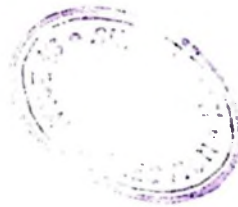


EFFECTS OF RATE AND TIME OF NITROGEN APPLICATION
ON GROWTH, LEAF NUTRIENT CONTENTS AND YIELD OF
SUGARCANE AT KILOMBERO SUGAR ESTATES

BY



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1985

DECLARATION

I, Abdallah Salum Mkelenda do hereby declare to the Senate of The University of Dar es Salaam that this thesis is my own original work and it has not been submitted for the award of a degree in any other University.

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ABSTRACT

A field study on the effects of rate and time of nitrogen fertilization on growth, leaf nutrient contents and yield of sugarcane (Saccharum officinarum) variety N. Co.376 was conducted at Kilombero Sugar Estates in Morogoro region during the 1982/83 cropping season. Four rates of N and three different times of application were tested in factorial combination in a randomized block design using a plantcane crop. The N rates were 0, 100, 200 and 300 kg N/ha applied as ammonium sulphate. The times of application were (i) all the N applied at planting, (ii) all the N applied at three months, and (iii) N applied in two split doses: one half at planting, and the rest at three months. The crop was grown for twelve months.

The germination, stalk population counts, and the heights of the plants were determined. The N, P, K, Ca and Mg nutrition of the crop were assessed by analysing cane leaves sampled from two- and four-months old plants. The yield and quality of the crop were determined at harvest time.

The germination was good and was not affected by the treatments. Nitrogen fertilization increased stalk population, and cane growth significantly.

Nitrogen application increased the concentration of N in the leaves sampled at the two ages. For the two months samples the leaf N concentration ranged from 1.87% to 2.29%, while for the four months samples the concentration ranged from 1.38% to 1.94%. Leaf N

concentrations in the four months old plants were highly correlated with sucrose contents in the plants, cane yield, and sugar yield suggesting that leaf N concentration could be used in predicting these parameters. Using a curvilinear relationship between leaf N concentration and sugar yield a tentative critical N concentration of 1.78% was established. The concentrations of P, K, Ca, and Mg were considered to be within the adequate range for the crop.

All rates of N increased cane yield significantly but sugar yield increased with increase in applied N only up to 100 kg N/ha. Further increase in N did not cause further increase in sugar yield mainly because of the negative effect of higher rates of N on sucrose accumulation in cane plants. In addition, nitrogen application reduced the quality of the juice; i.e. the brix, pol and juice purity. Time of application did not have any significant effect on any of these parameters.

The results of the study suggest that the optimum rate of N for sugar production in Ruaha area of Msolwa Estate is around 100 kg N/ha and that all the N can be applied in the furrows at planting. Also leaf analysis technique can be used for assessing the sufficiency of N in cane plants.

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1. INTRODUCTION

The sugar industry in Tanzania plays a great role in the national economy. At the national level, sugar production does not only earn the nation foreign currency, but also reduces the national expenditure on importing it. Sugar is among the raw materials used in some chemical and food processing industries in the country. Apart from industrial use, sugar is one of the food components widely used by the people throughout the country. Because of the importance of sugar in the national economy, the government has been urging high production of the commodity to meet internal demand and to have surplus for export (Anonymous, 1983a).

Although the need for self sufficiency in sugar production has been realised for a long time (BRD, 1961), local demand for the commodity is still far above production. During the recent past sugar production has not been steady (Anonymous, 1983b), and in some of the estates the production has been declining markedly. Sometimes these production trends have been caused by low cane yield and poor quality of the crop.

Sugar production in the country can be improved by improving yield and quality of the crop through good crop management especially N fertilization. Response of sugarcane to applied N is normally high and consequently, N fertilizers are widely used by cane growers to improve yield. However, in Tanzania where optimum rates and time of N fertilization have not been established, overdependence on N

fertilization to improve yield may be frustrating. Excessive N supply to sugarcane normally has a negative effect on the quality of the crop and often causes a decline in sugar yield (Wood, 1968; Humbert, 1968; Husz, 1972; Wang, 1976). In addition such high amounts of N can be expensive and may easily cause pollution because N is highly mobile in soil.

This study was therefore, aimed at:-

1. determining the optimum rate of N for sugarcane;
2. determining the appropriate time of applying the nutrient to the crop as well as assessing the significance of applying N in single dose versus split doses;
3. assessing the effect of rate and timing of N application on sugar yield and other yield components of sugarcane;
4. and evaluating the possibility of using leaf analysis data in assessing N supply capacity of the soil, and N sufficiency in sugarcane plants.

2. LITERATURE REVIEW

2.1 Effect of N Application on Sugarcane Yield

Various studies have shown that economic yield of sugarcane depends on the quality and quantity of cane during harvesting, and that N supply to the crop during growth highly affect both of these factors (Wood, 1968; McAleese et al., 1970; Gupta and Prasad, 1971a,b; segura and Martinez, 1973; Ojha et al., 1974; Singh, 1974b; Singh, 1975; Rao et al., 1975; Patil et al., 1979). Generally an abundant supply of N to sugarcane results in high tillering and fast growth, while under inadequate supply of the nutrient, the life cycle of the crop is usually shortened and early senescence occurs.

Humbert (1968) summarized the role of N on sugarcane growth and stated that the nutrient plays a great role in cane growth and development as well as in tillering. Husz (1972) pointed out that N enables the suckers and bull shoots to mature earlier without affecting older stalks. Takahashi (1972) and Salunkhe et al. (1981) found N application to have a positive effect on stalk population, while Singh (1974a), and Thomas and Oerther (1975) reported an increase in cane growth when N was applied.

Many workers have shown that N supply to sugarcane has some effect on the quality of cane juice extracted at milling (Humbert, 1968, Clements, 1962, Ojha et al., 1974; Wang, 1976). The nutrient affects

the apparent percentage of sucrose in the juice i.e. the pol, as well as the percentage of soluble solids in the juice i.e. the brix, both of which determine the final commercial yield of the crop. Generally, high supply of N to sugarcane has a negative effect on the juice quality at harvest. In Queensland, McAleese et al. (1970), after surveying eight different cane growing areas, found that excessive use of N fertilizers in some areas decreased sugar content. Ojha et al. (1974) found a decrease in pol and purity of the juice over the control as N rates were increased although there was a significant increase in cane yield due to the treatment. Singh (1974b) obtained similar results with farm-yard manures, oil cake, and sulphate of ammonia. despite the differences in N supply capacity he noticed among the N sources he used. The negative effect of N rate of application on pol in the juice has also been reported by Gervet et al. (1978). Thomas and Schimidt (1978) found low juice pol and purity when N in juice was high. On the other hand, Valdivia et al. (1978) applied about 119 to 454 kg N/ha in split doses but did not find significant effect of N rate of application on pol, brix, or purity of the juice.

Reduction in juice quality due to excessive supply of N to sugarcane has been described in terms of NO_3^- accumulation in cane leaves which depresses sucrose formation in the stalks (Wang, 1976).

Many studies have shown a negative relationship between sugar yield and intensity of flowering especially when the crop is harvested.

at some three or more months after flowering. Clements and Awada (1964) estimated that about 25% yield loss occurs to a two year crop when tasseling is between 75 to 80%. These workers observed that for the two year crop, first season tasseling was one of the major problems frustrating cane growers. In Barbados, Rao (1973) found a decrease in cane weight, juice brix and total sugars due to flowering in the two varieties he tested.

Nitrogen supply to sugarcane affects cane flowering. Heavy application of the nutrient normally has an inhibitory effect on flowering. Gosnell (1973) investigated flowering behaviour of 52 cane varieties and found flowering to increase with reduction in rates of N applied. Similar results were reported by Allam et al. (1977). The intensity of flowering also varies with timing of N fertilization. Burr (1950) found heavy flowering when all N was applied at planting, and fewer flowers when the nutrient was applied in split doses.

2.2 Nitrogen Requirement by Sugarcane

Although the soil contains the highest N reserve (Delwiche, 1970), many studies have shown that much of it is not immediately available to plants because it occurs as a constituent of organic matter. In addition, many workers have shown that the amount of N released by mineralisation in the tropics is not, in most cases, adequate for crop needs. Although these areas have high rates of biochemical

decomposition of organic matter, the prevailing conditions favour rapid losses of N as soon as it is released. Consequently, sugarcane grown in these areas can not meet its N requirements from this source. Many studies have thus shown high response of sugarcane to applied N, and have found the rates of N applied to the crop to be normally high. However, due to differences in environmental conditions, many workers have found the rates of N applied to the crop to vary considerably (Carley and Robinson, 1953; Hodnett, 1956; De Gues, 1967). Reviews of rates of N applied to sugarcane are given by Wood (1968), Husz (1972) and Wang (1976).

Wang (1976) described variation in rates of fertilizers applied to sugarcane to be due to variation in age of the crop, time of planting, soil properties, climate and varieties grown. The rates of N used on sugarcane depend on whether the crop is plant or ratoon cane, and whether the crop is irrigated or rainfed. Carley and Robinson (1953) and Hodnett (1956) found plantcane to have lower response than subsequent ratoons. In addition, these workers found irrigation to have a positive influence on cane response to applied N even where rainfall was high. Lakshmikantham et al. (1962) showed that application of about 112 kg N/ha gave higher sugar yield when irrigation was done once every six days than when done once after every 18 days. In Puerto Rico, Samuels (1965) reported that application of about 168 kg N/ha gave 50% more cane from irrigated than from rainfed conditions.

In South Africa, Wood (1968) reported variation in cane response to applied N with soil types. He reported high responses by plant-cane in soils derived from ordinary Table Mountain sandstones and Dwykatillite.

On the other hand, Kar and Bajpai (1971) found differences in nutrient absorption capacities among varieties. They found high yielding varieties to have greater absorption capacity for nutrients than low yielding varieties. The former had, therefore, higher fertilizer requirements.

