^2 = 0.90^{****}$

8-10 int. K = $0.414 + 0.016\ K^{1/2} + 0.002\ K$
$R^2 = 0.97^{****}$

15-month old sugarcane (harvest)

Total K uptake = $167.6 + 5.483\ K^{1/2}$
$R^2 = 0.77^{****}$

[†] n = 35

****Significant at .01% level.

yields increased at a decreasing rate witb a decrease at the highest K rate. The pattern of response of +3 leaf K concentration to added K was similar to that of cane yield, especially in the 4-month old sample (Figure 20). At 4 months, +3 leaf K increased linearly with the first two K increments and then more gradually thereafter (Figure 20), whereas at 10 months, the increase in +3 leaf K were very small but almost linear with increasing K (Figure 21). This overall pattern is probably the reason cane yield is most highly correlated with +3 leaf K concentration. Total uptake prediction equation included the square root term probably because K uptake increased but not in direct proportion to increasing K applied.

Correlation coefficients for the relationships between tissue K concentration, rates of K applied, and K level in the soil were highest for 8-10 internodes, followed by the 3-6 sheaths, and lowest for the +3 leaf in both the 4- and 10-month samples (Table 23). Apparently the 8-10 internode sample is the most sensitive to available K (applied and soil K) while the +3 leaf sample is the least sensitive and the 3-6 sheaths are intermediate. The small change in K concentration in the +3 leaf K with applied K would account for its having the lowest correlation coefficient of the three tissues with applied K (Table 23).

The 8-10 internodes which were the most highly correlated with applied K had the lowest correlation with cane yields among the three tissues for both the linear (Table 23) and square root models (Table 22). This is due to the relatively larger increases in 8-10 internode K than in cane yield with increasing K rates.

Table 23. Correlation coefficients for cane and sugar yields, total K uptake, soil K rates of K from stillage broadcast and tissue K concentration in 4- and 10-month old sugarcane[†]

	K rates from stillage	Soil K at 120 days	Soil K at 300 days	Total K Uptake	Cane Yield	Sugar Yield
Cane yield	0.42*	0.49**	0.48**	0.81****	-	0.73****
Total K uptake	0.82****	0.86****	0.86****	-	0.81****	0.35*
4-month old sugarcane						
+3 leaf K	0.72****	0.77****	-	0.91****	0.74****	0.34*
3-6 sheath K	0.84****	0.87****	-	0.95****	0.72****	0.25 ns
8-10 int. K	0.91****	0.93****	-	0.94****	0.66****	0.20 ns
10-month old sugarcane						
+3 leaf K	0.72****	-	0.79****	0.93****	0.74****	0.31 ns
3-6 sheath K	0.83****	-	0.86****	0.92****	0.71****	0.28 ns
8-10 int. K	0.92****	-	0.91****	0.93****	0.63****	0.12 ns

[†] n = 35

*Significant at 5% level.

**Significant at 1% level.

***Significant at .1% level.

****Significant at .01% level.

ns Nonsignificant

Sheath K was not as well correlated with K rates as was 8-10 internode K but, on the other hand, it was more highly correlated with cane yields than 8-10 internode K (Table 23). This is probably related to the more gradual increase in sheath K with increasing K rates than that of the 8-10 internodes as already discussed and, therefore, more closely followed the response of cane yield.

Total K uptake was highly correlated with K concentration in the three tissues, with rates of K applied and also with soil K concentration at both sampling dates (Table 23).

Sugar yields were generally poorly correlated with K concentration in the three tissues at both 4 and 10 months (Table 23). Furthermore, no regression model was found to adequately describe the relationship between sugar yields and applied K from stillage broadcast. This is probably due to sugar yields increasing with only the first two K rates and then decreasing thereafter with higher K rates, while tissue K concentrations generally increased with increasing K rates (Figures 22 and 23). This is a typical case of luxury consumption of K.

Based on these results, the 8-10 internodes are probably the best tissue for assessing the K status of soil, followed very closely by the 3-6 sheaths. Since K concentrations in these two tissues are highly correlated with both applied and soil K and also have a wide range of applied K (Figures 20 and 21), they can easily separate deficient from non-deficient plants. Therefore, either tissue may be recommended for assessing plant K status. However, because sheath K is affected by water content, this tissue may be more appropriate for irrigated conditions where water stress is less likely to occur.

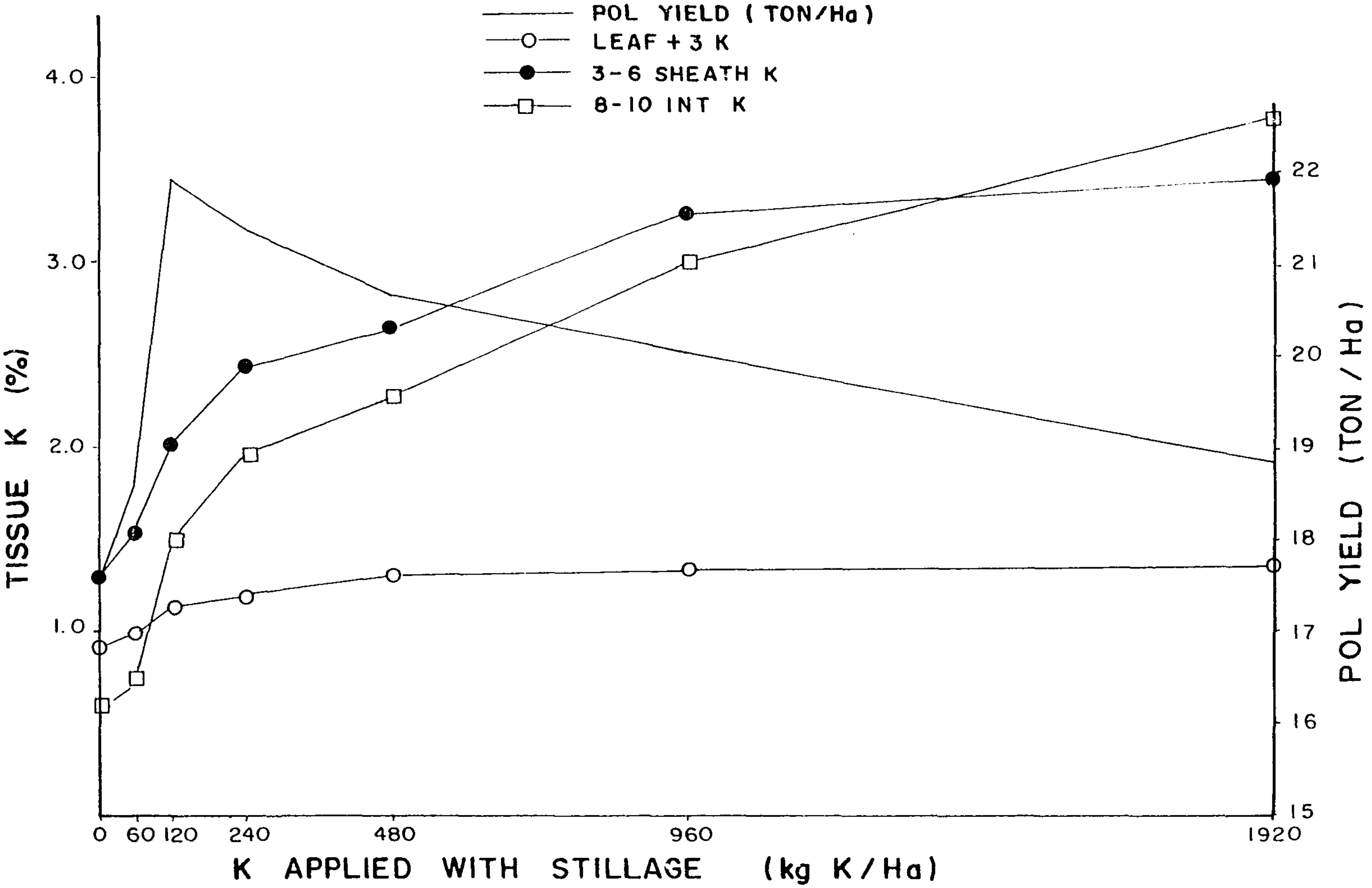

Figure 22. Effect of stillage broadcast rates on K concentration of sugarcane tissues at 4 months of age and yields of sugar.

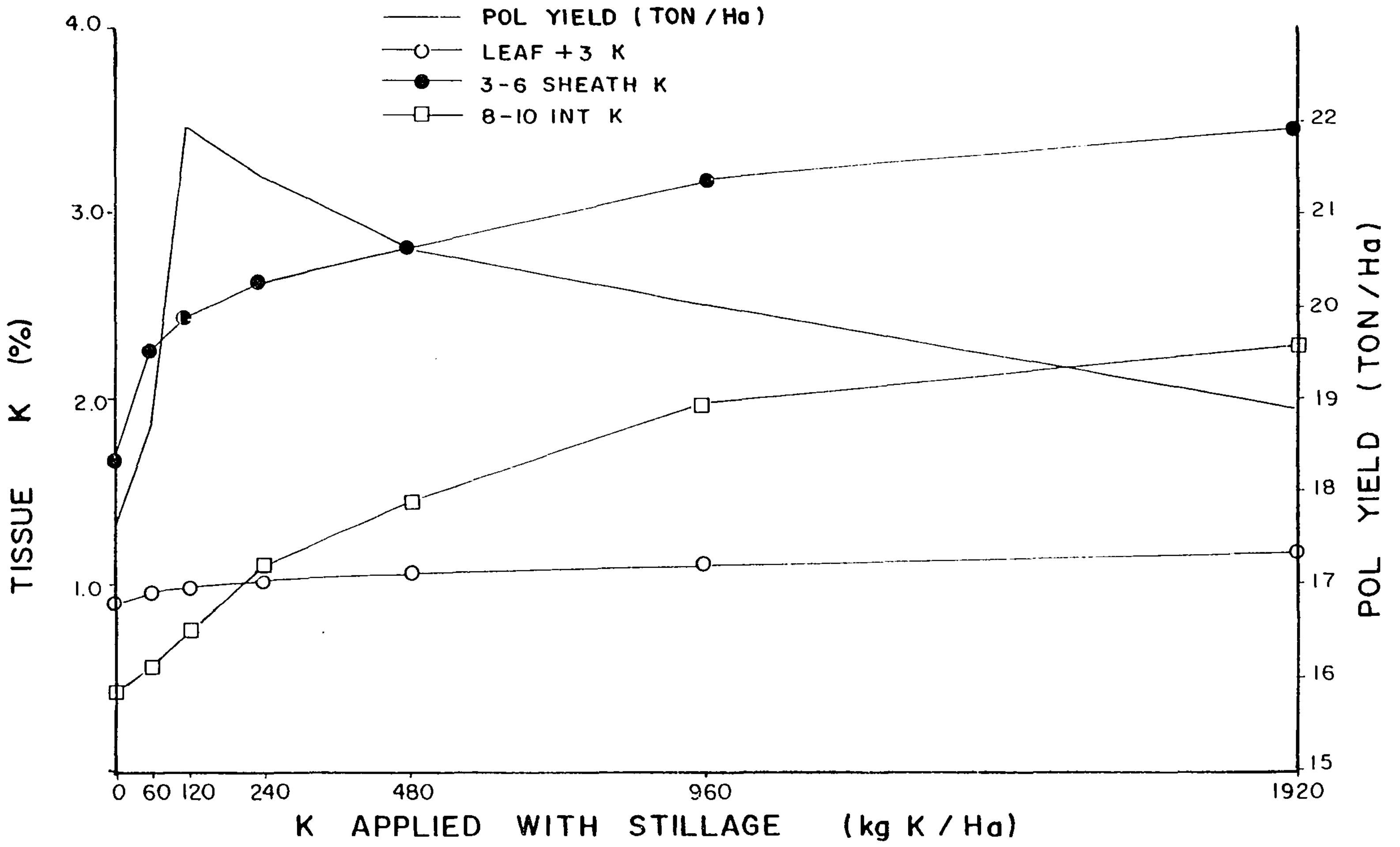

Figure 23. Effect of stillage broadcast rates on K concentration of sugarcane tissues at 10 months of age and yields of sugar.

Although the 8-10 internodes are more difficult to collect, they may be recommended for unirrigated conditions since they appear to be less sensitive than the sheaths to the effects of water stress on K content.

In spite of the fact that the +3 leaf K concentration is highly correlated with cane yield, is relatively easy to collect and relatively unaffected by water stress, it is not as well correlated with soil K and applied K as the other two tissues. Therefore, it is not considered as good an index tissue for K because it has a narrow range of K concentration with increasing rates of applied which make it relatively insensitive to separating K deficient from non-deficient plants.

Effects of Dolomite on K Concentration and Total Uptake

Dolomite generally reduced tissue K concentrations especially at 10 months of age, although the decrease was significant only in the 8-10 internodes (Table 24). Total K uptake also decreased significantly with dolomite application. It should be pointed out that the largest decrease in tissue K and K uptake was at the higher K rate.

This significant decrease in 8-10 internode at 10 months is probably related to the soil K content which was lower with than without dolomite application at comparable K rates, as previously discussed (Table 17). Therefore, since the 8-10 internode K is the most highly correlated with soil K, this tissue may better reflect the changes in soil K than the other tissues. In addition to the effect of dolomite in lowering soil K levels and therefore K uptake, there is some evidence that both Ca and Mg can decrease K absorption by plants (Bower et al., 1944; York et al., 1953; Anderson et al., 1971). Cordeiro (1978) has reported that both Ca and Mg may reduce K

Table 24. Effect of dolomite application on K concentration of sugarcane tissues and total K uptake[†]

	K Concentration (%)		
	+3 leaf	3-6 sheath	8-10 int.
		4 month sample	
480 Kg K/ha SB[††]	1.28	2.62	2.26
960 Kg K/ha SB	1.32	3.25	2.99
480 Kg K/ha SB + dolomite	1.25	2.72	2.26
960 Kg K/ha SB + dolomite	1.28	3.04	2.84
Avg. for K SB	1.30 a	2.94 a	2.62 a
Avg. for K SB + dolomite	1.26 a	2.88 a	2.55 a

10 month sample

	K Concentration (%)			Total K Uptake (Kg/ha) (15 months)
	+3 leaf	3-6 sheath	8-10 int.	
480 Kg K/ha SB	1.06	2.79	1.45	293.4
960 Kg K/ha SB	1.01	2.16	1.96	347.6
480 Kg K/ha SB + dolomite	1.04	2.89	1.46	297.2
960 Kg K/ha SB + dolomite	1.07	3.05	1.57	286.7
Avg. for K SB	1.08 a	2.97 a	1.70 a	320.8 a
Avg. for K SB + dolomite	1.05 a	2.89 a	1.51 b	291.9 b

[†] Values are means of five replicates.