Variation in the rates of N applied to sugarcane seems to be related to variation in cane response to applied N. Wood (1968) described variation in response of cane to applied N to be due to factors which have greater influence on yield than the fertilizer itself. He named those factors as season, soil moisture, and soil type. Some workers have demonstrated relationships between sugarcane yield and those factors. Ibrahim (1977) found high correlation between yield and soil exchangeable K and clay content in Sudan. While Golden (1975) found cane yield to be more related to depth of top soil than to the soil chemical properties.

Other workers have also found yield and yield components of sugarcane to be influenced by climatic conditions. Tung (1969) described abnormal temperatures, irregular rainfall pattern and low sunshine to be responsible for low sugar yield during 1968/69 season.

In Jamaica it was found that the low cane sucrose content in the 1969 and 1970 crops was due to high minimum winter temperature and late rains before and during harvesting (Anonymous, 1970). Puyaoan and Cruz (1973) found solar radiation and rainfall to be important factors in sugarcane production at Cantubarg Sugar Estates. Shaw and Innes (1965) reported yield and the manner it accumulated to be primarily influenced by seasonal conditions, while Aughtry (1958) found growth rates to be governed by climatic factors.

Due to variation in N requirement by sugarcane, every cane growing area usually establishes its N rates of application to the crop. Tissue analysis is a useful tool in establishing the requirements of N and other nutrients for sugarcane (Barnes, 1964; Humbert, 1968; Husz, 1972). However, many workers have found data from tissue analysis to vary considerably. Steenbjerg (1951) and Cottenie (1980) described mineral element composition of plants to be influenced by (1) soil properties, (2) plant species, (3) climatic condition of the place, (4) physiological age of the plant and (5) part of the plant sampled. In Mauritius a decrease in N, P, Mn and S levels was reported in cane leaves with increase in cane age (Anonymous, 1973). However, no alterations in K, Ca, and Mg contents were observed under the same condition. Cottenie (1980) described the variation in mineral composition of plants with age as due to differences in the rates of dry matter accumulation in the plants which cause dilution effect.

Due to variations in leaf analysis data, many workers have emphasized the importance of standardization of sampling techniques

and proper understanding of environmental conditions (Broeshart and Schouweinburg, 1961; Husz, 1972; Cotteni^o, 1980). For sugarcane the 3rd, 4th, 5th and 6th leaves from the apex are normally used for analysis (Husz, 1972). And for proper assessment of changes in the nutrient status of the crop, Husz (1972) recommended collection of the leaves every 35 days.

Inspite of the general variation in leaf analysis data, many studies have shown some significant correlations between nutrient concentrations in cane leaves and yield and many yield parameters of sugarcane (Singh 1973, 1975). Singh (1973) conducted N fertilizer trials and found a strong positive correlation of leaf N concentration with cane yield. He also observed strong negative correlation between N concentration in cane leaves with sucrose content in the plants, and purity of juice. In Texas, Thomas and Oerther (1975) found cane yield to be significantly related to leaf N concentration during early June. Singh (1974a) found positive linear relationship between leaf N concentration and growth of sugarcane plants. Perumal (1979) showed.

that maintenance of high leaf sheath moisture and K concentration and high leaf N in the early stages of growth contributed to high cane and sugar yield at harvest. He further found that reduction in all the three parameters at harvest was necessary for high sugar yield. Similar observations were made by Raghavaiah et al. (1981).

In order to describe the relationship between nutrient concentration in plant tissues and crop performance it is necessary to have a concentration value separating deficient from sufficient supply of the nutrient in question. Among the levels commonly used is the critical level which is used to indicate the concentration below which reduction in yield may be expected as a consequence of nutrient deficiency (Cottenie, 1980). This level has been defined by others as the content below which the yield is less than 90% of that obtained with adequate fertilization (Braud, 1972, quoted by Cottenie, 1980). Schmehl and Humbert (1964) reported a 1.0% N in 3rd, 4th, 5th and 6th leaf blades as the critical level for sugarcane. Clements (1953, 1957) gave 2.0% N as minimum leaf N concentration for six to eight months old sugarcane crop. In Guyana Evans (1955a,b) reported different minimum N concentration according to cane age. He found the minimum N concentration to be 2.5% for three months old cane, 2.2-2.3% for four and half months old cane, and 2.0-2.1% N for six months old cane. However, the later two workers did not include the midribs of the leaves during the analyses. Cottenie^o (1980) cited N critical level in sugarcane leaves to range from 1.0-1.5% on dry matter basis.

Summaries of other reports are given by De Gues (1967), Chapman (1968), Humbert (1968), and Husz (1972). It is evident from these reports that critical N levels vary with age of the crop, sampling technique employed and location, and thus values established in one area may not be valid in another.

From plant analysis data it is also possible to establish quantities of N removed by sugarcane. Barnes (1964) reported that a crop of 50 tons cane per acre removed 75 - 90 kg N/acre. Kisselmann (1969) estimated that for a yield of 100-180t cane/ha, sugarcane removed 150-180 kg N/ha. In general, many workers have shown that for every metric ton of cane 0.5-1.2 kg N is normally removed from soil (Barnes, 1953; Du Toit, 1955; Humbert, 1963; Husz, 1968).

2.3 Timing of N Fertilizers to Sugarcane

Proper timing of N application is important to ensure high sugarcane yield and good quality of the juice (Baver, 1963; Takahashi, 1966; Humbert, 1968; Wood, 1968; Tripathi and Jaiswal, 1974; Wang, 1976; Espironelo et al., 1977). Many studies have shown that in order to get high cane response to applied N, the nutrient has to be applied to the crop at early stages of growth (Baver, 1963). Wood (1968) and Wang (1976) reviewed literature on the effect of timing of N fertilization to sugarcane and reported that improper timing of N fertilizers resulted in low cane yield, poor juice quality and subsequently, low sugar yield. Wang (1976) therefore suggested ways of improving

sucrose content of sugarcane in Taiwan with respect to N fertilization by stressing the need to control the rates of N applied at ripening, and proper timing of the last N doses.

Takahashi (1966) found recovery of applied N to be appreciably affected by rate and time of N applied. From Brazil it was reported that out of the seven experiments done in four types of soil to study the effects of rate and time of N application, five experiments with total application of N at two months caused a significant increase in cane yield (Espironelo et al., 1977). In addition, a combined analysis of four experiments in two years on Latosol showed a favourable effect of N on cane and sugar production with tendency of better utilization of the nutrient by the crop in the case of split and total application of N at two months after planting than at eight months. Tripathi and Jaiswal (1974) reported high yields and greater profit when all N was applied at planting than when it was applied in split doses despite the lower germination percentages experienced in the former practice. Humbert (1968) recommended from results of many experiments carried out in Java that in order to secure higher yields from 14 months crop N had to be applied not later than two months after planting.

The influence of timing of N fertilization on sugarcane yield is related to the way N is utilized by the crop. In India, Srivastava and Pandit (1970) found application of adequate doses of N during the formative phase of the crop to give higher yields than when the nutrient

was applied even in split doses during the period of maximum removal of N by the crop. Srivastava (1970a, 1970b) noted that unlike many other agricultural crops where N application had to be done according to their requirement, application of N to sugarcane during elongation phase when the highest N absorption occurs did not commonly result into high yields. He related his observation to the general role of N on enhancing tillering. And he concluded that since early tillering was of decisive importance in building up the commercial crop, N had to be applied at early stages of crop growth so that the nutrient can be used effectively in developing tillers. The importance of early tillering in sugarcane yield has been reported by Dillewijn (1952) who described early tillering to be necessary for the generation of greater number of millable stalks used at harvesting. Takahashi (1966) described application of large quantities of N at early stages of growth as necessary to enable larger yields of dry matter. He pointed out further that at that age cane plants possessed high efficiency of utilizing N, and could therefore recover much of the applied N. He described application of N at later stages of cane growth to cause substantial amounts of N to be unutilized by the crop.

Although application of N at early stages of sugarcane growth is described to be necessary in building up the commercial crop, some workers have pointed out the need for late N application in areas with light textured soils where N losses through leaching are high (Clements, 1960; Srivastava, 1970b). Ortega and Segura (1963) however, did not find higher yields when N was applied to the crop.

grown on sandy and sandy loam soils at ages later than four months.

The significancy of applying N to sugarcane in split doses varies. Many workers have found no significant effect of splitting N fertilization on sugarcane yield (Tanimoto and Burr, 1959; Ortega and Segura, 1963; Bieske, 1972; Tripathi and Jaiswal, 1974). Borden (1949) summarised results from 14 cooperative experiments and found that half of them favoured split application of N, but found the differences to be less than 10%, and the three which were statistically significant favoured single application.

Other workers have found split N application to have a positive effect on sugarcane yield, application of N in split doses has been reported to result into higher yields (Guedes et al., 1979), and better utilization of the nutrient by the crop (Espironalo et al., 1977). In Lousiana, Golden (1970) found that at least half of the experiments he did performed better with split application of N. Dagade et al. (1979) found similar results from applying 150 kg N/ha at 90 days after planting followed by a further 150 kg N/ha 45 days later.

On the other hand Samuels and Alers (1964) and Clements (1979) found low yields due to split N application. They ascribed the poor yields due to split N application to be due to deterioration in juice quality and general decline of sucrose content of the effected crop at harvesting.

It is thus evident from the above review that most of the experiments seem to favour early application of N. The negative effect found when N is applied in split doses seems to be related to the effect of the doses applied late in the growing season on sugarcane quality. It shows therefore, that N has to be applied at early stages of cane growth and that the practice of applying the nutrient in split doses has to be restricted to places where it has been found to be advantageous.