[††] SB = Stillabe Broadcast.

Numbers in the same column followed by the same letter are not significantly different at the 5% level.

absorption, but under some conditions both nutrients can stimulate K absorption.

This decrease in total K uptake with dolomite may significantly improve juice quality by reducing the K content of ash.

Tissue K Concentration in Relation to Cane and Sugar Yields

Maximum statistical yields of cane and sugar were obtained at the 120 Kg K/ha from stillage broadcast application and the three tissues (+3 leaf, 3-6 sheaths, and 8-10 internodes) evaluated in this study, had K concentrations that were near or above their reported critical K levels (Figures 3 and 4).

Samuels (1969) reported critical K levels of 1 to 1.25% for +3 leaf, 2.25% for 3-6 sheaths, and 1.0% for 8-10 internodes for 4- to 6-month old sugarcane. In the present study, tissue K at 4 months was associated with maximum statistical yields of cane and sugar was approximately 1.10, 2.00, and 1.50% for +3 leaf, 3-6 sheaths, and 8-10 internodes, respectively (Figures 24 and 25). Therefore, the critical tissue K levels determined in this experiment are in agreement with those reported in the literature. Sampling at 4 months was chosen because tissues are usually collected for analysis at this age where cane cycle is relatively short (12 to 18 months) as it is in Brazil. However, if the 10-month sample is considered the critical levels (0.98% for +3 leaf, 2.43% for 3-6 sheaths, and 0.75% for 8-10 internodes) found in this study (Figures 26 and 27) are also in agreement with those (1.00 - 1.25% for +3 leaf, 2.25% for 3-6 sheaths, and 0.7 - 0.8% for 8-10 internodes) reported for sugarcane at this age (Samuels, 1969).

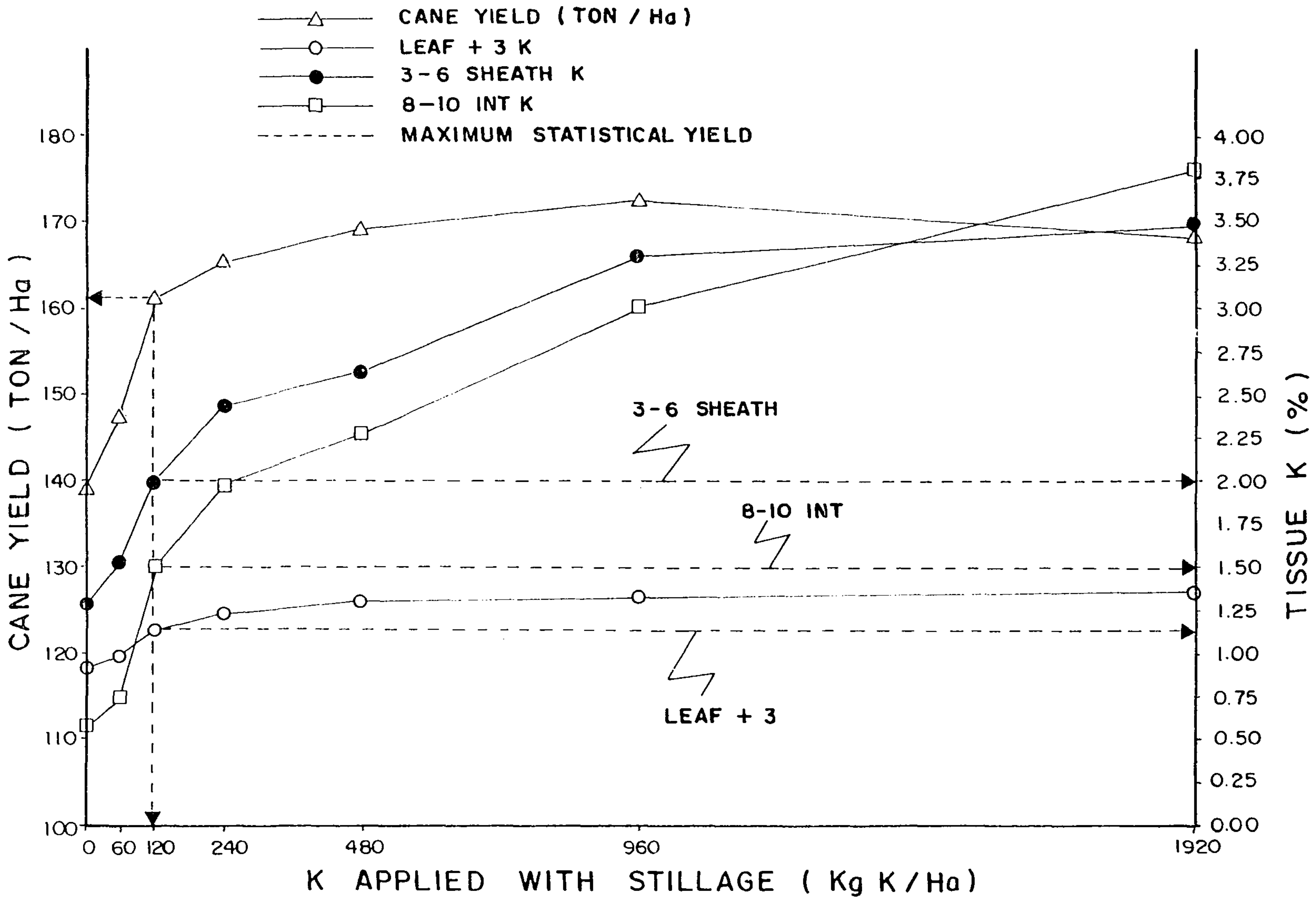

Figure 24. Relationship between applied K, cane yield, and tissue K in 4-month old sugarcane.

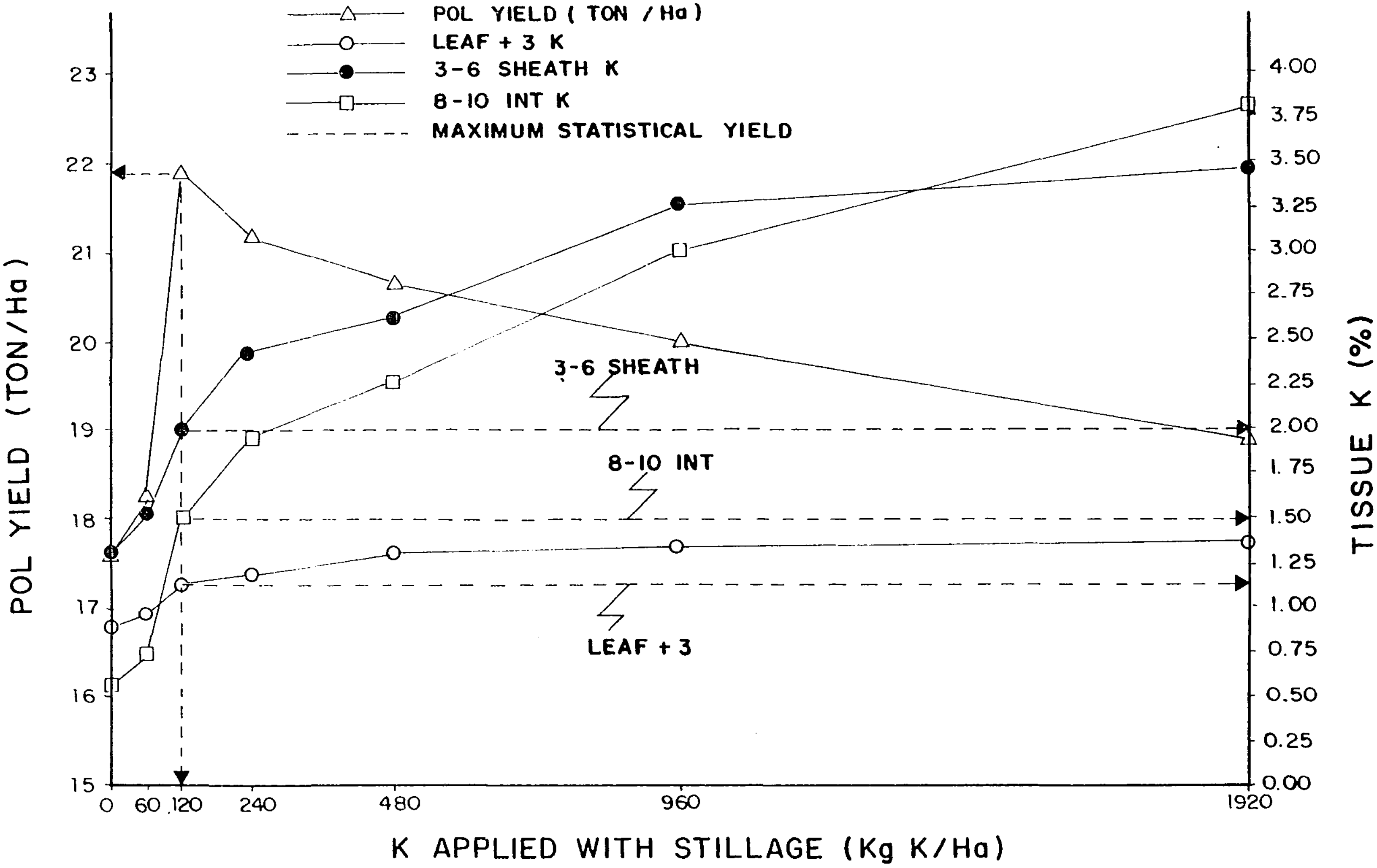

Figure 25. Relationship between applied K, Pol yield, and tissue K in 4-month old sugarcane.

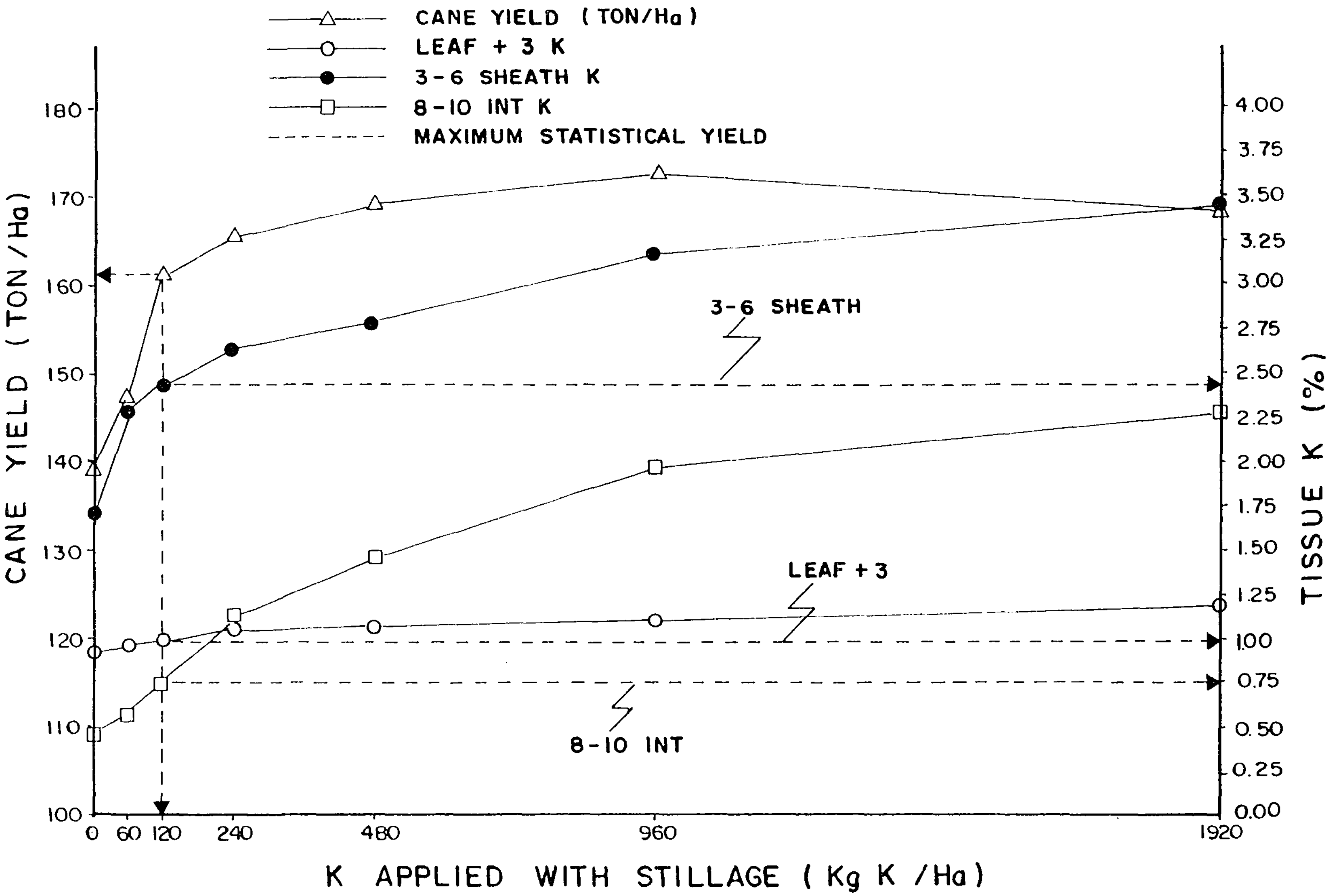

Figure 26. Relationship between applied K, cane yield, and tissue K in 10-month old sugarcane.