3. MATERIALS AND METHODS

3.1 Some Characteristics of the Study Area

The experiment was conducted at Kilombero Sugar Estates in Morogoro region. These estates lie between latitudes $7^{\circ} 30'$ and $7^{\circ} 50'$ South and longitudes $36^{\circ} 50'$ and $37^{\circ} 10'$ East. The geology of the area is composed of colluvial and alluvial sediments of neogene time overlying the Usagara rocks (Whittingham, 1963). These sediments are thought to have originated from the surrounding Gologolo and Migomberana mountains. They were deposited in the valley by the Great Ruaha river and its tributaries.

The area has a unimodal rainfall pattern. The rainy season starts in November/December and ends in May (Appendix 1). Annual precipitation is about 1400 mm. Since the rains are irregular and unreliable, unpredictable droughts and floods are not uncommon. The temperatures are usually high with an average of 28°C (Mnikonga, 1981), with little seasonal variation (Appendix 2). The relative humidity is also high with great seasonal fluctuations (Appendix 3). The mean annual evaporation is 1899 mm, while the mean annual sunshine hours is 6.4 (Mnikonga, 1981). April to September inclusive, have the least sunshine (Appendix 2).

Because of a long period of drought between June and October, a moisture deficit occurs during this period and thus most of the cane fields are irrigated during the period.

This study was conducted in field no. 86 of Msolwa estate in Ruaha area. The field was selected randomly but in accordance with the uprooting programme. About 0.5 ha of land was taken for this study from the 21 ha of the field.

3.2. Design of the Experiment and Field Layout

Twelve treatment combinations were evaluated in this study. These were: four rates of N from ammonium sulphate viz: 0, 100, 200 and 300 kg N/ha, and three different times of application viz: (i) application of all N at planting in the furrows with seed-sets, (ii) application of all N as a side dressing to three months old cane and (iii) application of N in two equal split doses one in furrows at planting and the other at three months as a side dressing.

A randomized block design was used for this experiment with three replicates. The size of the plots was 1.45 x 10m, and the spacing between the rows was 1.45m. Each plot was separated from adjacent plots by two guard rows one on each side.

3.3. Cane Planting and Post-planting Routine Operations

Cane planting was done on 28th October, 1982 by vegetative method using seed-sets with two buds. The variety used was N.Co 376. The seed-sets were planted by hand, and were placed horizontally in the furrows at about 20 cm depth with buds facing sideways. Seventy seed-sets, at 50% overlap were used for each treatment. Where N was

applied at this time, appropriate amounts of N as ammonium sulphate were placed in the furrow below the seed-sets. The seed-sets were covered with 3-4 cm of moist soil as recommended by other researchers (Humbert, 1968).

Weeding was done by hand hoes twice per month. When the soil appeared dry by hand feel, the field was irrigated by using overhead sprinklers. During irrigation sprinklers with net capacity of 12 mm water/hr. were fixed at 30m intervals to allow an 80% overlap of the discharge. The irrigation setting was normally three hours; and the interval varied depending on the occurrence and intensity of natural precipitation.

Excessive water in the field was avoided by digging parallel ditches which were about 70 cm deep at intervals of 30m. Waterpools were drained by cross ditches which were usually dug immediately after heavy rains.

Smut, a serious fungal disease in Kilombero estates was minimized by roguing the affected stools and disposing them by burying in deep pits outside the experimental field.

3.4 Sampling of Soil and Plant Materials

3.4.1 Soil sampling

For physico-chemical characterisation of the soil, soil samples from 0-15 cm, 15-30 cm, and 30-60 cm depths from two profiles in each block were collected prior to planting. The samples were air-dried and divided into two portions. One portion was sieved to pass through 2 mm sieve, while the other was ground to pass 60 mesh sieve; and stored in separate plastic bottles for analysis.

When the cane was three months old, soil samples were collected from the field for determination of inorganic N. This sampling was done in plots which were due for N application at three months. The samples were collected just before fertilizer application at the distance of 30 cm from the furrows, at the depth of 0-30 cm and 30-60 cm using an auger. The samples were dried at low temperature to facilitate sieving through 2 mm mesh and to stabilize the content of mineral N in soil (Jackson, 1958). The sieved samples were put into plastic bags and frozen to await the determination of mineral N.

3.4.2 Leaf sampling

Sugarcane leaves were sampled at the age of two and four months, respectively. In sampling, ten healthy cane stalks were selected randomly from every plot, and were permanently marked for leaf sampling. A sharp and clean knife was used to cut the third and fourth leaves from the top, from each of the selected plants as recommended by Jones

and Steyn (1973). The samples were collected into plastic bags and transported to the laboratory on the following day. At the laboratory, every leaf was decontaminated by first cleaning with tap water and rinsing thrice with distilled water. The samples were then put into paper bags and dried at 70°C for 48 hours. The samples were then ground and stored in plastic containers until they were analysed for N, P, K, Ca, Mg and Na.

3.5 Field Observations and Measurements

3.5.1 Germination percentages

The sprouting stools were counted three weeks after planting from every treatment, and the percentage germination was calculated by taking 140 stools per plot as 100%.

3.5.2 Growth measurements

Cane growth was measured monthly from the second month to the fifth month inclusive. Three stalks from each treatment previously ear-marked for leaf sampling were selected for this purpose. At the bottom of each of these stalks a wooden peg, 10 cm high, was fixed to make a constant base for the measurement, and the height of each stalk was measured accordingly.

3.5.3 Stalk counting

Cane counting was done three months after planting. During the process, a counting machine was used to count cane plants present in the plots.

3.6 Cane harvesting

The experimental plots were harvested on 28th October 1983 when the crop was twelve months old. Prior to harvesting, the field was burnt to reduce the amount of trash. The stalks were cut at soil level and the tops were removed by sharp pangas. The cane bundles from the plots were weighed using a scale hanging on a tractor-mounted jumbo crane. For laboratory analysis, three stalks were taken randomly from each plot.

3.7 Laboratory Analysis

3.7.1 Soil analysis

The soil texture was determined by the Hydrometer method as described by Day (1965). The pH values were determined in both 1:1 soil:water, and 1:1 soil:0.1N KCl paste, respectively (Dewis and Freitas, 1970).

Organic carbon was determined by the wet digestion method of Walkley and Black (Allison, 1965). Total nitrogen was determined by

the Macro-Kjeldahl method, while inorganic nitrogen was determined by the steam distillation method after extraction with 1N KCl (Bremner, 1960). The available phosphorus in the soil was determined by the Bray and Kurtz No. 1 method (Bray and Kurtz, 1945).

Cation exchange capacity was determined by the ammonium acetate saturation method (Chapman, 1965) and exchangeable bases were determined by using atomic absorption spectrophotometer from the ammonium acetate leachate.

3.7.2 Leaf analysis

Leaf analysis was done in a filtrate obtained firstly by igniting 0.5 g of oven dry, finely ground samples, in a muffle furnace at 450°C for eight hours (AOAC, 1965). The greyish-white ash obtained was cooled and dissolved in 5 ml of 1N HNO₃. The solution was evaporated to dryness on a hot plate and then returned to the furnace and heated for 15 minutes. The sample was then cooled and mixed with 10 ml of 1N HCl and filtered. The residue in the funnel was washed with three portions of 10 ml of 0.1N HCl. The filtrate was put into 50 ml volumetric flask and made to volume with 0.1N HCl.

Calcium, Mg, K, and Na in the filtrate were determined by atomic absorption spectrophotometer as described by Juo (1979).

Phosphorous was determined colorimetrically by the Vanado-Molybdate method (AOAC, 1965). In this method 5 ml of sample solution was pipetted into 100 ml volumetric flasks, 45 ml distilled water added and the yellow colour developed by adding Vanado-Molybdate solution. The absorbance was determined at 400 m μ wave length. Phosphorous concentration was deduced from a standard curve determined by running samples of known concentration.

Total N in the samples was determined by Micro-Kjeldahl digestion method (Black et al., 1965), whereby 0.1g of finely ground sample was digested in a test tube using concentrated sulphuric acid and in the presence of a salt mixture catalyst. The digest was cooled, diluted and distilled into 5 ml of boric acid-indicator mixture. The N content in the samples was determined by titrating the distillate against standard (0.01N) H₂SO₄ solution.

3.7.3 Cane analysis

Each cane stick was cut into three equal pieces and the pieces were analysed separately. The samples were prepared by chopping up the pieces into smaller sizes using a sharp knife. The fine pieces were then ground by a Jaffco grinder. The product was fine bagasse-cane which was collected and tightly sealed up in plastic bags awaiting analysis.

The samples were analysed by the methods which are commonly used by the estate laboratories (South African Sugar Association, 1971) and are summarised below. The moisture content in the bagasse-cane was determined by drying up 100g of the substance in a moisture teller at 110°C for 45 minutes. The fibre content in cane (F) was determined by putting 300g of the bagasse-cane into a strong cotton bag. The soluble solids were removed by adding water into the bag and squeezing it out several times until only water came out from the bag. Then, the brix-free bagasse was oven dried over night at 105°C to a constant weight (x). The percent fibre in cane (F) was found by expressing the oven dry weight of the bagasse as a percentage of the original weight, viz.

$$F = \frac{x \times 100}{300}$$

The brix index of the extract which refers to the total soluble solids in the bagasse-cane was extracted using a varigrator. In this extraction 100g of bagasse-cane was mixed with 300 ml of water and stirred vigorously by using an electrical stirrer for 20 minutes to dissolve the soluble solids. The warm dilute juice formed was screened and cooled in cylinders kept under cold running water. The brix in the extract (b) was determined by using a refractometer. The brix content in the cane (B) was calculated as:-

$$B = b(4 - 0.0125F).$$

The pol in the extract (p) which refers to the apparent sucrose concentration in the extract was measured by means of a saccharimeter and pol content in the cane (P) was calculated as:-

$$P = p(4 - 0.0125F).$$

The juice purity was deduced by expressing P as a percentage of B viz:-

$$\text{Purity} = \frac{100 \times P}{B}.$$

Sucrose content in the cane plants (R) was calculated by using the following relationship:-

$$R = \frac{P(170 - 2.1F)}{100 - F} - 0.7B.$$

The sugar yield, which is commonly expressed as tons of sugar per hectare (TSH) was found by the relationship:-

$$\text{TSH} = \frac{R \times \text{TCH}}{100} \quad \text{where TCH} = \text{tons cane/ha.}$$

3.8. Statistical Analysis of the Data

For the purpose of statistical evaluation of the results, the data were analysed by the method appropriate for the randomized complete block design (Snedecor and Cochran, 1967). And the means were compared by the Duncan multiple range test at 5% level of significance, as described by Steel and Torrie (1960).