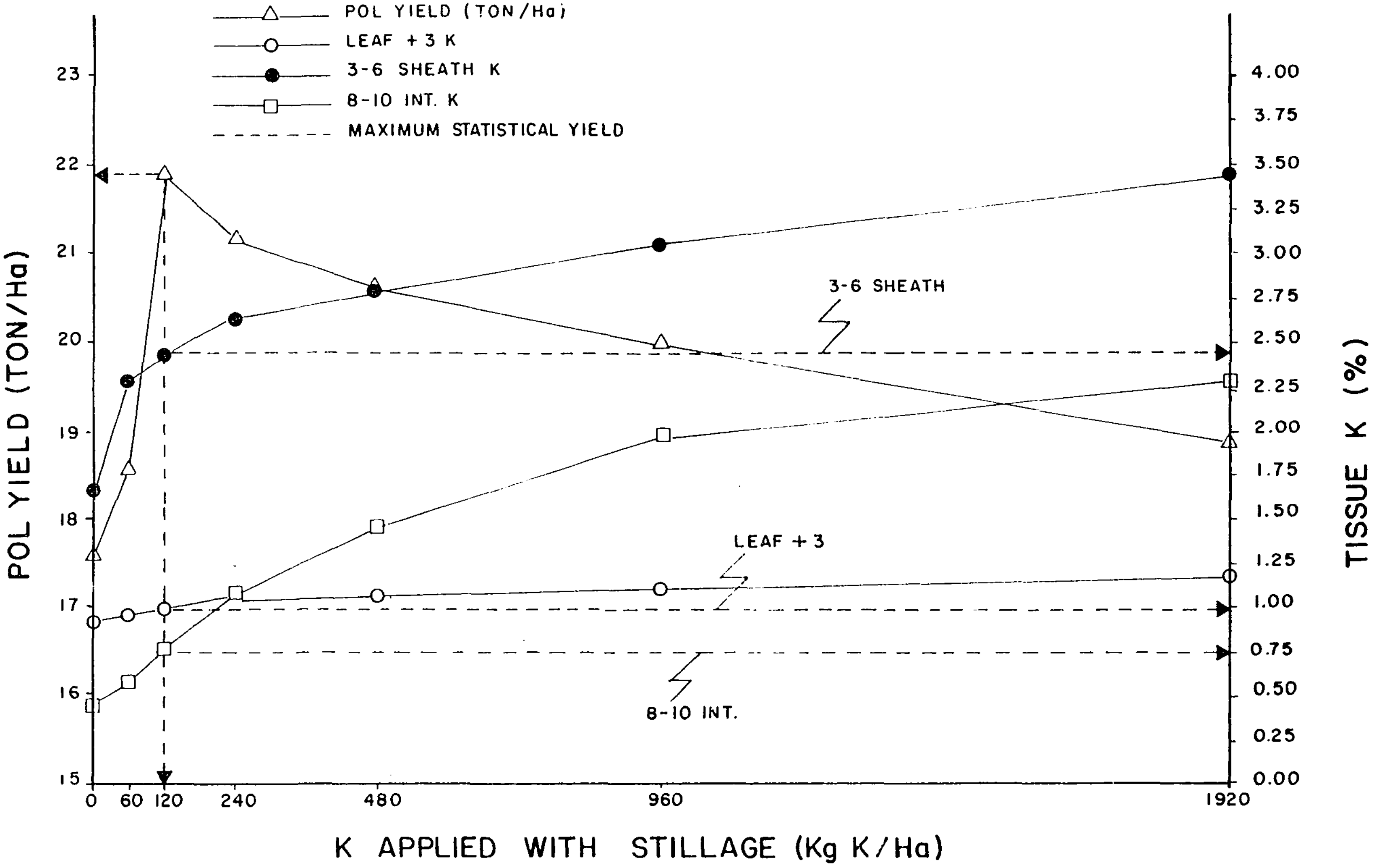

Figure 27. Relationship between applied K, Pol yield, and tissue K in 10-month old sugarcane.

It should be noted that application of 120 Kg K/ha from stillage resulted in soil K and sugarcane tissue K concentrations above the respective critical levels that in both cases were associated with maximum yields. These results indicate that while soil analysis can be very useful for predicting the amounts of K from stillage to be applied, tissue analyses are useful for monitoring the K status of the sugarcane plant.

<u>Regression equations for cane and pol yields in relation to tissue K</u>: Regression equations to predict yields of cane and Pol in relation to tissue concentration of K are shown in Table 25.

The +3 leaf at 4 and 10 months gave the best prediction models for cane yield which included only the quadratic term, probably because both +3 leaf K and cane yield had curvilinear responses with increasing K rates (Figures 24 and 26). However, for Pol yield, the +3 leaf equation resulted in the worst model, in spite of including linear, square root and quadratic terms at 4 months and square root and quadratic terms at 10 months. This may be due to the fact that Pol yield increased sharply between 0 and 120 Kg K/ha, whereas +3 leaf K increased gradually at these K rates. At the higher K rates, +3 leaf K increased gradually while Pol yield decreased (Figures 25 and 27). Therefore, a prediction model which adequately described this relationship could not be developed.

The second best models for cane yield obtained with the 3-6 sheaths at 4 and 10 months included only the square root term (Table 25). This indicates that cane yields increased more gradually than 3-6 sheath K concentration at higher K rates (Figures 24 and 26). The

Table 25. Regression equations describing cane and Pol yields in relation to tissue K concentration (Figures 24, 25, 26, and 27)

4-month old sugarcane

+3 leaf

Total cane yield = 116.719 + 31.434 (+3 leaf K)^{2}
R^{2} = 0.56****

Total Pol yield = - 23.268 + 44.390 (+3 leaf K)$^{1/2}$ + 9.9 (+3 leaf K) - 11.694 (+3 leaf K)^{2}
R^{2} = 0.17*

3-6 sheath

Total cane yield = 89.875 + 46.481 (sheath K)$^{1/2}$
R^{2} = 0.53****

Total Pol yield = - 15.487 + 45.591 (sheath K)$^{1/2}$ - 14.292 (sheath K)
R^{2} = 0.23*

8-10 internodes

Total cane yield = 92.766 + 80.650 (8-10 int. K)$^{1/2}$ - 22.033 (8-10 int. K) + 0.536 (8-10 int. K)^{2}
R^{2} = 0.50****

Total Pol yield = - 2.900 + 41.687 (8-10 int. k)$^{1/2}$ - 19.704 (8-10 int. K) + 1.096 (8-10 int. K)^{2}
R^{2} = 0.31**

10-month old sugarcane

+3 leaf

Total cane yield = - 72.851 + 229.801 (+3 leaf K)^{2}
R^{2} = 0.54****

Total Pol yield = - 96.038 + 147.398 (+3 leaf K)$^{1/2}$ - 31.282 (+3 leaf K)^{2}
R^{2} = 0.17*

3-6 sheath

Total cane yield = 55.058 + 65.357 (sheath K)$^{1/2}$
R^{2} = 0.50****

Total Pol yield = - 11.988 + 25.903 (sheath K)$^{1/2}$ - 1.373 (sheath K)^{2}
R^{2} = 0.20*

8-10 internodes

Total cane yield = - 35.882 + 423.018 (8-10 int. K)$^{1/2}$ - 251.271 (8-10 int. K) + 27.698 (8-10 int. K)^{2}
R^{2} = 0.49****

Total Pol yield = - 20.992 + 95.803 (8-10 int. K)$^{1/2}$ - 59.547 (8-10 int. K) + 6.055 (8-10 int. K)^{2}
R^{2} = 0.28**

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*Significant at 5% level.
**Significant at 1% level.
***Significant at .1% level.
****Significant at .01% level.
ns = nonsignificant

3-6 sheaths also gave the second best models for Pol yield which included square root and linear terms for the 4-month sample and the square root and quadratic terms for the 10-month sample. The equation for Pol yield at 4 months suggests that while Pol yield decreased sharply, 3-6 sheath K increased sharply at the higher K rates (Figure 25). At 10 months there was a sharp decrease in Pol yield with a more gradual increase in 3-6 sheath K at the higher K rates (Figure 27).

The relationships between cane and Pol yields and 8-10 internode K are described by equations which include linear, square root, and quadratic terms at 4 and 10 months. Cane yield and 8-10 internode K followed a similar pattern at low K rates (< 480 Kg/ha); thereafter, the increase in cane yield was relatively lower than that for 8-10 internode K (Figures 24 and 26). Pol yield increased sharply up to 120 Kg K/ha then decreased sharply at higher K rates while 8-10 internode K increased steadily to the highest rate of K at both ages (Figures 25 and 27).

Ca Concentration and Total Uptake

Increasing K levels from stillage applied broadcast (Figures 28 and 29), in the furrow or from KCl generally decreased Ca concentration of the three tissues at both ages (Table 26).

The fact that correlation coefficients for the relationships between applied K or soil K and concentration of Ca in the tissues were all negative (Table 27), indicates that increasing soil K decreases the uptake of Ca by sugarcane.

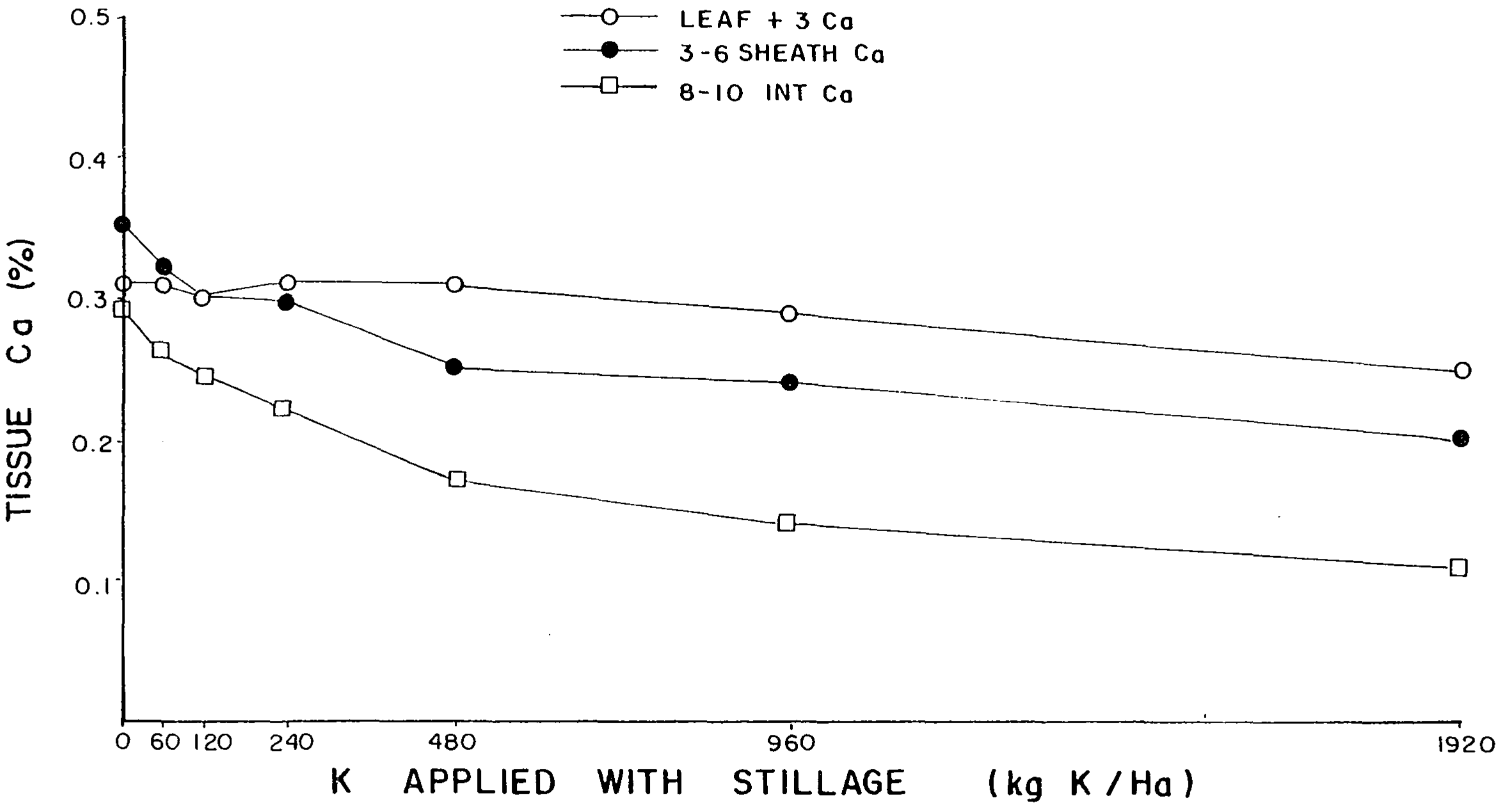

Figure 28. Effect of stillage broadcast rates on Ca concentration of tissues of 4-month old sugarcane.

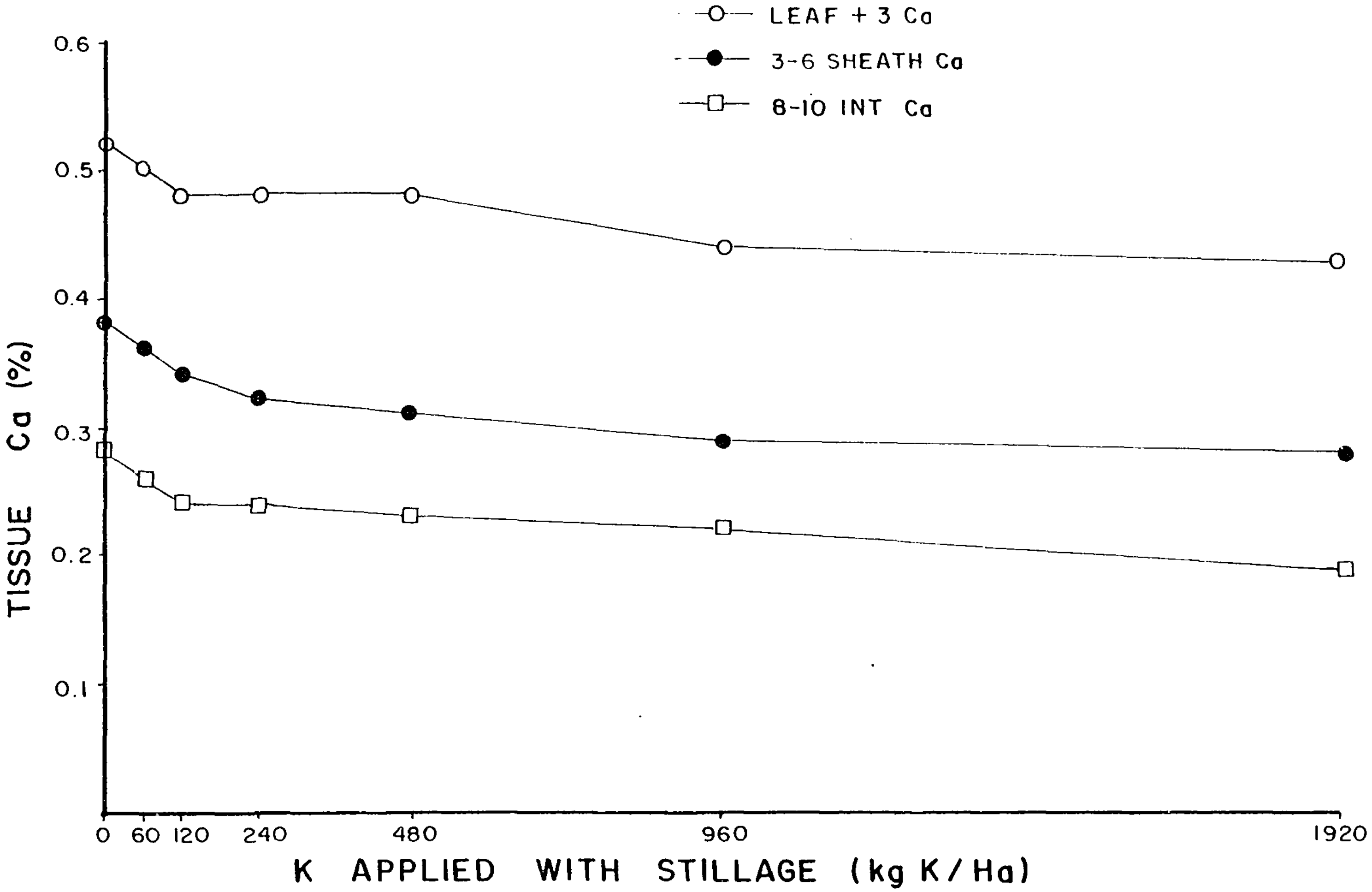

Figure 29. Effect of stillage broadcast rates on Ca concentration of tissues of 10-month old sugarcane.

Table 26. Effect of K from stillage, KCl, and stillage plus dolomite on Ca concentrations of tissues[†]

K Rates (Kg/ha)	Age in Months at Sampling						
	4			10			15
	+3 leaf %	3-6 sheaths %	8-10 int. %	+3 leaf %	3-6 sheaths %	8-10 int. %	Total uptake (Kg/ha)
			K from stillage broadcast				
0	0.31	0.35	0.30	0.52	0.38	0.28	85.7
60	0.31	0.32	0.26	0.50	0.36	0.26	94.6
120	0.30	0.30	0.24	0.48	0.34	0.24	95.4
240	0.31	0.30	0.22	0.48	0.32	0.24	98.5
480	0.31	0.25	0.17	0.48	0.31	0.23	89.2
960	0.29	0.24	0.14	0.44	0.29	0.22	86.0
1920	0.25	0.20	0.11	0.43	0.28	0.19	78.6
MSD[††]	0.04	0.04	0.03	0.04	0.04	0.03	17.8
			K from KCl broadcast				
0	0.31	0.35	0.30	0.52	0.38	0.28	85.7
60	0.32	0.36	0.27	0.55	0.37	0.26	101.2
120	0.31	0.32	0.24	0.50	0.35	0.24	92.4
240	0.30	0.27	0.19	0.49	0.31	0.24	81.7
480	0.29	0.27	0.18	0.45	0.30	0.23	86.2
MSD	ns	0.06	0.03	0.04	0.04	0.03	18.0
			K from stillage in the furrow				
0	0.31	0.35	0.30	0.52	0.38	0.28	85.7
60	0.30	0.32	0.25	0.53	0.37	0.26	91.3
120	0.30	0.31	0.22	0.52	0.35	0.24	91.1
240	0.29	0.31	0.19	0.49	0.35	0.24	103.4
480	0.28	0.28	0.15	0.47	0.31	0.21	102.0
MSD	ns	0.03	0.05	0.04	0.04	0.03	15.6
			K from stillage broadcast + dolomite				
480	0.31	0.25	0.18	0.50	0.32	0.25	105.4
960	0.30	0.24	0.15	0.47	0.30	0.24	97.1

[†] Values are means of five replicates.

[††] MSD = Minimum Significant Difference (P > 0.05) from the Waller-Duncan Multiple Range Test.

Table 27. Correlation coefficients for rates of applied K, soil K, and soil Ca, and tissue concentration of K and Ca in 4- and 10-month old sugarcane†

	+3 leaf Ca	3-6 sheath Ca	8-10 int. Ca	Total Ca Uptake
		4 month sample		
K rates	-0.47**	-0.82****	-0.85****	-0.30 ns
Soil K at 4 months	-0.42**	-0.81****	-0.84****	-0.23 ns
Soil Ca at 4 months	0.14 ns	-0.28 ns	-0.42*	0.37*
Total Ca uptake	0.75****	0.51**	0.44**	-
+3 leaf K	0.01 ns	-0.62****	-0.73****	0.18 ns
3-6 sheath K	-0.16 ns	-0.73****	-0.82****	0.04 ns
8-10 int. K	-0.28 ns	-0.80****	-0.86****	-0.07 ns
Total K uptake	-0.06 ns	-0.64****	-0.72****	0.20 ns
		10 month sample		
K rates	-0.74****	-0.59***	-0.61****	-0.30 ns
Soil K at 10 month	-0.67****	-0.51**	-0.52**	-0.16 ns
Soil Ca at 10 month	-0.05 ns	-0.01 ns	-0.06 ns	0.46**
Total Ca uptake	0.57***	0.64****	0.70****	-
+3 leaf K	-0.30 ns	-0.14 ns	-0.09 ns	-0.30 ns
3-6 sheath K	-0.63****	-0.48**	-0.44**	-0.08 ns
8-10 int. K	-0.73****	-0.59***	-0.54***	-0.13 ns
Total K uptake	-0.53**	-0.36**	-0.13 ns	0.20 ns

†n = 35

*Significant at 5% level.

**Significant at 1% level.

***Significant at .1% level.

****Significant at .01% level.

nsNonsignificant

Increasing K rates from 0 to 1920 Kg K/ha caused a drop of 0.06, 0.15, and 0.19% in Ca concentration of the +3 leaf, 3-6 sheaths, and 8-10 internodes, respectively, at 4 months of age (Table 26). Correlation coefficients between rates of K applied and Ca concentration in these tissues were negative and followed the order: +3 leaf > 3-6 sheaths > 8-10 internodes (Table 27).

At 10 months of age the correlation coefficients for the relationships between rates of applied K and tissue Ca concentration were also negative for all three tissues (Table 26). However, the decreases in Ca concentration of these tissues with increasing K rates from 0 to 1920 Kg K/ha were 0.09, 0.10, and 0.09% for the +3 leaf, 3-6 sheaths, and 8-10 internodes, respectively (Table 26). Values for these correlation coefficients decrease in the order: 3-6 sheaths > 8-10 internodes > +3 leaf.

Ca concentrations in the tissues increased from 4 to 10 months of age for the +3 leaf and 3-6 sheaths (Table 26). The increases in +3 leaf Ca were generally constant, regardless of K rates. However, the increases for the 3-6 sheaths were larger for the higher stillage rates. The Ca concentration of 8-10 internodes increased by a nearly constant amount for the 0 to 120 Kg K/ha treatments; thereafter, the increase was larger for the higher K rates (Table 26).

The greater increase in 3-6 sheath and 8-10 internode Ca with higher K rates was probably due to the decrease in soil K during the crop that may have allowed greater Ca uptake by the plant. As discussed previously, the higher the K rate, the larger the decrease in soil K during the crop which results in a lower K/Ca ratio that probably enhances Ca uptake by the plant. Further support for these observations is given by the change in the negative values of correlation coefficients for 3-6 sheath and 8-10 internode Ca and K concentrations from the 4- to 10-month sample (Table 27).

These results may also explain the higher correlation coefficients between Ca concentration of 3-6 sheaths and 8-10 internodes with total Ca uptake at 10 than at 4 months. Samples taken 10 months after K application probably reflected the increased Ca uptake resulting from the decrease in soil K due to leaching. There appears to be no explanation for the relatively large increase in Ca concentration of the +3 leaf from 4 to 10 months, regardless of K rates (Table 26).

These decreases in Ca concentration with increasing K rates are in agreement with the results of many other studies. Humbert (1955) showed that increasing K fertilization decreased the concentration of Ca, Mg, and N which may cause nutritional imbalance mainly by the increase in sheath K concentration. In fact, Ca and K concentrations in the 3-6 sheaths and 8-10 internodes were negatively correlated and the correlation coefficients were higher at 4 than at 10 months. For +3 leaf, however, this correlation coefficient was negative only at 10 months, but was not significant. Clements (1980) also reported a reduction in sheath Ca concentration due to increased K fertilization. The negative and significant values of the correlation coefficients between 3-6 sheath and 8-10 internode Ca and K, at 4 and 10 months (Table 27), indicate that soil K concentration is important in controlling Ca uptake.

These relationships between K and Ca may be reflected better in the 3-6 sheaths and 8-10 internodes than the +3 leaf, because the former are reported to be very sensitive to Ca and K (Humbert, 1968). Therefore, any change in the Ca and K levels in the plant is likely to be more evident in these tissues.

Critical Ca levels reported for the +3 leaf, 3-6 sheaths, and 8-10 internodes are 0.15 to 0.30, 0.17 to 0.20, and 0.06%, respectively (Samuels, 1969). Therefore, in the present study, Ca probably was not limiting even at the highest stillage rates. It should be pointed out that Ca was relatively high in the soil initially. However, since there is an evident drop in soil Ca levels due to increasing stillage rates, K applications may cause Ca to become limiting especially in soils low in Ca.

Effect of Dolomite on Ca Concentration and Total Uptake

Application of dolomite is reported to increase tissue Ca concentration and decrease K concentration (Humbert, 1968). In the present study, 8-10 internode Ca increased slightly at 4 months while Ca in the other tissues remained nearly constant (Table 26). However, at 10 months, Ca concentration in all three tissues increased. This relatively long period required for Ca concentration in the tissue to increase may be due to the decrease in soil K with time discussed previously. Total Ca uptake was increased by dolomite application. This increase was due to increased yield and increased plant Ca concentration (Table 26).

Mg Concentration and Total Uptake

Change in Mg concentration in tissues with increasing K levels from stillage applied broadcast and in the furrow or from KCl did not follow the same pattern in the three tissues and two ages (Table 28).

At 4 months, increasing K levels significantly decreased Mg concentration in the 8-10 internodes and 3-6 sheaths while +3 leaf Mg was apparently not affected (Table 28; Figure 30). However, at 10 months Mg concentration in +3 leaf was significantly decreased, whereas the slight decrease in 8-10 internode Mg was non-significant (Table 28; Figure 31). Mg concentration in 3-6 sheaths, however, decreased with increasing K rates at both ages (Figures 30 and 31). It should be mentioned that none of the Mg concentrations decreased below critical levels for these tissues.

These results are supported by correlation coefficients in Table 28 where only the correlation coefficient for the relationship between K rates and +3 leaf Mg at 4 months and for K rates and 8-10 internode Mg at 10 months are very low and non-significant (Table 29).

Mg concentrations in the +3 leaf generally increased from 4 to 10 months for all K levels and the incremental increases were larger for the lower stillage rates (Table 28). However, 3-6 sheath Mg generally decreased as K increased and the magnitude of the decrease was larger for the lower than the higher K levels. The Mg concentration in 8-10 internodes decreased from 4 to 10 months at the lower stillage rates, but increased at the higher rates. Therefore, it becomes difficult to establish a relationship among these tissues.

Table 28. Effect of K from stillage, KCl,and stillage plus dolomite on Mg concentration of tissues[†]

K Rates (Kg/ha)	Age in Months at Sampling						
	4			10			15
	+31 leaf %	3-6 sheaths %	8-10 int. %	+3 leaf %	3-6 sheaths %	8-10 int. %	Total uptake (Kg/ha)
			K from stillage broadcast				
0	0.10	0.25	0.26	0.18	0.17	0.22	64.3
60	0.09	0.24	0.25	0.17	0.15	0.20	74.5
120	0.10	0.23	0.21	0.16	0.14	0.20	68.6
240	0.10	0.23	0.19	0.15	0.14	0.20	70.4
480	0.09	0.17	0.17	0.15	0.13	0.21	72.2
960	0.09	0.15	0.14	0.14	0.13	0.21	74.1
1920	0.10	0.13	0.12	0.13	0.12	0.21	72.9
MSD[††]	ns	0.04	0.05	0.03	0.04	ns	12.3
			K from KCl broadcast				
0	0.10	0.25	0.26	0.18	0.17	0.22	64.3
60	0.09	0.24	0.24	0.18	0.15	0.22	77.5
120	0.09	0.23	0.22	0.16	0.14	0.21	79.0
240	0.10	0.19	0.19	0.16	0.13	0.21	73.8
480	0.09	0.17	0.18	0.15	0.12	0.20	81.8
MSD	ns	0.04	0.04	ns	0.03	ns	13.0
			K from stillage in the furrow				
0	0.10	0.25	0.26	0.18	0.17	0.22	64.3
60	0.09	0.23	0.23	0.18	0.16	0.21	73.4
120	0.09	0.22	0.20	0.17	0.17	0.21	78.9
240	0.11	0.22	0.18	0.17	0.16	0.22	91.9
480	0.10	0.19	0.14	0.15	0.13	0.20	86.1
MSD	ns	0.04	0.04	ns	0.03	ns	10.4
			K from stillage broadcast + dolomite				
480	0.09	0.20	0.18	0.16	0.16	0.22	89.0
960	0.10	0.18	0.15	0.16	0.14	0.21	82.4

[†] Values are means of five replicates.

[††] MSD = Minimum Significant Difference ($P < 0.05$) from the Waller-Duncan Multiple Range Test.