4. RESULTS AND DISCUSSION

4.1 Some Characteristics of the Soil in the Experimental Area

The summary of some physical and chemical properties of the soil in the test-field is shown in Table 1. The soil was moderately coarse textured. There was a slight increase in sand, and a slight decrease in silt and clay fractions down the profiles. Although sugarcane can be grown in a wide range of soils, it is generally believed that deep loam and clay-loam soils provide best rooting medium for the crop, and need little management to minimize possible reduction in yields due to poor soil condition (De Gues, 1967; Yates, 1977; ILACO, 1981). Incidences of nematode infestations, need for intensive irrigation, and heavy nutrient losses through leaching are more pronounced in coarse textured soils (Yates, 1977), and are among the factors which make light soils not ideal for sugarcane production. Since at Kilombero Sugar Estates the crop is normally irrigated and nematode infestations have not been reported, this soil still appears to be suitable for sugarcane production as far as texture is concerned.

The soil was medium in reaction with pH values in water ranging from 5.8 to 5.9. These values suggest the presence of insignificant content of exchangeable Al^{3+} . The soil was therefore free from Al toxicity. The values of soil pH in 0.1N KCl were generally lower than those determined in water. Such differences indicate that the soil had a net negative electric charges, and therefore capable of retaining positively charged nutrient elements present in it. The

Table 1: Physical and chemical properties of the soil in the experimental area

| Depth | pH | | Total N (%) | C/N ratio | Avail-able P (ppm) | Exchangeable bases | | | | C.E.C. (meq/100g) | Base saturation (%) | Texture (%) | | Textural Class | | |
|---------|------------------|-----|-------------|-----------|--------------------|--------------------|-----|-----|------|-------------------|---------------------|-------------|-----------|----------------|------|------------|
| | H ₂ O | KCl | | | | Ca | Mg | K | Na | | | Sand | Silt Clay | | | |
| 0-15cm | 5.8 | 5.1 | 0.84 | 0.10 | 8.4 | 18.3 | 4.6 | 3.8 | 0.67 | 0.72 | 16.7 | 58.7 | 63.9 | 16.6 | 19.5 | sandy loam |
| 15-30cm | 5.9 | 5.2 | 0.68 | 0.08 | 8.5 | 15.6 | 4.4 | 3.5 | 0.52 | 0.65 | 16.2 | 55.9 | 69.7 | 11.2 | 19.1 | sandy loam |
| 30-60cm | 5.9 | 5.1 | 0.55 | 0.07 | 7.9 | 14.4 | 4.0 | 3.5 | 0.39 | 0.59 | 14.8 | 57.9 | 71.7 | 10.2 | 18.1 | sandy loam |

optimum soil pH for sugarcane is 6.5, but the crop can grow well at pH values ranging from 4.0 to 8.5 (ILACO, 1981; Yates, 1977) provided that good management is used. The soil pH values obtained in this field are therefore within the range for normal sugarcane production.

The organic carbon in the soil was low and decrease down the profiles. The highest organic carbon was 0.84% and the lowest was 0.55%. The high content of organic carbon on the top soil is probably due to higher organic matter from plant residues. The organic matter in this soil appears to be very low for sugarcane. Yates (1977) reported 2 to 4% organic matter (about 1.2-2.3% organic carbon) in soil to be the appropriate range for the crop. This worker emphasized the need for incorporating organic materials in soils having low organic matter so as to maintain the above range.

The total N in soil decreased down the profiles and ranged from 0.10% to 0.07%. Since N is the most important nutrient for sugarcane (ILACO, 1981) and since the crop is a heavy feeder of the nutrient, the total N in this soil was not adequate for sugarcane production. In Philippines the critical N content in soil is 0.30% (Demeterio, 1960). And it is reported also that for every ton of sugarcane produced, the crop removes 0.50-1.2 kg N from soil (Du Toit, 1953, 1955; Barnes, 1953; Humbert, 1963; Husz, 1968). This shows therefore that for high sugarcane yields, N in soil has to be higher than that found in this soil.

The soil inorganic N varied from 3.10 to 7.62 ppm (Appendix 4). Plots applied with N at planting had slightly higher contents than unfertilized plots. The C/N ratios were low and ranged from 7.9 to 8.5. The low C/N ratios are favourable for N mineralization. However due to little content of organic matter in the soil, the amount of N released during mineralization is likely to be very low. This is indeed the case as evident from data on Appendix 4.

The soil extractable P ranged from 14.4 ppm in the bottom soil to 18.3 ppm in the top soil, and its distribution trend was similar to that of organic carbon and clay percentage. Since the content of organic carbon in the soil was generally low it is not likely that organic matter contributed much to the content of extractable P in this soil. It seems, therefore, that the clay minerals in this soil were rich in P. The content of P in this soil appears to be within sufficient range for normal sugarcane growth. Yates (1977) estimated 25 ppm P (Truog) and 5 ppm P (Olsen) as the critical levels for sugarcane response to applied P. However Ayres and Humbert (1957) found the response of the crop to fertilizer P in acid and neutral soils having available P less than 25 lb/acre foot (about 6 ppm P).

The soil had a medium exchange capacity which decreased slightly down the profiles. The highest and lowest CEC were 16.7 and 14.8 meq/100g soil, respectively. These CEC values are within sufficient levels for sugarcane production. Soils with CEC values less than 15 meq/100g soil are normally prone to leaching losses (Yates, 1977).

Except for exchangeable Mg, the distribution trends down the profiles for exchangeable bases were similar to that for CEC and the clay content. These trends show the role of clay minerals in retaining exchangeable cations in the soil.

The concentration of exchangeable Ca in the soil ranged from 4.0 to 4.6 meq/100g soil. Although the critical concentration of Ca²⁺ in soil for sugarcane varies, the values from this soil appear to be sufficient for the crop. Yates (1977) generalised that sugarcane crop growing on soils with exchangeable Ca more than 3.5 meq/100g soil cannot respond to Ca fertilization. In other places the critical level is fixed as 400 lb Ca/acre-foot soil (about 0.5 meq/100g) (De Gues, 1967). However, Evans (1959) found that the response to lime in the Berbice province of British Guyana resulted from increased availability of P, and in the other areas was due to lowering of toxic Al and Fe found in the soil.

The exchangeable Mg in the soil was high and ranged from 3.5 to 3.8 meq/100g soil. This level appears to be sufficient for normal sugarcane production. (Yates, 1977).

The soil had a medium content of exchangeable K, and it ranged from 0.39 to 0.67 meq/100g soil. Sugarcane response to K fertilization in this soil is therefore very unlikely (Demeterio, 1960; ILACO, 1981; Yates, 1977).

In general, high yields can be expected from this soil provided that N fertilizers are used and rainfall is supplemented by irrigation.

4.2 Effects of Rate and Time of N Fertilization on Yield Parameters of Sugarcane.

4.2.1 Germination percentages

The relationship between N rates of application and sugarcane germination is given in Table 2. The sugarcane germination was not significantly affected by N fertilization. However, the highest mean germination was 80.7% obtained when 100 kg N/ha was applied. Application of 300 kg N/ha gave slightly lower germination. The overall mean germination was 79.7%. Lack of significant effects of N fertilization on sugarcane germination have also been reported by Dagade et al. (1979) and Singh et al. (1970).

In general, germination observed in this study was satisfactory.

4.2.2 Number of stalks

The relative number of stalks counted at three months of age are summarised in Table 2. The effect of increasing N levels was both positive and significant. Nitrogen fertilization increased the number of stalks from 244 in the unfertilized plots to 292 in plots treated with 300 kg N/ha. The average stalk count was 263 stalks per ten meters.

Table 2: Effects of N rate and time of application on germination percentages, sugarcane height and number of stalks

| Parameter | N rate (kg/ha) | | | | | | Mean | CV % |
|------------------------------|----------------|-------|-------|-------|-------|-------|------|-------|
| | 0 | 50 | 100 | 150 | 200 | 300 | | |
| Germination (%) | 80.0a | 79.1a | 80.7a | 80.5a | 80.5a | 77.4a | 79.7 | 13.32 |
| Cane height (cm) | 29a | 29a | 31ab | 33bc | 34bc | 36c | 32 | 4.38 |
| | 83d | 93a | 99ac | 108b | 104bc | 108b | 99 | 5.59 |
| Cane population (stalks/10m) | 244a | 253a | 254a | 279b | 258ab | 292c | 263 | 4.61 |

Means with a common letter in the same row are not statistically different at P = 0.05 by Duncan's multiple range test.

The positive effects of N fertilization on the number of stalks of sugarcane plants have also been reported by Salunkhe et al. (1981) who found increase in the number of milable stalks with N application and Takahashi (1967) who found tillering to increase with increase in N rate.

4.2.3 Cane height

Data for cane height measured at two to five months of age, inclusive, are summarized in Tables 2 and 3. At two months of age the effect of N application on cane height was both positive and significant. Nitrogen application increased cane height from 29 cm in the unfertilized plots to 36 cm in plots treated with 300 kg N/ha. The mean height was 32 cm. For the three months old crop, the effect of N was also significant. There was an increase in growth from 83 cm in the unfertilized plots to 108 cm in plots applied with 150 kg N/ha but application of N beyond this rate did not result in a significant increase in heights. Mean cane height at this age was 99 cm.