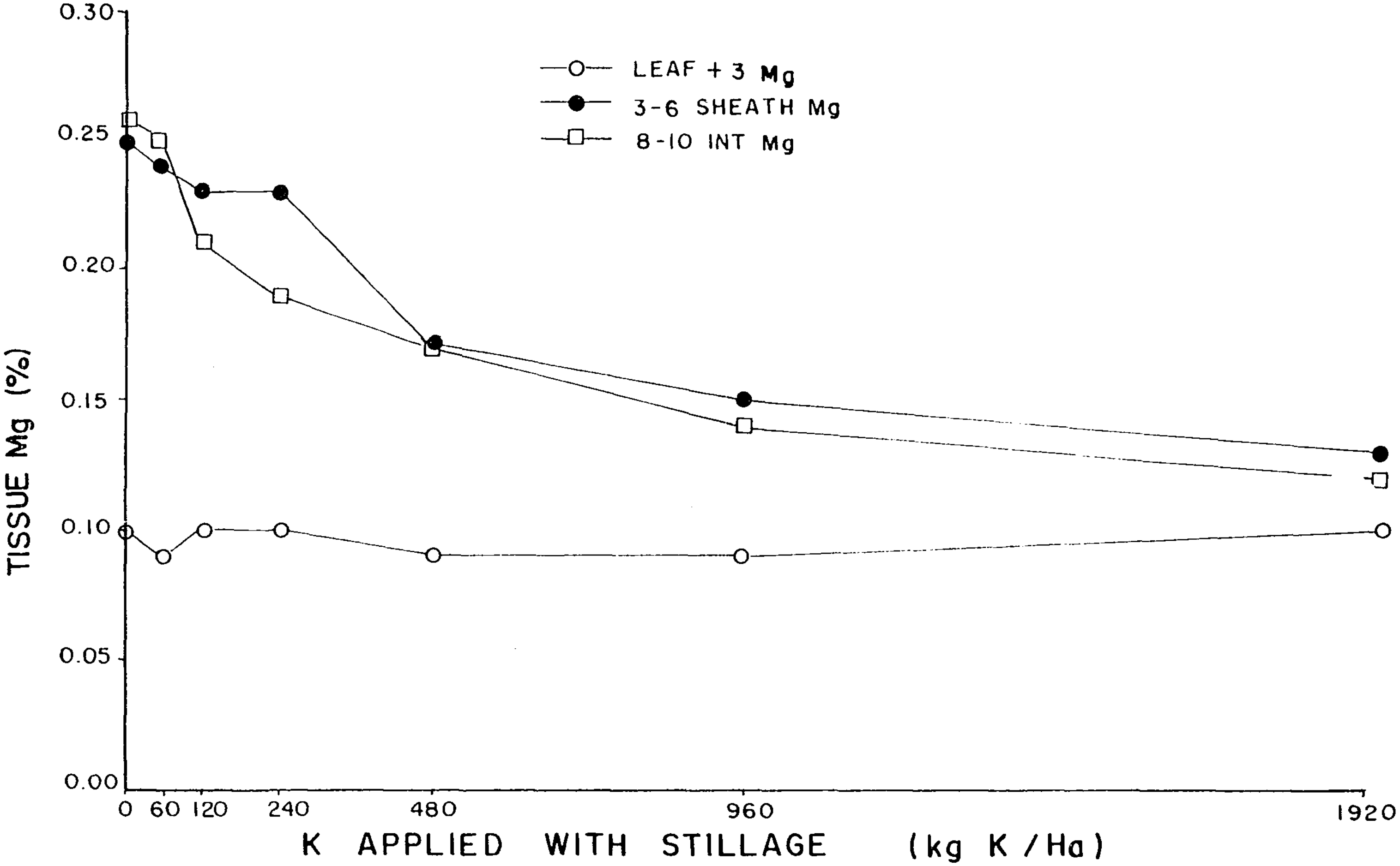

Figure 30. Effect of stillage broadcast rates on Mg concentration of tissues of 4-month old sugarcane.

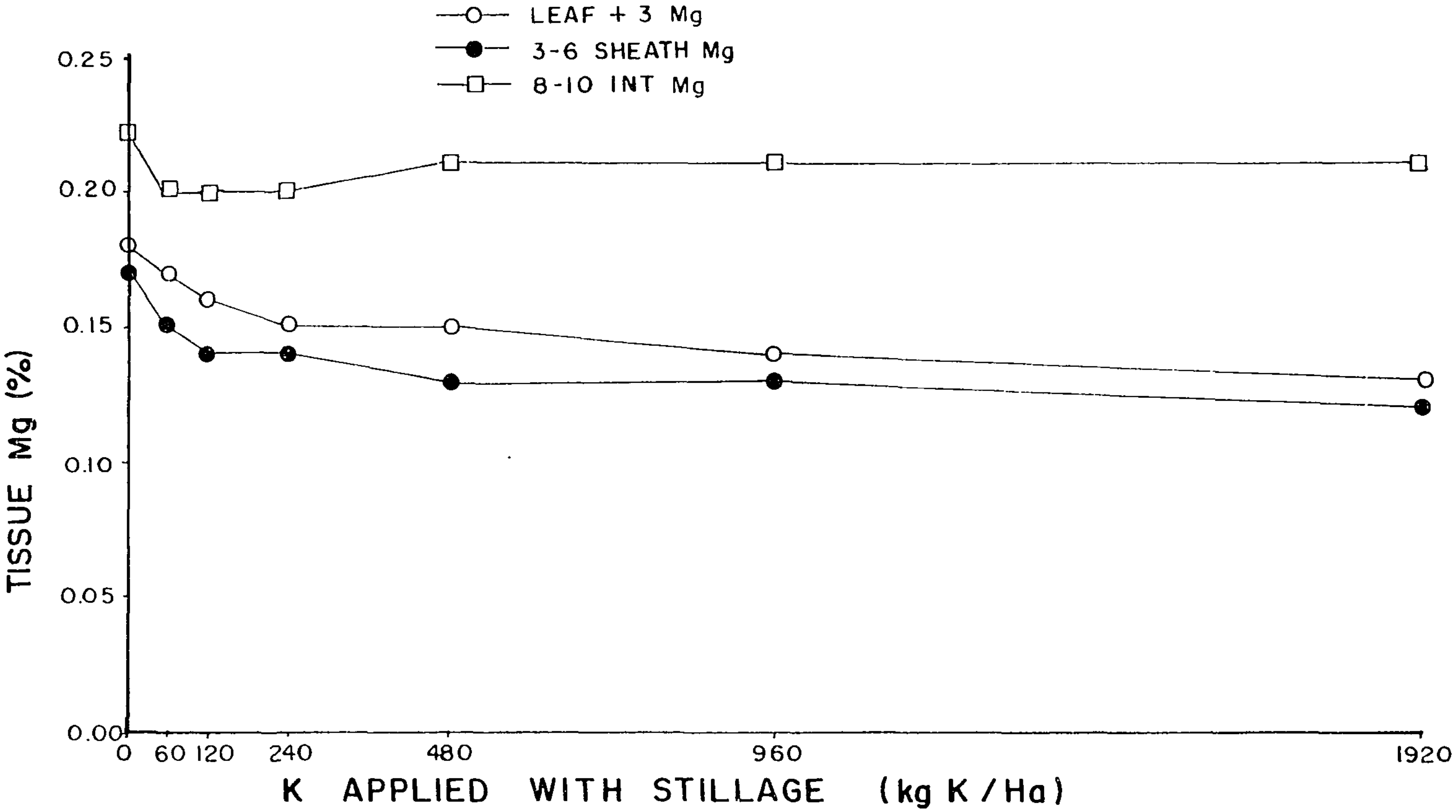

Figure 31. Effect of stillage broadcast rates on Mg concentration of tissues of 10-month old sugarcane.

Table 29. Correlation coefficients for rates of applied K, soil K, and soil Mg, and tissue concentration of K and Mg in 4- and 10-month old sugarcane†

	+3 leaf Mg	3-6 sheath Mg	8-10 int. Mg	Total Mg uptake
		4-month sample		
K rates	0.11 ns	-0.85****	-0.82****	0.17 ns
Soil K at 4 months	0.13 ns	-0.84****	-0.82****	0.23 ns
Soil Mg at 4 months	0.15 ns	-0.79****	-0.78****	0.38*
Total Mg uptake	0.27 ns	0.01 ns	0.06 ns	-
+3 leaf K	0.21 ns	-0.67****	-0.70****	0.45**
3-6 sheath K	0.14 ns	-0.77****	-0.80****	0.40*
8-10 int. K	0.16 ns	-0.82****	-0.85****	0.31 ns
Total K uptake	0.25 ns	-0.69****	-0.69****	0.57***
		10-month sample		
K rates	-0.72****	-0.53**	-0.01 ns	0.17 ns
Soil K at 4 months	-0.65****	-0.45**	0.09 ns	0.26 ns
Soil Mg at 4 months	0.64****	-0.43**	0.14 ns	0.33 ns
Tltal Mg uptake	0.12 ns	0.29 ns	0.49**	-
+3 leaf K	-0.39*	-0.10 ns	0.44**	0.64****
3-6 sheath	-0.69****	-0.46**	0.07 ns	0.46**
8-10 int. K	-0.76****	-0.52**	0.05 ns	0.31 ns
Total K uptake	-0.56***	-0.32 ns	0.27 ns	0.57***

†n = 35
*Significant at 5% level.
**Significant at 1% level.
***Significant at .1% level.
****Significant at .01% level.
ns Nonsignificant

Only the 3-6 sheath tissue showed similar patterns at both ages, and, therefore, may be considered the preferred index tissue to reflect the Mg status of the plant. It should be pointed out that 3-6 sheath Ca was also very consistent at both ages. Therefore, the discussion hereafter is based primarily on 3-6 sheath Mg concentration.

Evans et al. (1954) reported that high levels of the +3 leaf Mg were reduced to below normal values with applications of potash. Malavolta et al. (1959) also found reduction in the +3 leaf Mg with increasing potash application. Clements (1980) reported that sheath Mg levels were affected by increasing K rates, but to a smaller extent than Ca.

As discussed for Ca, there was also a singificantly negative correlation between 3-6 sheath K and 3-6 sheath Mg at both ages (Table 29). In addition, these correlation coefficients are higher at 4 than at 10 months, as was also observed for Ca (Table 27). However, with Ca, the decrease in the correlation coefficient was probably due to an increase in Ca concentration at higher stillage rates (Table 26), whereas with Mg, the drop was probably due to a larger decrease in Mg concentration at lower stillage rates (Table 28). Clements (1980) showed that sheath Mg concentration decreases with age. Therefore, the relatively large decrease in sheath Mg between 4 and 10 months at the lower stillage rates may be due to the increased age of the plant, but the small decrease at the higher stillage rates is most probably due to lower soil K levels at 10 months, which allowed the greater uptake of Mg so that aging had considerably less influence.

Although Clements (1980) reported that Ca is generally more affected than Mg by increasing K rates, these results seem to show that both are almost equally affected. Correlation coefficients for the relationships between 3-6 sheath K and Ca concentration (Table 27) and 3-6 sheath K and Mg concentration (Table 29) were similar at both 4 and 10 months. In fact, the drop in sheath Ca with increasing stillage rates was 43 and 26% for 4 and 10 months, respectively, whereas the drop in sheath Mg was 48 and 29% for 4 and 10 months, respectively. However, the ratio of soil Ca to Mg was relatively high, and this may have reduced the difference between Ca and Mg levels in the sheath. Even so, sheath Ca levels were slightly more depressed than Mg levels.

Stillage added Ca and Mg to the soil, but Ca and Mg levels in the tissues were very similar for both the stillage and KCl treatments (Tables 26 and 28), which implies that added K had a greater effect on the uptake of these cations. This is probably the cause of the negative correlation coefficients for the relationship between both soil K and 3-6 sheath Mg and 8-10 internode Mg at 4 months (Table 29). Therefore, it may be concluded that soil K plays a major role in controlling Ca and Mg uptake. Prince et al. (1947), and McColloch et al. (1957) have reported that soil K levels are as important in Mg uptake as are soil Mg levels.

Critical Mg concentrations in tissues have been reported as 0.08, 0.10, and 0.05% for the +3 leaf, 3-6 sheaths, and 8-10 internodes, respectively (Samuels, 1969). Therefore, it is apparent that Mg was not likely to limit yields in the present experiment, even though its concentration in the sheaths at the highest stillage rate was very close to the critical level (Table 28). Based on these results, it may be concluded that Mg, like Ca, can become limiting, especially in soils low in Mg if high stillage rates are applied.

Effects of Dolomite on Mg Concentration and Total Uptake

Dolomite application increased the concentration of 3-6 sheath Mg at both ages whereas Mg concentration of the +3 leaf was increased only at 10 months and that of the 8-10 internodes was increased at 4 months. Total Mg uptake was also increased (Table 28). This increase in total uptake was due to increase in yields and increase in plant Mg concentration. These results suggest that even though soil K affected Mg uptake, increasing soil Mg probably decreased the K/Mg ratio and therefore increased Mg uptake by the plant.

N Concentration and Total Uptake

N concentration generally increased in the three tissues with increasing stillage rates, especially at 10 months of age (Table 30). Application of KCl did not have any significant effect on the N concentrations of tissues at both ages. Stillage applied in the furrow followed a pattern similar to that of stillage broadcast, but N concentrations of all three tissues, especially at 10 months, were somewhat lower than those for stillage broadcast probably due to a higher rate of leaching as observed for K (Table 30).

N concentrations in all tissues generally dropped from 4 to 10 months (Table 30) and the drop was relatively larger for the lower than the higher K rates from stillage. The 8-10 internode N even increased from 4 to 10 months at the highest stillage rates (1920 Kg K/ha). However, with KCl treatments, the drop was relatively uniform, regardless of K rates (Table 30).

Table 30. Effect of K stillage broadcast and applied in the furrow, KCl and stillage with dolomite on N concentration of tissues†

K rates (Kg/ha)	Total N (Kg/ha)	Age in months at sampling						
		4			10			15
		+3 leaf %	3-6 blades %	8-10 int. %	+3 leaf %	3-6 blades %	8-10 int. %	Total Uptake (Kg/ha)
				K from stillage broadcast				
0	170	1.99	1.94	0.60	1.83	1.79	0.39	182.2
60	170	1.99	1.94	0.60	1.88	1.78	0.37	200.0
120	170	2.00	2.00	0.62	1.88	1.77	0.43	233.5
240	170	2.00	2.00	0.63	1.91	1.81	0.45	255.5
480	170	2.04	2.00	0.64	1.96	1.83	0.53	267.0
960	240	2.05	2.01	0.64	1.99	1.86	0.61	289.1
1920	410	2.14	2.01	0.66	2.02	1.99	0.68	332.4
MSD††		0.09	0.10	0.04	0.07	0.09	0.07	30.7
				K from KCl broadcast				
0	170	1.99	1.99	0.60	1.83	1.79	0.39	182.2
60	170	1.96	1.99	0.58	1.83	1.75	0.37	188.4
120	170	2.00	2.00	0.58	1.88	1.77	0.38	247.8
240	170	2.00	2.00	0.62	1.89	1.72	0.37	220.3
480	170	1.96	2.00	0.62	1.89	1.76	0.43	253.1
MSD		ns	ns	ns	ns	ns	ns	37.1
				K from stillage in the furrow				
0	170	1.99	1.94	0.60	1.83	1.79	0.39	182.2
60	170	1.93	1.90	0.63	1.87	1.76	0.37	195.3
120	170	1.96	1.95	0.62	1.82	1.76	0.39	217.3
240	170	2.02	1.89	0.60	1.90	1.79	0.42	270.1
480	170	1.97	1.85	0.63	1.90	1.82	0.45	305.0
MSD		ns	ns	ns	ns	ns	0.05	27.4
				K from stillage broadcast + N				
240	250	2.15	1.95	0.65	1.95	1.86	0.63	289.8
				K from stillage broadcast + dolomite				
480	170	2.12	2.02	0.65	1.86	1.82	0.49	280.1
960	240	2.10	2.05	0.64	1.84	1.76	0.41	267.0

†Values are means of five replicates.

††MSD = Minimum Significant Difference ($P < 0.05$) from the Waller-Duncan Multiple Range Test.

This decrease in N concentration from 4 to 10 months was mainly related to aging as has been reported by Samuels (1969). However, there was a relatively lower drop in all tissues with higher stillage rates that received less fertilizer N, an increase in the 8-10 internode N with the highest stillage rate, and a nearly constant drop of N in all tissues for all K levels in the KCl treatments. This may suggest that part of the organic N added with stillage was mineralized slowly and therefore supplied N to the crop throughout its growth. Since larger amounts of organic N were added with higher stillage rates (Table 5), it would be expected then, that these higher stillage rates would have higher N concentrations in the tissues throughout the crop cycle.

Higher stillage broadcast rates (480, 960, and 1920 Kg K/ha) had significantly higher N concentrations in the +3 leaf at harvest than the lower rates (< 240 Kg K/ha) which did not show any significant differences (Table 31). Also, there were no significant differences among N levels of the KCl and stillage in the furrow treatments.

The correlation coefficients between stillage N and tissue N concentration improved with age (Table 32). The correlation coefficients for the relationship between fertilizer N added and tissue N concentration become more negative with age. These observations support the suggestion that part of the fertilizer N added initially to the crop was taken up while part of it may have been lost. However, part of the stillage N was mineralized slowly, and thereby constantly supplied N to the crop. This is also supported by the 240 Kg K/ha from stillage broadcast plus N treatment which had higher tissue N

Table 31. Effect of K rates from various sources on +3 leaf N at harvest[†]

K Rates (Kg/ha)	N Added (Kg/ha)			K Sources and Interactions					
	stillage	fertilizer	total	stillage broadcast	KCl	stillage in furrow	stillage + N[††]	stillage + ripener	stillage + dolomite
0	0	170	170	1.45					
60	15	155	170	1.49	1.45	1.48			
120	30	140	170	1.49	1.48	1.48			
240	60	110	170	1.51	1.42	1.48	1.59		
480	120	50	170	1.59	1.49	1.52		1.39	1.54
960	240	0	240	1.63				1.48	1.58
1920	410	0	410	1.66					
MSD[†††]				0.09	ns	ns			

[†] Values are means of five replicates.

[††] Stillage + N received an additional 80 Kg/ha of fertilizer N, for a total of 25 Kg N/ha.

[†††] MSD = Minimum Significant Difference ($P < 0.05$) from the Waller-Duncan Multiple Range Rest.

Table 32. Correlation coefficients for the relationships between N level in tissues and applied N for the stillage treatments[†]

	Stillage N	Fertilizer N	Total Uptake N
+3 leaf N at 4 months	0.37*	-0.20	0.50**
+3 leaf N at 7 months	0.69****	-0.67****	0.85****
+3 leaf N at 10 months	0.74****	-0.72****	0.82****
+3 leaf N at harvest	0.79****	-0.73****	0.88****
8-10 int. N at 4 months	0.56***	-0.56***	0.83****
8-10 int. N at 10 months	0.89***	-0.77****	0.90****

[†] n = 35

*Significant at 5% level.

**Significant at 1% level.

***Significant at .1% level.

****Significant at .01% level.

ns Nonsignificant

concentrations and uptake along with lower juice quality. It should be pointed out that the Pol % juice of this treatment was comparable to that of the 960 Kg K/ha stillage broadcast treatment (Table 13) even though the K rates were different (240 and 960 Kg/ha); the N rates were comparable, i.e., 240 and 250 Kg/ha, respectively (Table 30). These results further support the suggestion that high K rates can not overcome the detrimental effects on Pol yield due to high N application.

These findings may explain the reported difficulty in ripening cane fertilized with high rates of stillage (Stupiello, 1977; Magro, 1978). This slow mineralization of stillage N would keep the crop in the vegetative state, which makes ripening more difficult, especially if climatic conditions are unfavorable for ripening at harvest. Humbert (1968) reported that it was important to have low N at ripening to avoid adverse effects on juice quality.

Based on the critical levels reported for N concentration of the +3 leaf (1.90%) and of 8-10 internodes (0.30%) at 4 and 6 months of age, it seems that the amounts of fertilizer N added to the crop in those treatments that received low amounts of stillage N was adequate. However, the fact that in the higher stillage treatments N concentration was well above these levels at 10 months of age, whereas at lower stillage rates, N either approached or was below the critical levels, indicates the possible adverse effects of high stillage levels on cane ripening.

The 8-10 internodes are very sensitive and reflect the N status of the plant (Humbert, 1968), although the +3 leaf also appears to be sensitive. In fact, correlation coefficients for the relationships between tissue N and stillage N, fertilizer N and total N uptake were somewhat higher for the 8-10 internodes than for the +3 leaf (Table 32). However, the +3 leaf appears to be adequate for N because it may be collected as early as 3 months which is important for a short cycle crop, i.e., 12 months.

Effects of Dolomite on N Concentration

Dolomite application had a significant effect on the N concentration of the +3 leaf and 8-10 internodes (Table 33). At 4 months, the N concentration of the +3 leaf was significantly higher in treatments that received dolomite. However, in older plants there was a tendency for N concentrations of dolomite treatments to be lower than those of treatments that had received only stillage. With the 8-10 internodes the pattern was somewhat similar, except that at 4 months there was no significant difference in the N concentrations of the stillage treatments with and without dolomite.

These results are probably due to the increased soil pH with dolomite application that resulted in greater microbiological activity that decomposed stillage more rapidly with earlier release of N. This would result in a greater N availability in the beginning of the crop followed by a shortage of N at the end, which is desirable for proper ripening.

Alexander (1975) has reported that acidification of soil tends to depress, but does not eliminate N mineralization. The liming of acid soils is commonly stimulatory to the activity of soil microflora as pH is brought closer to the optimum. Organic N accumulates in acid sites, presumably because of slow mineralization, so that a rapid

Table 33. Effect of dolomite on N concentration of sugarcane tissues[†]

Treatment	Age in Months at Sampling			
	4	7	10	15
	+3 leaf N concentration			
Stillage	1.99 b[††]	2.01 a	1.98 a	1.61 a
Stillage + dolomite	2.11 a[††]	2.01 a	1.85 b	1.56 b
Avg. for N	2.05	2.01	1.92	1.59

Harvest

8-10 internode N and total N uptake

Treatment	Age in Months at Sampling		
	4	10	Total N Uptake
Stillage	0.64 a	0.57 a	278.05 a
Stillage + dolomite	0.64 a	0.54 b	277.05 a
Avg. for N	0.64	0.51	277.55

[†] Means of 10 values.

[††] Numbers in the same column followed by the same letter are not significantly different at the 5% level according to Duncan's Multiple Range Test.

release of N is noted when such soils are limed. Ayres (1961) obtained an increase of 160 pounds of nitrogen per acre which was released by mineralization in a limed soil over an 8-month period.

Therefore, these results suggest that dolomite application with stillage to acid soil may stimulate the early release of stillage N and thus prevent the negative effects of stillage on juice quality.

Effect of a Ripener on N Concentration

Application of a ripener (Polaris) 10 weeks prior to harvest lowered the N concentration in the +3 leaf at harvest for the 480 and 960 Kg K/ha stillage treatments (Table 34). At 10 months N levels of the +3 leaf were not significantly different for the two treatments before ripener was applied, but after ripener was applied, there was a sharp decrease in N concentration in the +3 leaf of treatments that received ripener (Table 34).

Clements (1980) reported that after application of Polaris, cane stops growing and becomes chlorotic at harvest and the purity and brix are improved. According to Alexander (1973) the action of Polaris seems to be due to blockage of N metabolism in the plant, hence sugar accumulates instead of being used in new growth.

The decrease in N concentration observed after ripener application is in agreement with other reports of the influence of ripener on N levels of the sugarcane plant. Therefore, this drop in N probably resulted in slower growth and better juice quality at harvest. This improvement in juice quality was observed in the present experiment as discussed previously.

Table 34. Effect of application of ripener[†] (Polaris) on +3 leaf N concentration[††]

	Age in Months at Sampling	
	10	15
Stillage	1.97 a[††]	1.61 a
Stillage + ripener	1.92 a	1.44 b[†††]

[†] Ripener (Polaris) was applied when the crop was 12.5 months old which was 10 weeks prior to harvest at 15 months.

[††] Means of 10 values

[†††] Numbers in the same column followed by the same letters are not significantly different at the 5% level according to Duncan's Multiple Range Test.

These results suggest that chemical ripening is a possible method for lowering N in the plant prior to harvest and, therefore, improving juice quality that may be used for fields that receive high stillage rates and are likely to have low juice quality.

SUMMARY AND CONCLUSIONS

A sugarcane field experiment was carried out to evaluate the effects of untreated stillage application on cane and sugar yields, and juice quality. Concentrations of N, Ca, Mg, and K in the +3 leaf, 8-10 internodes and 3-6 sheaths were also evaluated. In addition, changes in soil pH, Ca, Mg, K, Na, and P were measured.

The soil in the experimental area was classified as an Udifluvents low in K. Treatments applied consisted of seven K rates (0, 60, 120, 240, 480, 960, and 1920 Kg K/ha) from stillage broadcast, five K rates (0, 60, 120, 240, and 480 Kg K/ha) from KCl broadcast, five K rates (0, 60, 120, 240, and 480 Kg K/ha) from stillage applied in the furrow, one K rate (240 Kg K/ha) from stillage broadcast plus additional N, two K rates (480 and 960 Kg K/ha) from stillage broadcast that received ripener (Polaris) 10 weeks prior to harvest, and two K rates (480 and 960 Kg K/ha) from stillage broadcast plus 6 tons of dolomite. All batches of stillage were analyzed for N and K to control the amounts of K applied and also to determine the amounts of N to be added. After soil preparation treatments received a blanket application of 2 tons of dolomite/ha, and at planting 180 Kg P_2O_5, 30 Kg $ZnSO_4$ and 10 Kg Borax/ha were applied below the seed-piece. N added with stillage was determined for each plot, and fertilizer N was applied to all plots to provide a total of 170 Kg N/ha. Only treatments that received 960 and 1920 Kg K/ha from stillage did not receive fertilizer N, since the amounts added with stillage were 240 and 410 Kg N/ha, respectively. The experiment was irrigated by furrow irrigation, and water applied whenever soil moisture tension reached 1.2 atm.

Tissue samples (+3 leaf, 8-10 internodes, and 3-6 sheaths) were collected at 4 and 10 months after planting, and leaf +3 was also collected at 7 and 15 months. At harvest samples of the whole plant were collected and total nutrient uptake determined. Soil samples were collected at 15, 120, 210, 300, and 450 days after planting at 0-20, 20-40, and 40-60 cm depth. Plant samples were analyzed for N, P, K, Ca, Mg, and Na. Soil samples were analyzed for pH, P, K, Ca, Mg, and Na.

At harvest cane yields of primaries and tillers were recorded and the juice from the bottom and top part of primaries and juice of tillers analyzed for Pol, Brix, Reducing Sugars, Fiber, and Ash.

Results showed that yields of cane and sugar increased up to 120 Kg K/ha from both stillage and KCl broadcast. At this K rate, soil K concentration at 15 days after planting was 0.22 meq/100 g (86 ppm). The +3 leaf, 3-6 sheath, and 8-10 internode K concentrations were 1.12, 1.99, and 1.51%, respectively, at 4 months and 0.98, 2.43, and 0.75, respectively, at 10 months of age. Since these soil and tissue K levels were associated with the highest yield from K broadcast, it may be concluded that they are adequate for sugarcane growth. Furthermore, these soil and tissue K levels are in agreement with those reported in the literature for adequate growth and production of sugarcane. In the present study, it was necessary to apply 100 m^3 of stillage from cane juice fermentation to supply 120 Kg K which agrees with the recommended rates for this type of stillage.

Rates of K from stillage up to 480 Kg/ha appear to have no detrimental effects on cane and sugar yields. However, 960 and 1920 Kg K/ha from stillage, increased cane yields, but decreased sugar yields. In addition, juice quality was lowered because Pol, brix, and purity decreased, and reducing sugars and ash increased, especially with the highest stillage rate. This decrease in sugar yield and juice quality with high stillage rates is related to the N added with stillage because part of it was mineralized slowly throughout the crop. This is supported by the fact that N levels in the +3 leaf were always higher in the stillage treatments, especially for the highest rates. Therefore, at harvest, since the climatic conditions were not favorable for ripening, cane from the higher stillage treatments was growing and not accumulating sugar due to high plant N levels. This indicates that the lower sugar yields associated with high stillage rates are due to N and not K added with stillage. However, the increase in ash content of juice which is related to the K levels of high stillage rates, is detrimental to juice quality because it interferes during sugar processing.

Application of dolomite increased yields of cane and sugar and juice quality. Results showed a small but non-significant increase in Pol and brix. However, it resulted in a significant reduction of reducing sugars in the top and bottom internodes of primary stalks. This may be due to increased rates of mineralization of stillage N due to the increase in soil pH with dolomite application. The higher mineralization rate of stillage N resulted in higher N levels in the +3 leaf at the beginning of the crop, but lower levels at harvest in treatments that received dolomite, which favored ripening. In addition, dolomite supplied Mg to the soil that favored the K/Ca + Mg ratio, since the soil was relatively low in Mg. Therefore, this improved nutritional balance may have contributed to higher cane and sugar yields. These results show that in soils low in Ca, Mg, or both, application of dolomite or lime can be beneficial if high stillage rates are applied. This is because these materials improve the K/Ca + Mg ratio as well as raise soil pH that increases the mineralization rate of stillage N, especially in acid soils. Therefore, this better nutritional balance may produce high yields and the increased rate of mineralization of stillage N allows the crop to ripen thus improving juice quality.