Growth measurement for four months old cane still showed a positive effect of N on the growth. The effect of timing was significant at 5% level. At this age mean cane height increased from 129 cm in control plots to 228 cm in plots applied with 300 kg N/ha and the overall mean height was 174 cm. In five months old crop only N rate had a significant influence on the growth of sugarcane.

Table 3: Cane height (cm) of four and five months old crop as related to rates and time of N fertilization

| Time of application | N. applied (kg/ha.) | | | | | | | | | | | |
|--------------------------------|---------------------|------|------|------|-------|-------|-------------------|------|------|------|--|--|
| | 0 | 100 | 200 | 300 | Mean | 0 | 100 | 200 | 300 | Mean | | |
| | 4 months old cane. | | | | | | 5 months old cane | | | | | |
| at planting | 126 | 160 | 190 | 244 | 180b. | 143 | 182 | 240 | 271 | 209a | | |
| at 3 months | 130 | 148 | 186 | 227. | 173a | 146 | 174 | 236 | 253 | 202a | | |
| at planting and at 3 months | 130 | 146 | 189 | 212 | 169a | 138 | 178 | 241 | 258 | 204a | | |
| Mean | 129o | 151d | 188e | 228f | 174 | 142b. | 178b | 234c | 261c | 205 | | |
| | CV 4.75% | | | | | | CV 28.39% | | | | | |

Means with a common letter in the same row/column are not statistically different at P = 0.05 by Duncan's multiple range test.

The effect of time of application was not statistically significant.

To assess the rate of growth in relation with time and N rate, data for monthly growth rates was calculated and is presented in Appendix 5. The growth rate increased with increase in the rate of N applied. The effect of time of N fertilization on the rate of growth seemed to be minor. However, the mean growth rates for plots applied with N in split doses were slightly different from the growth rates in plot applied with the nutrient in single doses (see growth rates in February and March). The highest growth rates occurred during February when the crop was four months old. At the age of five months the plants had the least growth rate.

It is evident that cane growth varied with age and was influenced by the rates at which N was applied. The positive effect of N on cane growth is related to the general function of N on cane growth, and has been similarly reported by Singh (1974c). Changes in growth rate with cane age is frequently related to the development of root system and the changes in leaf area index (Humbert, 1968). At early stages of growth the root system is poorly developed and thus limiting the amount of nutrients which can be absorbed from the soil, and hence hindering the rate of growth. At later stages, plants start shedding their leaves. This reduces the leaf area which in turn results in a decrease in photosynthesis, and hence a decrease in cane growth.

4.2.4 Smut infection

The number of stools which were infected by smut during the first six months of cane growth are given in Appendix 6. Smut infection was not affected by treatments. The overall mean of number of stools infected by smut was 2.0 per plot. Lack of statistical significance between treatments and the infection of the disease indicates that no plants under any treatments which were prone to the disease. This shows that N fertilization did not induce smut infection in sugarcane in this experiment. And the interferences of the disease with the results of this experiment are unlikely.

4.2.5 Cane flowering

Up to the time of harvesting, the experimental field had no sugarcane plants which had flowered although such plants were seen in some of the fields within the estate. In this estate flowering reaches its peak in April. At that time the age of most of the crop is, or more than, four months. Although many factors influence flowering in sugarcane plants i.e. day length, temperature, physiological age of the plants, N supply to the crop, and soil moisture (Brett, 1950; Burr et al., 1957; Clements, 1968; Clements and Awada, 1962, 1964; Humbert et al., 1969; Arceneaux, 1974), the failure of cane plants to flower in this case could not be clearly explained in terms of these factors.

4.3. Effects of Rate and Time of N Fertilization on Nutrient Concentration in Sugarcane Leaves

4.3.1 Nitrogen

The data on the effects of rate and time of N fertilization on N concentration of sugarcane leaves sampled at two and four months of age are given in Table 4 and Appendix 7. Nitrogen application had a positive and significant effect on N concentration in the sugarcane leaves at both two and four months old plants. The N concentration in the leaves generally increased steadily with increase in rate of N applied. For the two months old plants, N concentration ranged from 1.87% to 2.29%, and the average was 2.06%. At this age the effect of N application was not significant when the nutrient was applied below 100 kg N/ha. Probably at low rates of N the soil N reserve was able to suppress the effect of applied N on the concentration of N in the leaves. In the four months old cane plants, the leaf N concentration ranged from 1.38% to 1.94%. The overall average was 1.69%. At this age application of N at 100 and 200 kg/ha did not give significant difference in leaf N concentration despite the great difference in cane growth experienced under the two treatments at the same age (See Table 2).

The positive effect of N fertilization on the concentration of N in the leaves was expected since the soil analysis data showed a low level of N in the soil (Table 1). These observations are also closely

Table 4: Effects of rate and time of N application on N and P concentrations in leaves of four months

old sugarcane plants

| Time of application | N applied (kg/ha) | | | | | Mean | P% in leaves | | | | |
|--------------------------------|-------------------|-------|-------|-------|-------|--------|--------------|-------|-------|--------|------|
| | 0 | 100 | 200 | 300 | Mean | | 0 | 100 | 200 | 300 | Mean |
| at planting | 1.39 | 1.68 | 1.72 | 1.89 | 1.67a | 0.19 | 0.19 | 0.21 | 0.19 | 0.20b | |
| at 3 months | 1.41 | 1.65 | 1.72 | 1.84 | 1.66a | 0.18 | 0.18 | 0.19 | 0.15 | 0.18a | |
| at planting and at 3 months | 1.38 | 1.76 | 1.85 | 1.94 | 1.73a | 0.20 | 0.18 | 0.20 | 0.19 | 0.19ab | |
| Mean | 1.39d | 1.70b | 1.76b | 1.89c | 1.69 | 0.19cd | 0.18d | 0.20c | 0.18d | 0.19 | |
| | cv 5.54% | | | | | | cv 8.64% | | | | |

Means with a common letter in the same row/column are not statistically different at P = 0.05 by Duncan's multiple range test.

related to the general consideration that accumulation of mineral nutrients in plant tissues is highly related to the availability of the minerals in the growing media (Capo, 1970; Mengel and Kirkby, 1982).

The effect of time of N application on the concentration of N in leaves was not significant. However application of N in split doses gave slightly higher leaf N concentration than application of the nutrient in single doses either at planting or at three months. The lower leaf N concentration in the later cases could probably be due to higher rates of growth experienced under those treatments as can be seen in Table 3 and Appendix 5. Production of dry matter in this case might have been faster than the rates at which N was absorbed from the soil. For that reason the N absorbed was distributed in greater dry matter, and thus reducing the concentration in the leaves. In addition, the low leaf N concentration in plants applied with N at planting could also be due to a decrease in the supply of the nutrient which was applied four months earlier. Although there were some significant difference in cane growth between plants applied with N at planting and those applied at three months (Table 3), the leaf N concentrations in these plants were not statistically different. This observation may probably be due to the fact that plants applied with N at planting had more advantage of accumulating the nutrient in the leaves possibly because they had longer time to absorb the nutrient.

The concentration of N in cane leaves did not only depend on the quantity of fertilizer N applied but also to the degree at which the plants accumulated dry matter. For that reason, leaf N concentration varied with the age of the plants. In four months old crop, N concentration in leaves was generally lower than for two months old plants. Higher N concentration in leaves of young plants and subsequent decline in older plants could be due to increase in growth which did not keep pace with the rates at which the plants absorbed N from the soil. The reduction in leaf N concentration with the increase in cane age has also been reported by other workers. (Anonymous, 1973; Raghavaiah et al., 1981).

4.3.2 Phosphorous

The leaf P concentrations as affected by rates and time of N application are summarised in Table 4 and Appendix 7. At both ages of leaf sampling, N fertilization significantly affected the concentration of P in the sugarcane leaves. However, the degree of significance was not the same. Application of N increased P concentration from 0.22% in the control to 0.26% in plots treated with 200 kg N/ha for the two months old crop. In four months old crop leaf P concentrations ranged from 0.16% to 0.21%. These values are generally within the adequate range for normal growth of sugarcane as shown by other workers (Du Toit, 1953; Clements, 1953; Evans, 1955; Capo et al., 1955; Wahhab, 1961; Schmehl and Humbert, 1964).

Although the effect of application of NH_4^+ to soil on the uptake of P by sugarcane plants has not been studied much, the stimulatory effect of N application on the uptake of P by cane plants as observed in the two months old crop when N was applied up to 200 kg/ha could probably, be related to the general dependence of availability of some forms of soil P on the soil pH. Application of NH_4^+ fertilizer to soil may acidify the soil (Villamizar and Latero, 1967). Soil acidification is reported to increase the solubility of some sparingly soluble P minerals in the soil and thus promoting the uptake of P by the plants. This relationship has been observed in some crops other than sugarcane. For example Riley and Barber (1971) found that the decrease in soil pH due to N application was associated with increase in P uptake by soybeans. A similar observation has been reported in bean plants by Hendix (1967).

In four months old crop there was no significant difference in leaf P concentration between control plots and plots applied with N. It is likely that in this case the increase in growth observed when N was applied had diluted the concentration of P in the leaves. This implies that the rate of dry matter accumulation in the plants due to N fertilization was higher than the rate at which P was absorbed by the plants.

Makled et al. (1974) have reported a negative effect of N fertilization on the concentration of P in the blades and petioles of sugarcane leaves.

The time at which N was applied also influenced the concentration of P in leaves. Highest leaf P concentration was found when the nutrient was applied at planting. Application of N at three months resulted in the lowest P concentration. These differences could, perhaps be due to the differences in time at which the plants were exposed to soil P released by soil acidification.

The leaf P concentration of four months old cane were slightly lower than for two months old plants. Similar observations have been reported by other workers (Anonymous, 1973; Makled et al., 1974; Valdivia et al., 1978). The change in leaf P concentration with cane age could probably be due to differences in the rates of P uptake by the plants in relation to the rates of dry matter accumulation. It could also be due to the changes with time in the internal requirement of P by the sugarcane plants.