Ripener (Polaris) application decreased total cane yields because cane yields of tillers decreased, although primary cane yield was not affected. This is because tillers were growing vigorously at the time of application. However, total Pol yield increased because Pol yield of primaries increased while Pol yield of tillers was not different from that in treatments that did not receive ripener. This was due to the increase in Pol % cane of tillers by ripener application which compensated for the decrease in tiller cane yield. Juice quality of primary stalks increased since Pol, Brix and purity increased, and reducing sugars decreased in the top and bottom internodes of primary stalks. Juice quality of tillers was also increased and was greater than the increase in juice quality of primary stalks. The N levels in the +3 leaf of treatments that received ripener were lower than those of the controls. This shows that ripener application improved sugar yields and juice quality because it probably interfered in N metabolism in the plant and decreased vegetative growth, thus favoring accumulation of sugar. Ripener application improved juice quality because it reduced growth and lowered +3 leaf N concentration while dolomite application also improved juice quality because it increased N mineralization that resulted in lower +3 leaf N concentration at harvest. These findings give further support to the conclusion that higher stillage rates lower juice quality because of the added N and not added K. These results suggest that sugarcane ripener can be applied to overcome ripening problems from application of high stillage rates.

Stillage applied in the furrow resulted in higher yields of cane and sugar compared to stillage or KCl broadcast, especially with rates of 240 and 480 Kg K/ha. In fact, the highest total yield of cane (185.67 ton/ha) and Pol (23.97 ton/ha) observed in this experiment was obtained with 240 Kg K/ha from stillage applied in the furrow immediately after planting. It was observed that germination and emergence of cane was faster and growth rates were higher for stillage in the furrow treatments, which resulted in higher yields. This was probably due to the activity of soil microorganisms around the seed-pieces which may have raised soil temperature and improved germination. This soil microorganism activity may also have produced organic acids which may have softened the sugarcane buds and hastened germination. In addition, placement of organic matter in the furrow may have improved retention of nutrients as well as increased the water holding capacity of the soil near the seed-piece and enhanced initial growth. These results suggest that stillage may be applied in the furrow, especially in those plantations that have a furrow irrigation system where it is a good and economical method of stillage application. For the types of soil used in this study, rates of stillage to supply up to 480 Kg K/ha can be applied in the irrigation furrow or planting furrow (in case of unirrigated plantations) at one time without any detrimental effects to the crop or soil.

Soil pH increased and Al decreased with stillage application which was probably due to the mineralization of organic N that produced NH_4^+ and NO_2^- in combination with basic cations such as Ca, Mg, and K added with stillage. Application of high stillage rates may induce a high K/Ca + Mg ratio, because it adds relatively more K than Ca and Mg. Therefore, this high K/Ca + Mg ratio reduces the uptake of Ca + Mg by the plant, as indicated by the decrease in tissue Ca and Mg with increasing K levels. Even at the highest stillage rate (1920 Kg K/ha) the electric conductivity of a saturation extract was below the levels for a saline soil. However, it should be emphasized that with other soil types, salinization may occur with such high K rates. It was observed that a large amount of K added with stillage was lost through leaching from the 0.60 cm soil layer, especially for stillage rates above 480 Kg K/ha. However, although Ca and Mg were leached from the 0-20 cm layer, they accumulated in the 20-40 and 40-60 cm layers indicating that the clay fraction of this soil preferentially adsorbs Ca and Mg over K.

Concentrations of Ca and Mg in the tissues (+3 leaf, 3-6 sheaths, and 8-10 internodes) decreased and K increased with increasing rates of K from stillage or KCl. These results indicate that raising K levels in the soil decreased the uptake of Ca and Mg which is due to competition among them. In addition, it seems that the uptake of these cations is controlled more by the K/Ca + Mg ratio than by their concentration in the soil alone. Therefore, when high rates of stillage are to be applied, it is recommended that soil levels of Ca and Mg be determined so that deficiencies of these cations may be avoided. Of the three tissues evaluated, 3-6 sheaths and 8-10 internodes appeared to be more sensitive in relfecting soil K levels as well as variation in tissue Ca and Mg due to increased soil K. However, since 3-6 sheaths appeared to be more affected by water stress this tissue may be more appropriate for irrigated fields whereas the 8-10 internodes, although more difficult to collect, may be recommended for unirrigated fields. In addition, the 8-10 internodes were also very sensitive to N. Although the +3 leaf had the highest correlation between tissue K concentration and yields, it had a very narrow range of K concentrations between the lowest and highest K rates. Thus, it was unable to separate a deficient from a non-deficient K plant. In addition, it was not as sensitive to Ca and Mg as the 3-6 sheaths and 8-10 internodes. The 8-10 internode was the most sensitive tissue for plant N; however, the +3 leaf was considered a more suitable tissue for a short cycle crop because it could be sampled early.

It should be mentioned that since stillage composition is highly variable, its content of N and K should be determined so that the appropriate K application can be made and that supplemental N can be added, if necessary.

The optimum amounts of K to be applied as stillage can be used on a response curve of sugarcane to K fertilization. In determining the maximum amount of stillage that can be applied (waste management), one should consider possible problems such as difficulty in ripening, poor juice quality, and soil salinization. However, the application of a chemical ripener can overcome the ripening problem and increase juice quality.

APPENDIX

Table 35. Total cane yields (ton/ha) of individual replicates

K Rates (Kg/ha)	Rep. I	Rep. II	Rep. III	Rep. IV	Rep. V
			K from stillage broadcast		
0	129.04	153.18	129.54	146.19	137.52
60	142.33	150.12	136.44	152.39	155.00
120	165.00	158.64	158.55	161.81	160.82
240	188.05	161.99	154.53	153.02	168.61
480	181.29	166.08	149.50	173.16	174.83
960	198.67	178.74	138.22	181.77	166.20
1920	175.63	161.66	144.50	177.76	182.17
			K from KCl broadcast		
0	129.04	153.18	129.54	146.19	137.53
60	172.71	155.08	146.78	145.78	142.39
120	188.93	161.65	160.50	165.52	172.60
240	181.07	157.11	163.14	160.77	169.13
480	178.35	178.20	166.06	171.09	177.17
			K from stillage in the furrow		
0	129.04	153.18	129.54	146.19	137.53
60	165.62	136.63	130.53	135.23	163.75
120	185.73	156.87	137.49	140.68	164.08
240	196.31	183.41	172.99	165.10	210.52
480	209.38	169.88	174.11	171.20	188.57
			K from stillage broadcast + N		
240	176.41	165.31	147.99	164.09	166.70
			K from stillage broadcast + ripener		
480	169.19	145.38	132.90	153.69	163.39
960	159.26	157.82	134.18	166.74	156.26
			K from stillage broadcast + dolomite		
480	185.77	172.30	157.47	197.47	176.18
960	185.65	149.83	146.85	147.82	152.76

Table 36. Total Pol yield (ton/ha) of individual replicates

K Rates (Kg/ha)	Rep. I	Rep. II	Rep. III	Rep. IV	Rep. V
		K from stillage broadcast			
0	15.83	18.14	16.23	19.64	18.05
60	18.22	19.13	18.34	17.61	19.43
120	21.49	21.26	21.12	23.18	22.44
240	22.93	20.69	19.25	20.85	22.13
480	22.56	19.08	16.20	23.83	21.44
960	22.10	19.88	16.64	22.00	19.24
1920	18.29	17.51	15.98	22.70	19.78
		K from KCl broadcast			
0	15.83	18.14	16.23	19.64	18.05
60	21.38	18.67	18.50	20.34	19.80
120	23.08	20.82	21.15	20.56	22.61
240	21.36	21.29	21.17	21.00	22.63
480	23.69	23.36	22.06	22.02	22.58
		K from stillage in the furrow			
0	15.83	18.14	16.23	19.64	18.05
60	20.17	16.94	17.70	17.54	19.80
120	23.96	20.17	18.68	18.96	21.73
240	26.08	23.16	22.03	22.17	25.93
480	25.72	20.87	21.28	22.20	25.16
		K from stillage broadcast + N			
240	19.08	18.64	17.80	22.41	22.06
		K from stillage broadcast + ripener			
480	25.14	20.98	19.01	22.32	23.83
960	21.14	22.11	17.61	24.05	23.42
		K from stillage broadcast + dolomite			
480	23.66	21.45	19.70	25.95	21.60
960	23.53	19.25	21.25	19.54	19.77

Table 37. Brix and Pol percent juice of indivdual replicates[†]

K Rates (Kg/ha)	Rep. I		Rep. II		Rep. III		Rep. IV		Rep. V	
	Brix	Pol	Brix	Pol	Brix	Pol	Brix	Pol	Brix	Pol
K from stillage broadcast										
0	19.2	16.3	17.0	14.5	18.5	17.6	19.2	16.9	18.4	16.6
60	18.8	16.2	18.8	16.0	20.0	17.1	18.0	15.4	18.4	16.1
120	20.0	16.4	19.7	17.3	19.8	17.3	19.6	17.6	20.2	18.0
240	18.6	15.1	18.7	16.3	19.2	16.9	19.5	17.1	17.6	16.0
480	17.6	15.4	18.4	15.2	18.3	15.9	19.8	17.6	17.4	15.5
960	17.0	14.1	16.6	14.1	19.6	15.4	18.2	15.9	17.0	15.1
1920	16.6	13.7	16.6	13.1	18.2	15.2	18.4	14.5	16.8	14.0
K from KCl broadcast										
0	19.2	16.3	17.0	14.5	18.5	17.6	19.5	16.9	18.4	16.6
60	18.5	16.2	18.6	15.4	18.6	16.0	19.2	17.5	19.2	16.9
120	19.0	16.7	18.3	16.0	18.7	16.6	18.8	16.4	18.5	15.7
240	19.3	16.5	20.0	16.8	19.8	17.2	19.2	16.7	18.3	16.6
480	19.2	16.6	18.8	16.1	18.6	16.6	19.2	16.9	18.1	16.0
K from stillage in the furrow										
0	19.2	16.3	17.0	14.5	18.5	17.6	19.5	16.9	18.4	16.6
60	18.2	15.9	18.0	15.2	18.9	16.7	18.5	16.0	18.6	16.0
120	18.3	15.2	18.8	16.5	18.0	15.2	19.0	16.6	18.2	16.1
240	18.6	16.2	18.4	15.8	18.4	16.1	18.2	16.8	18.4	16.0
480	17.8	15.1	19.3	16.3	17.5	15.0	19.2	16.8	18.6	16.6
K from stillage broadcast + N										
240	16.0	13.3	16.5	13.6	17.8	15.5	19.4	17.1	19.0	16.5
K from stillage broadcast + ripener										
480	19.6	17.5	19.4	17.3	19.2	17.1	20.0	17.8	19.6	17.6
960	18.3	15.6	17.7	16.6	18.7	15.3	19.9	17.8	20.6	17.7
K from stillage broadcast + dolomite										
480	18.3	15.5	18.0	15.0	18.2	15.8	19.0	16.8	18.0	15.6
960	17.9	14.9	18.8	15.8	19.7	17.4	18.8	15.7	18.6	15.5

[†] Values are means of five replicates.

Table 38. Effects of K from stillage and KCl, dolomite on soil exchangeable cations and Al, and soil pH before and after cropping at 20-40 cm depth†

K Rates (Kg/ha)	Exchangeable Cations						Exch. Al		Soil pH	
	15 days			450 days			15 days	450 days	15 days	450 days
	Ca	Mg	K	Ca	Mg	K				
	meq/100 g									
	K from stillage broadcast									
0	3.60	0.39	0.07	3.68	0.26	0.05	0.58	0.63	4.60	4.80
60	3.72	0.42	0.08	4.39	0.35	0.06	0.56	0.92	4.74	4.72
120	4.00	0.45	0.09	4.41	0.36	0.09	0.60	0.88	4.78	4.76
240	4.10	0.49	0.11	4.46	0.43	0.10	0.56	0.86	4.82	4.88
480	4.14	0.55	0.13	4.50	0.52	0.11	0.28	0.70	4.90	4.86
960	4.24	0.60	0.27	4.68	0.56	0.13	0.17	0.46	5.08	4.94
1920	4.38	0.67	0.53	4.82	0.80	0.21	0.22	0.40	5.20	5.14
	K from KCl broadcast									
0	3.60	0.39	0.07	3.68	0.26	0.05	0.58	0.63	4.60	4.80
60	3.50	0.38	0.07	4.02	0.24	0.06	0.40	0.91	4.58	4.88
120	4.20	0.39	0.08	4.12	0.31	0.09	0.30	0.54	4.80	4.92
240	4.04	0.42	0.08	4.16	0.34	0.11	0.54	0.79	4.74	4.94
480	3.80	0.41	0.10	4.20	0.40	0.11	0.50	0.92	4.58	4.70
	K from stillage in the furrow									
0	3.60	0.39	0.07	3.68	0.26	0.05	0.58	0.63	4.60	4.80
60	3.80	0.44	0.09	3.64	0.24	0.05	0.64	0.96	4.58	4.88
120	3.96	0.48	0.13	3.46	0.28	0.06	0.60	0.84	4.78	4.90
240	4.08	0.54	0.15	3.25	0.32	0.07	0.59	0.92	4.80	4.88
480	4.20	0.60	0.24	3.28	0.41	0.08	0.52	0.98	4.90	4.92
	K from stillage broadcast + dolomite									
480	4.10	0.60	0.14	4.16	0.60	0.13	0.13	0.59	5.18	5.10
960	4.30	0.72	0.26	4.46	0.72	0.15	0.14	0.48	5.30	5.20

†Values are means of five replicates.