4.3.3 Potassium

The data on the effect of rate and time of N application on K concentration in cane leaves are given in Apendices 7 and 8. At both ages of sampling N application significantly influenced the concentration of K in sugarcane leaves. However, the effect of treatment was more pronounced in the four months old crop. In the two months old crop the leaf K concentration ranged from 1.66% in unfertilized plots to 1.92% in plots applied with 150 kg N/ha.

The mean concentration was 1.82%. At four months of cane growth, highest mean concentration was 1.96%. These values are within the sufficient range as reported by Innes and Chinlay (1951), Du Toit (1953), Evans (1955a and B), Capo et al. (1955), and Wahhab (1961). But they are slightly lower than those reported by Clements (1953), and Schmehl and Humbert (1964).

In the two months old plants application of N up to 150 kg/ha had a positive effect on the concentration of K in the leaves. But application of N beyond 150 kg/ha resulted in a slight but non significant decrease in K concentration in the leaves. These trends could probably be related to the positive effect of fertilizer N on dry matter accumulation in the plants as well as the general influence of NH_4^+ on K^+ uptake by plants.

It is generally considered that application of N in the form of NH_4^+ increases the concentration of H^+ and NH_4^+ in the soil. Since these ions are very similar to K^+ in ionic radius, they can compete effectively with K^+ for the K^+ fixing sites of the soil colloids (Rich and Black, 1964; Bartlett and Simpson, 1967). For that reason application of N up to 150 kg/ha as ammonium sulphate in this experiment might have improved available K from the soil by releasing it from the fixing sites. However, application of N beyond 150 kg/ha may still have improved K availability from the soil, but the plants in these treatments could not absorb equivalent amounts of K from the soil to march with the gain in dry matter.

The effect of time of N application on leaf K concentration was not significant.

The concentration of K in cane leaves of four and two months were not significantly different. These results are similar to those reported by other workers (Anonymous, 1973).

4.3.4 Calcium

The concentration of Ca in sugarcane leaves sampled from two and four months old plants are summarized in Appendices 7 and 8. The effect of N application on Ca concentration in leaves was negative and significant only at four months of leaf sampling. In two months old cane, the Ca concentration ranged from 0.14% to 0.16% with a tendency for the higher values to be associated with the control and low N rates. In four months old crop the concentration ranged from 0.13% to 0.17%. Overall, Ca values observed in the study were slightly lower than those reported by Evans (1955). Evans (1955) reported that for leaves (with midribs removed) from three to six months old plants the adequate Ca concentration was 0.17-0.18%.

The negative effect of N rate of application on the concentration of Ca in sugarcane leaves could be due to dilution brought about by the high production of the plant material. It is also possible, however that the decrease in the concentration of Ca in leaves was related to

the general behaviour of Ca^{2+} in the soil under the presence of NH_4^+ . Normally the uptake of Ca^{2+} by plants can be competitively depressed by the presence of NH_4^+ in the growing media (Mengel and Kirkby, 1982). The negative effect of N fertilization in this case may therefore be due to reduction in Ca^{2+} uptake by the cane plants in the presence of NH_4^+ supplied through the fertilizer.

Apart from that factor, under good drainage condition NH_4^+ from fertilizers can easily be nitrified (Duisberg and Buhner, 1954). The H^+ released from the reaction can release Ca^{2+} from the exchange sites of the soil colloids by the exchange reaction. Under such condition, the soil can easily be acidified and Ca^{2+} lost by leaching (Abruna et al., 1958). The reduction in Ca^{2+} concentration in the soil may reduce the quantity of it absorbed by the plants.

The effect of time at which N was applied was significant. Plots applied with N at three months had highest Ca concentration in leaves, while application of the nutrient in split doses gave the lowest. This could probably be related to the differences in cane growth brought about by N fertilization.

The effect of cane age on Ca concentration in leaves was not apparent. This observation is similar to that reported by Anonymous (1973).

4.3.5 Magnesium

Appendices 7 and 9 show the summary of the data on the effects of rate and time of N fertilization on Mg concentration in sugarcane leaves from two and four months old crops, respectively. In two months old cane the leaf Mg concentration ranged from 0.14% to 0.17% and the overall mean was 0.15%. For the four months old crop the leaf Mg concentration ranged from 0.13% to 0.19% and the overall average was 0.17%. These values are higher than the adequate levels reported by Evans (1955) although he did not include the midribs of the leaves in his analysis. At both ages of sampling, N application significantly affected Mg concentration in the leaves. At two months, highest Mg concentration was found in plots applied with 50 kg N/ha. Application of N beyond this level resulted into a decrease in leaf Mg concentration. This was also observed in leaves sampled at four months, but in this case the decrease was observed when N was applied at the rate beyond 100 kg/ha. The decrease in leaf Mg concentration when N was applied beyond those levels could be due to dilution effect brought about by the gain in growth due to the fertilizer. It could also be due to reduction in Mg^{2+} uptake by the cane plants, in the presence of ammonium ions as reported in other crops (Mulder, 1956).

The effect of time of N application on Mg concentration in the leaves was also significant. Application of N at three months as a single dose resulted into highest Mg concentration in the leaves. But there was no difference in leaf Mg concentration between plots.

treated with N as single dose at planting and those applied in split doses.

The concentration of Mg in leaves did not vary significantly with the age of cane plants. A similar observation has been reported by Anon. (1973).

4.4 Effects of Rate and Time of N Application on the Quality of Sugarcane

4.4.1 Fibre content in cane

The effects of rate and time of N application on the fibre content of sugarcane plants is summarised in Table 5. There was a slight increase in fibre content in the plants with increase in the rate of N applied. The control plots had the lowest fibre content (12.0%), and this increased to 13.6% at 200 kg N/ha. However the effect of N application on fibre content was not statistically significant. Similarly the time of application did not have a significant effect on the fibre content.

The effect of rate and time of N application on the fibre content of sugarcane is not well documented, but the values obtained in this experiment were within the expected range for Kilombero Sugar Estates.

4.4.2 Brix in the extract

The relationship between the rate and time of N application and the brix in the sugarcane extract is shown in Table 6. The effect of N fertilization was significant. The brix decreased steadily from 4.88% in the unfertilized plots to 4.38% in the plots treated with 200 kg N/ha. The trends

Table 5: Effects of rates and time of N application on
fibre content of cane at harvesting

| Time of application | N rate (Kg/ha) | | | | |
|--|-------------------|------|------|------|------|
| | 0 | 100 | 200 | 300 | Mean |
| | Fibre content (%) | | | | |
| at planting | 11.9 | 12.3 | 14.0 | 11.6 | 12.5 |
| at 3 months | 12.6 | 13.2 | 13.1 | 12.7 | 12.9 |
| $\frac{1}{2}$ at planting and $\frac{1}{2}$ at 3 months | 11.4 | 12.5 | 13.6 | 13.4 | 12.7 |
| Mean | 12.0 | 12.7 | 13.6 | 12.6 | 12.7 |
| cv 10.19% | | | | | |

Table 6: Brix and pol contents in cane juice at harvest time as related to rates and time of N fertilization

| Time of application | N applied (kg/ha) | | | | Mean | Pol in the extract (%) | Mean |
|--|-------------------------|--------|-------|-------|-------|------------------------|-------|
| | 0 | 100 | 200 | 300 | | | |
| | Brix in the extract (%) | | | | | | |
| at planting | 4.80 | 4.54 | 4.16 | 4.63 | 4.53d | 4.10 | 3.81e |
| at 3 months | 4.84 | 4.52 | 4.57 | 4.70 | 4.66d | 4.12 | 3.86e |
| $\frac{1}{2}$ at planting and $\frac{1}{2}$ at 3 months | 5.01 | 4.60 | 4.42 | 4.62 | 4.66d | 4.25 | 3.87e |
| Mean | 4.88c | 4.55ab | 4.38b | 4.65a | 4.62 | 4.16a | 3.85 |
| | cv 4.42% | | | | | cv 2.44% | |

Means with the same letter in the same column/row are not statistically different at P = 0.05 by Duncan's multiple range test.

observed in this experiment are different from those reported by Valdivia et al. (1978. This worker found no effect of N on the brix percentage. The negative effect of N on the brix in this case could be due to the influence of the nutrient on sucrose formation in the sugarcane plants. This may be the case since more than 80% of the substances found in the brix is normally sucrose.

The effect of timing of N application on the brix in the extract was not statistically significant, however application of N at three months of age gave relatively higher mean brix in the juice.

The values of brix obtained in this experiment were within the normal range for Kilombero Sugar Estates.

4.4.3 Pol content in the extract

A summary of the effects of rate and time of N fertilization on percentage pol in the sugarcane extract is given in Table 6. Nitrogen fertilization highly affected the pol percentage in the juice. The effect was negative and significant. The Nitrogen application decreased the pol concentration from 4.16% in the unfertilized plots to 3.66% in plots applied with 200 kg N/ha. A similar trend has been reported by Thomas and Schmidt (1978) and Gervet et al. (1978) and could be due to the negative effect of N application on sucrose formation in sugarcane plants. Valdivia et al. (1978) found contrary results when using

HC 32-8560 cultivar. Since different varieties may differ in their ability to utilize N (Clements, 1962), the difference in the results could be due to varietal differences.

The effect of time of N application on pol concentration in the juice was not significant.

The values of pol in the juice observed in this experiment are within the normal range for Kilombero estates.

4.4.4 Juice purity

The data on the purity of cane juice as affected by rate and time of N fertilization is given in Table 7. The juice purity was highly and negatively affected by N fertilization. The juice purity decreased from 85.1% in the unfertilized plots to 79.4% in plots applied with 300 kg N/ha. The overall mean purity was 83.0%. These values however, are within the range commonly observed at Kilombero estates. Similar trends of the effect of N fertilization on the purity of sugarcane juice have been reported by other workers (Ojha et al., 1974; Singh, 1974b; Singh, 1975). However Valdivia et al. (1978) found no effect of N application on juice purity.

Table 7: Effect of rates and time of N fertilization on juice purity and sucrose content in cane at harvesting

| Time of application | N applied (kg/ha) | | | | | Mean | Mean | | | |
|-----------------------------|-------------------|-------|-------|-------|-------|---------------------|-------|-------|-------|-------|
| | 0 | 100 | 200 | 300 | 300 | | | | | |
| | Juice purity (%) | | | | | Sucrose content (%) | | | | |
| at planting | 85.5 | 84.5 | 85.6 | 80.6 | 84.1a | 13.1 | 12.1 | 11.1 | 11.2 | 11.9a |
| at 3 months | 84.7 | 83.9 | 82.1 | 78.5 | 82.3a | 13.0 | 12.0 | 11.3 | 10.5 | 11.7a |
| at planting and at 3 months | 85.0 | 84.5 | 82.2 | 79.2 | 82.7a | 13.7 | 12.3 | 11.1 | 10.6 | 11.9a |
| Mean | 85.1b | 84.3b | 83.3b | 79.4c | 83.0 | 13.3b | 12.1c | 11.2d | 10.8e | 11.8 |
| | cv 2.74% | | | | | cv 3.46% | | | | |

Means with a common letter in the same row/column are not statistically different at P = 0.05 by Duncan's multiple range test.

The negative effect of N application on juice purity was probably related to the negative effect of N on sucrose formation in cane stalks.

The effect of time of N application on the purity of the juice at harvesting was not significant. However, application of all N at planting produced cane with slightly higher juice purity.

4.4.5 Sucrose content in cane

The data on the effects of rate and time of N fertilization on sucrose content in the sugarcane plants is given in Table 7. The overall effect of N application on sucrose content in the plants was negative and highly significant. The highest sucrose content of 13.3% was found in the unfertilized plots. The sucrose content decreased with increase in N rate of application to 10.8% at 300 kg N/ha. All the values of sucrose content found in this study are above the acceptable limit of 8.5% for the Kilombero estates. This implies that application of N at 300 kg/ha can not be rejected simply on the basis of its negative effect on the sucrose content of the crop.

The negative effect of N on the sucrose content in sugarcane plants has also been reported by other workers (McAleese et al., 1970; Singh, 1974b; Patil et al., 1979). This effect could probably be due to heavy consumption of applied N by the plants which may consequently impair sucrose accumulation in the stalks (Wang, 1976).

The effect of time of N application on sucrose content in the plants was not significant. It seems that the time interval between the last dose of N and harvesting (9 months) was sufficient for the crop to utilize the fertilizer N effectively without affecting the accumulation of sucrose in the stalks. Similar results have been reported in Taiwan (Anonymous, 1971) where high sucrose content was observed in the 1966/67 plantcane crop of sixteen months age applied with N as late as five months before harvesting.

The relationship between N rate of application and the sucrose content in the sugarcane plants is shown in Fig. 1. The figure shows that sucrose concentration in the plants were highly and negatively ($P = 0.01$) correlated to the N rates of application. An increase in N rate of 100 kg/ha reduces the sucrose concentration in the plants by 0.85%. The sucrose content was also correlated to leaf N concentration (Fig. 2). The correlation coefficient was negative and highly significant ($P = 0.01$) for samples taken at four months. For the samples taken at two months the correlation was significant at 5% level. Singh (1975) observed a similar trend between sucrose content and leaf N concentration. This worker calculated that an increase of leaf N concentration of 1% at 8 months of age would decrease sucrose content in cane by 3.29%. The decrease in sucrose content observed in this study for a similar increase in leaf N were 2.94% and 4.85% for the two and four months old sugarcane plants, respectively.

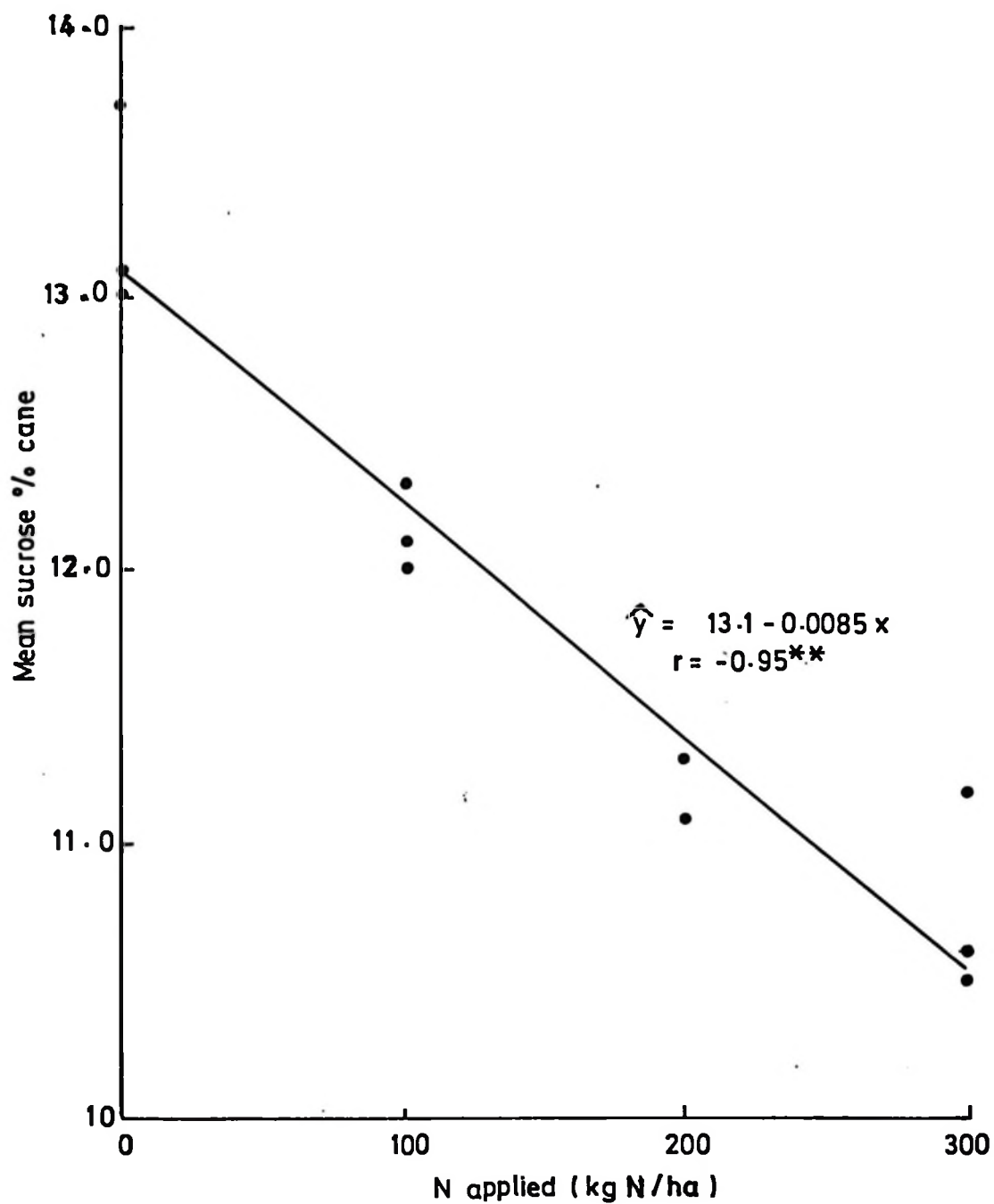


Fig. 1. The effect of N fertilization on sucrose content of sugarcane at harvesting