Table 39. Effects of K from stillage and KCl, dolomite on soil exchangeable cations and Al, and soil pH before and after cropping at 40-60 cm depth†

K Rates	Exchangeable Cations						Exch. Al		Soil pH	
(Kg/ha)	15 days			450 days			15	450	15	450
	Ca	Mg	K	Ca	Mg	K	days	days	days	days
	meq/100 g									
				K from stillage broadcast						
0	1.60	0.14	0.05	1.86	0.17	0.03	0.54	0.65	4.62	4.68
60	1.70	0.15	0.05	1.88	0.22	0.04	0.68	1.02	4.38	4.58
120	1.80	0.18	0.05	1.99	0.23	0.05	0.50	0.80	4.54	4.74
240	1.82	0.20	0.06	2.24	0.28	0.07	0.65	0.90	4.70	4.80
480	1.84	0.23	0.09	2.34	0.30	0.08	0.35	0.92	4.74	4.80
960	1.90	0.25	0.16	2.56	0.38	0.11	0.54	0.86	4.78	4.84
1920	2.02	0.29	0.24	3.16	0.55	0.16	0.44	0.80	4.92	4.86
				K from KCl Broadcast						
0	1.60	0.14	0.05	1.86	0.17	0.03	0.54	0.65	4.62	4.68
60	1.72	0.15	0.05	1.84	0.20	0.05	0.52	0.57	4.44	4.66
120	1.70	0.16	0.05	2.03	0.22	0.06	0.50	0.42	4.70	4.78
240	1.75	0.12	0.05	2.27	0.24	0.07	0.68	0.50	4.60	4.80
480	1.75	0.16	0.05	2.46	0.26	0.08	0.65	0.85	4.52	4.60
				K from stillage in the furrow						
0	1.60	0.14	0.05	1.86	0.17	0.03	0.54	0.65	4.62	4.68
60	1.29	0.17	0.08	1.74	0.16	0.03	0.62	0.68	4.52	4.68
120	1.36	0.21	0.10	1.89	0.20	0.04	0.58	0.70	4.64	4.80
240	1.39	0.24	0.12	2.01	0.23	0.05	0.63	0.72	4.70	4.78
480	1.46	0.28	0.16	2.14	0.26	0.06	0.48	0.80	4.80	4.84
				K from stillage broadcast + dolomite						
480	1.67	0.25	0.10	2.32	0.34	0.09	0.24	0.81	4.74	4.86
960	1.64	0.28	0.18	2.45	0.42	0.12	0.25	0.62	4.90	4.98

†Values are means of five replicates.

Table 40. Effects of K rates from stillage, KCl, and dolomite on exchangeable cations and Al and soil pH at the 0-20 cm depth[†]

K Rates (Kg/ha)	Exchangeable Cations									Exchangeable Al			Soil pH		
	120 days			210 days			300 days			120 days	210 days	300 days	120 days	210 days	300 days
	Ca	Mg	K	Ca	Mg	K	Ca	Mg	K						
	meq/100														
	K from stillage broadcast														
0	5.83	0.54	0.11	5.72	0.53	0.10	5.53	0.50	0.10	0.62	0.52	0.56	4.90	4.92	4.92
60	6.18	0.56	0.17	6.02	0.55	0.15	5.73	0.53	0.14	0.54	0.58	0.54	4.93	4.98	5.00
120	6.80	0.74	0.19	6.56	0.72	0.17	6.16	0.70	0.16	0.42	0.44	0.42	5.09	5.10	5.12
240	6.87	0.78	0.26	6.57	0.75	0.22	6.29	0.72	0.20	0.26	0.30	0.34	5.34	5.30	5.26
480	6.90	0.92	0.36	6.52	0.87	0.27	6.23	0.84	0.22	0.18	0.24	0.28	5.44	5.40	5.34
960	7.05	1.21	0.49	6.52	1.17	0.34	6.23	1.12	0.31	0.15	0.22	0.24	5.58	5.46	5.40
1920	6.85	1.18	0.88	6.60	1.12	0.60	6.12	1.06	0.55	0.12	0.18	0.20	5.68	5.54	5.50
	K from KCl broadcast														
0	5.83	0.54	0.11	5.72	0.53	0.10	5.53	0.50	0.10	0.62	0.52	0.56	4.90	4.92	4.92
60	5.32	0.54	0.13	5.21	0.53	0.11	5.16	0.53	0.09	0.54	0.57	0.58	5.00	4.96	4.98
120	6.12	0.64	0.16	5.94	0.62	0.15	5.66	0.59	0.14	0.31	0.37	0.42	5.09	5.10	5.10
240	5.45	0.58	0.21	5.30	0.55	0.17	5.28	0.52	0.15	0.45	0.48	0.52	4.98	5.12	5.12
480	5.60	0.58	0.27	5.42	0.54	0.24	5.21	0.50	0.21	0.60	0.66	0.56	4.86	4.94	4.98
	K from stillage in the furrow														
0	5.83	0.54	0.11	5.72	0.53	0.10	5.53	0.50	0.10	0.62	0.52	0.56	4.90	4.92	4.92
60	6.02	0.46	0.17	5.74	0.45	0.14	5.30	0.44	0.13	0.50	0.52	0.54	4.96	4.98	4.98
120	6.28	0.56	0.21	5.88	0.54	0.17	5.49	0.53	0.15	0.46	0.48	0.48	4.98	5.10	5.06
240	6.36	0.67	0.25	5.96	0.64	0.21	5.63	0.63	0.17	0.42	0.47	0.47	5.00	5.10	5.10
480	6.56	0.78	0.38	6.26	0.73	0.26	5.86	0.70	0.21	0.40	0.44	0.46	5.12	5.16	5.18
	K from stillage broadcast + dolomite														
480	7.26	1.41	0.30	6.98	1.38	0.21	6.86	1.34	0.18	0.04	0.08	0.10	5.54	5.58	5.68
960	7.46	1.68	0.45	7.16	1.52	0.30	6.92	1.40	0.26	0.02	0.06	0.10	5.84	5.88	5.72

[†]Values are means of five replicates.

Table 41. Effects of K rates from stillage, KCl, and dolomite on exchangeable cations and Al and soil pH at the 20-40 cm depth[†]

K Rates (Kg/ha)	Exchangeable Cations									Exchangeable Al			Soil pH		
	120 days			210 days			300 days			120 days	210 days	300 days	120 days	210 days	300 days
	Ca	Mg	K	Ca	Mg	K	Ca	Mg	K						
	meq/100														
	K from stillage broadcast														
0	4.12	0.41	0.06	4.00	0.37	0.06	3.92	0.32	0.06	0.60	0.63	0.65	4.64	4.80	4.78
60	4.70	0.45	0.08	4.61	0.42	0.08	4.54	0.40	0.08	0.70	0.74	0.88	4.84	4.74	4.74
120	4.86	0.50	0.09	5.00	0.45	0.12	4.82	0.41	0.11	0.74	0.74	0.84	4.76	4.74	4.72
240	4.96	0.55	0.15	4.68	0.52	0.14	4.59	0.49	0.13	0.74	0.78	0.84	4.88	4.94	4.88
480	4.93	0.73	0.17	4.69	0.66	0.16	4.61	0.60	0.14	0.52	0.60	0.68	4.94	4.98	4.92
960	5.32	0.79	0.22	5.11	0.70	0.19	4.99	0.65	0.17	0.37	0.39	0.41	5.12	5.14	4.98
1920	5.50	0.88	0.34	5.21	0.86	0.25	5.02	0.83	0.23	0.44	0.46	0.42	5.26	5.24	5.18
	K from KCl broadcast														
0	4.12	0.41	0.06	4.00	0.37	0.06	3.92	0.32	0.06	0.60	0.63	0.65	4.64	4.80	4.78
60	3.94	0.42	0.08	3.82	0.34	0.08	3.86	0.30	0.07	0.67	0.85	0.85	4.68	4.74	4.82
120	4.50	0.44	0.12	4.41	0.40	0.12	4.29	0.37	0.11	0.50	0.52	0.54	4.88	4.86	4.86
240	4.28	0.49	0.17	4.25	0.43	0.15	4.18	0.39	0.13	0.74	0.76	0.80	4.82	4.90	4.92
480	4.42	0.50	0.19	4.38	0.47	0.16	4.30	0.45	0.14	0.82	0.86	0.90	4.72	4.74	4.68
	K from stillage in the furrow														
0	4.12	0.41	0.06	4.00	0.37	0.06	3.92	0.32	0.06	0.60	0.63	0.65	4.64	4.80	4.78
60	3.92	0.40	0.10	3.81	0.38	0.07	3.73	0.32	0.06	0.86	0.88	0.92	4.80	4.86	4.90
120	4.24	0.45	0.11	4.19	0.38	0.08	4.09	0.34	0.07	0.73	0.76	0.82	4.94	4.92	4.94
240	4.50	0.50	0.12	4.10	0.44	0.09	3.65	0.39	0.08	0.82	0.85	0.88	4.92	4.92	4.86
480	4.90	0.54	0.16	4.40	0.50	0.12	3.90	0.47	0.10	0.68	0.88	0.92	4.96	4.98	4.94
	K from stillage broadcast + dolomite														
480	5.10	0.75	0.21	4.92	0.71	0.18	4.63	0.68	0.15	0.49	0.52	0.54	5.26	5.20	5.12
960	4.86	0.80	0.28	4.72	0.78	0.24	4.66	0.76	0.21	0.44	0.46	0.44	5.40	5.32	5.26

[†] Values are means of five replicates.

Table 42. Effects of K rates from stillage, KCl, and dolomite on exchangeable cations and Al and soil pH at the 40-60 cm depth[†]

K Rates (Kg/ha)	Exchangeable Cations									Exchangeable Al			Soil pH		
	120 days			210 days			300 days			120 days	210 days	300 days	120 days	210 days	300 days
	Ca	Mg	K	Ca	Mg	K	Ca	Mg	K						
	meq/100														
	K from stillage broadcast														
0	1.60	0.14	0.05	1.70	0.15	0.04	1.78	0.15	0.04	0.60	0.62	0.64	4.58	4.70	4.66
60	1.71	0.18	0.06	1.72	0.19	0.05	1.78	0.20	0.05	0.84	0.82	0.92	4.46	4.42	4.48
120	1.82	0.22	0.06	1.86	0.22	0.06	1.90	0.22	0.05	0.58	0.68	0.72	4.64	4.72	4.70
240	1.90	0.26	0.07	1.98	0.26	0.07	2.08	0.27	0.07	0.74	0.76	0.78	4.74	4.78	4.80
480	2.92	0.28	0.10	2.04	0.29	0.10	2.16	0.30	0.09	0.61	0.82	0.84	4.78	4.80	4.84
960	2.22	0.40	0.14	2.18	0.40	0.12	2.31	0.41	0.12	0.68	0.70	0.88	4.88	4.92	4.90
1920	2.32	0.48	0.21	2.46	0.51	0.19	2.64	0.52	0.18	0.52	0.66	0.76	4.98	4.94	4.96
	K from KCl broadcast														
0	1.60	0.14	0.05	1.70	0.15	0.04	1.78	0.15	0.04	0.60	0.62	0.64	4.58	4.70	4.66
60	1.76	0.17	0.06	1.78	0.17	0.06	1.80	0.18	0.05	0.64	0.63	0.64	4.60	4.64	4.70
120	1.81	0.20	0.07	1.74	0.21	0.07	1.82	0.21	0.07	0.56	0.58	0.58	4.68	4.70	4.68
240	1.92	0.15	0.08	2.01	0.17	0.08	2.11	0.19	0.08	0.70	0.72	0.74	4.60	4.84	4.88
480	2.18	0.22	0.11	2.26	0.23	0.10	2.56	0.24	0.10	0.64	0.72	0.78	4.54	4.66	4.58
	K from stillage in the furrow														
0	1.60	0.14	0.05	1.70	0.15	0.04	1.78	0.15	0.04	0.60	0.62	0.64	4.58	4.70	4.66
60	1.35	0.22	0.08	1.50	0.20	0.07	1.72	0.18	0.05	0.60	0.64	0.66	4.64	4.70	4.68
120	1.76	0.28	0.10	1.82	0.26	0.08	1.91	0.24	0.06	0.66	0.70	0.72	4.72	4.78	4.82
240	1.42	0.32	0.11	1.54	0.29	0.10	1.79	0.27	0.07	0.70	0.72	0.74	4.88	4.82	4.84
480	1.48	0.38	0.14	1.63	0.34	0.11	1.93	0.31	0.08	0.64	0,80	0.78	4.88	4.88	4.86
	K from stillage broadcast + dolomite														
480	1.90	0.38	0.11	2.02	0.37	0.11	2.12	0.36	0.10	0.62	0.78	0.79	4.82	4.88	4.90
960	2.04	0.50	0.15	2.16	0.48	0.14	2.23	0.46	0.14	0.35	0.57	0.60	4.98	5.04	5.02

[†] Values are means of five replicates.

Table 43. Effects of K from stillage, KCl broadcast and stillage plus dolomite on +3 leaf concentration, and total plant concentration at 15 months of age (harvest)†

K Rates	+3 Leaf (%)					Total Plant Conc. (%)				
(Kg/ha)	N	P	K	Ca	Mg	N	P	K	Ca	Mg
					K from stillage broadcast					
0	1.46	0.16	0.60	0.50	0.16	0.43	0.07	0.40	0.20	0.15
60	1.49	0.16	0.69	0.52	0.16	0.44	0.07	0.42	0.21	0.16
120	1.49	0.16	0.75	0.48	0.14	0.47	0.07	0.45	0.19	0.14
240	1.51	0.16	0.87	0.43	0.14	0.50	0.08	0.52	0.19	0.14
480	1.59	0.17	0.91	0.42	0.12	0.51	0.08	0.56	0.17	0.14
960	1.63	0.17	0.99	0.34	0.11	0.54	0.07	0.65	0.16	0.14
1920	1.66	0.17	1.03	0.33	0.11	0.62	0.07	0.76	0.15	0.14
					K from KCl broadcast					
0	1.46	0.16	0.60	0.50	0.16	0.43	0.07	0.40	0.20	0.15
60	1.45	0.16	0.68	0.51	0.15	0.40	0.07	0.42	0.21	0.16
120	1.48	0.17	0.83	0.48	0.14	0.47	0.08	0.48	0.18	0.15
240	1.42	0.16	0.84	0.44	0.14	0.43	0.06	0.50	0.16	0.14
480	1.49	0.16	0.84	0.42	0.13	0.47	0.06	0.56	0.16	0.15
					K from stillage in the furrow					
0	1.46	0.16	0.60	0.50	0.16	0.43	0.07	0.40	0.20	0.15
60	1.48	0.17	0.66	0.52	0.15	0.43	0.07	0.43	0.20	0.16
120	1.48	0.16	0.68	0.52	0.16	0.45	0.07	0.44	0.19	0.16
240	1.49	0.16	0.70	0.47	0.16	0.47	0.07	0.50	0.18	0.16
480	1.52	0.17	0.90	0.44	0.14	0.54	0.08	0.59	0.18	0.15
					K from stillage broadcast + N					
240	1.59	0.17	0.86	0.44	0.14	0.57	0.07	0.52	0.20	0.15
					K from stillage broadcast + ripener					
480	1.39	0.16	0.90	0.42	0.12	0.48	0.07	0.56	0.17	0.14
960	1.48	0.17	1.00	0.39	0.10	0.48	0.08	0.70	0.16	0.14
					K from stillage broadcast + dolomite					
480	1.54	0.18	0.83	0.43	0.14	0.51	0.09	0.54	0.19	0.16
960	1.58	0.18	0.83	0.43	0.13	0.55	0.09	0.59	0.20	0.17

†Values are means of five replicates.

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