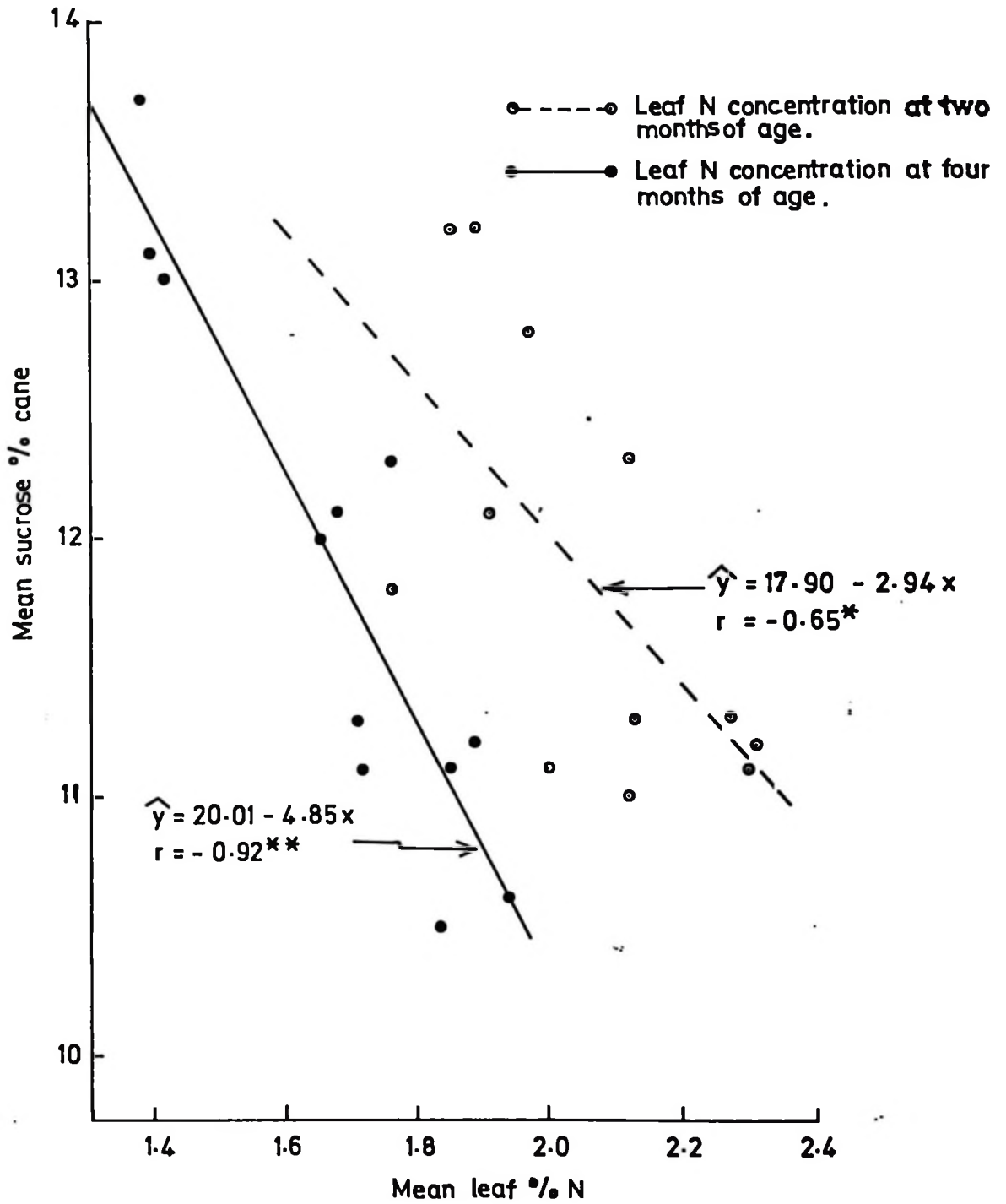


Fig.2. Sucrose concentration in sugarcane plants as related to N concentration in leaves.

4.5 Effects of Rate and Time of N Fertilization on Yield of Sugarcane

4.5.1 Cane yield

The data summarizing the relationship between cane yield and N fertilization is shown in Table 8. The effect of N application was both positive and significant albeit the increase in yield was in diminishing return. The first level of N (100 kg N/ha) increased the yield by about 84% over the control compared to an increase of 94%, and about 108% when N rates were doubled and trebled, respectively. The yield at 300 kg N/ha was however significantly different from that at 100 kg/ha. This implies that on the basis of cane yield the former level of N may still be justifiable.

The literature has many examples to show similar trends of sugarcane response to fertilizer N (Wood, 1968; Wang, 1976; Patil et al., 1979; Ojha et al., 1974). Such trends normally imply that at low rates of N this nutrient is often the major limiting factor to cane yield whereas at higher rates the sufficiency level is approached and the response decreases.

The effect of time of N application on cane yield was not significant. However application of all N at planting gave slightly higher yield than when the nutrient was applied at three months and in split doses.

Table 8: Cane and sugar yield as affected by rate and time of N application

| Time of application | N applied (kg/ha) | | | | | Mean | Mean | | | |
|--|-----------------------|--------|---------|--------|--------|------------------------|-------|-------|-------|-------|
| | 0 | 100 | 200 | 300 | 300 | | | | | |
| | cane yield (Tons/ha.) | | | | | sugar yield (tons/ha.) | | | | |
| at planting | 81.1 | 151.7 | 164.8 | 179.3 | 144.2d | 10.6 | 18.3 | 20.0 | 16.8c | |
| at 3 months | 82.8 | 149.4 | 151.7 | 160.9 | 136.2d | 10.7 | 17.9 | 17.0 | 15.7c | |
| $\frac{1}{2}$ at planting and $\frac{1}{2}$ at 3 months | 82.2 | 151.7 | 160.7 | 170.7 | 141.4d | 11.2 | 18.7 | 17.9 | 18.0 | 16.5c |
| Mean. | 82.0c | 150.9b | 159.1ab | 170.3a | 140.6 | 10.8b | 18.3a | 17.8a | 18.3a | 16.3 |
| | CV 12.06% | | | | | CV 12.12% | | | | |

Means with a common letter in the same row/column are not statistically different at P = 0.05 by

Duncan's multiple range test.

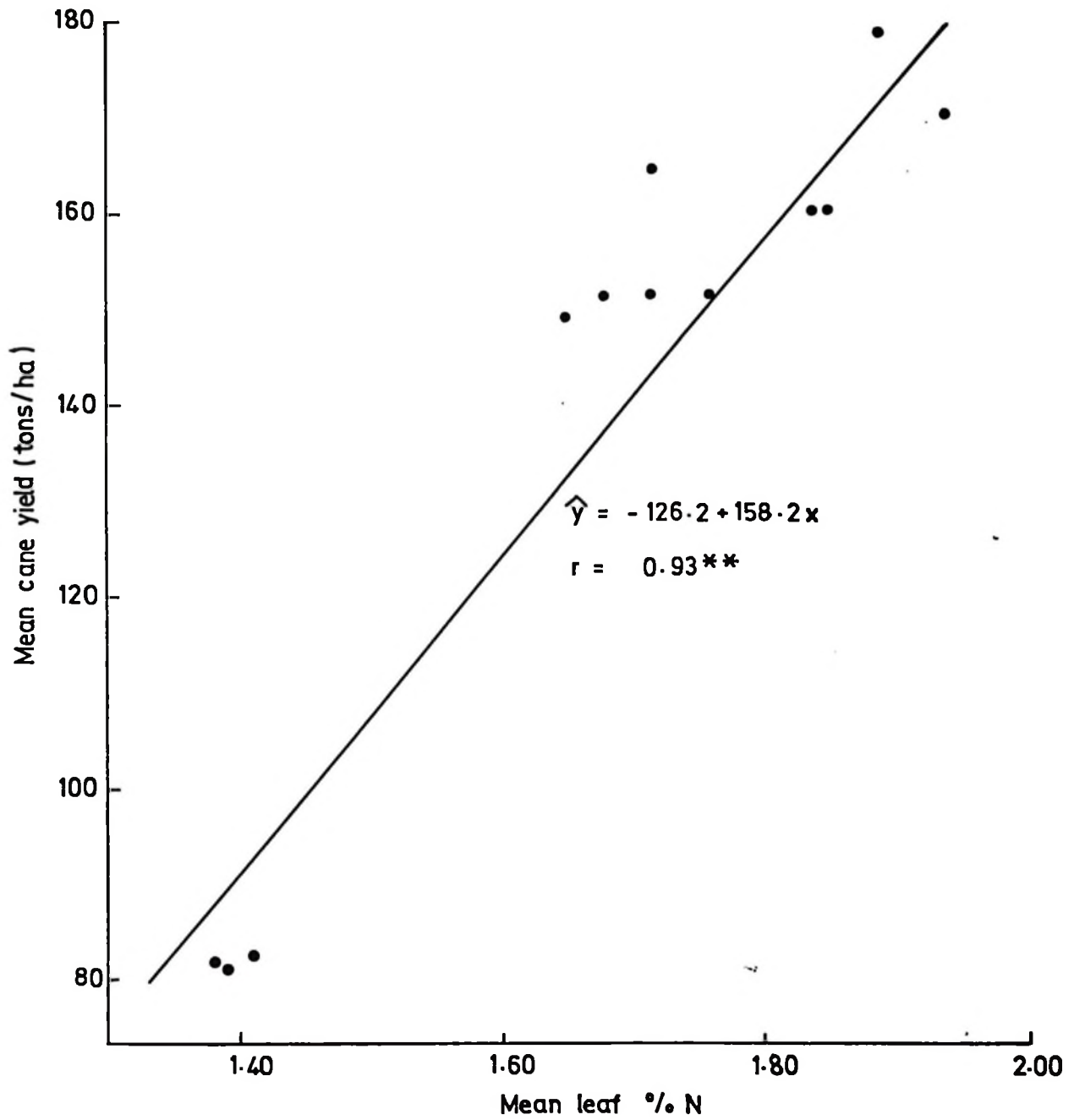


Fig.3. Cane yield as related to percentage N in leaves at four months .

The relationship between sugarcane yield and N concentration in sugarcane leaves is shown in Fig. 3. The yield was highly ($P = 0.01$) and positively correlated to leaf N concentration of four months old plants. For the two months old plants the correlation was not significant (the data not shown in the figure). An increase of 1% N in the leaves increased cane yield by about 158.2 tons cane/ha. From this relationship therefore, one may predict cane yield by using leaf N concentration obtained from four months old crop. A positive correlation between leaf N and cane yield has similarly been observed by Singh (1973).

4.5.2 Sugar yield

Table 8 gives a summary of the data on the effect of rate and time of N application on sugar yield. The effect of N rate was positive and significant. But the differences in yield among the fertilized plots were not statistically significant. Nitrogen application increased sugar yield from 10.8 tons/ha in the control to 18.3 tons/ha at 100 kg N/ha. Higher rates of N did not cause any further increase in sugar yield. Since sugar yield is a function of sugarcane yield and sucrose content, these results indicate that at N rates of 100 kg/ha or less, the increase in sugarcane yield has a greater effect on sugar yield than the decrease in sucrose content. While at N rates greater than 100 kg/ha up to 300 kg/ha, the decrease in sucrose content is just balanced/offset by the increase in sugarcane yield so that there is no substantial change in sugar yield.

The effect of time of N application on sugar yield was not significant. However application of all N at planting resulted into slightly higher yield than application of the nutrient in split doses, or at three months. Lack of statistical significance in this case shows that up to the age of three months the crop was still able to utilize the fertilizer N without affecting the final yield.

The relationship between sugar yield and the concentration of N in the sugarcane leaves was plotted in a linear graph (Fig. 4). Sugar yield was highly ($P = 0.01$) and positively correlated to leaf N concentration of the four months old plants. At this age an increase of 1% N in leaves was associated with an increase of about 15.5 tons of sugar per hectare. The correlation coefficient between sugar yield and leaf N concentration of two months old plants was not significant (the data not shown in Fig. 4). These results suggest that leaf samples from two months old sugarcane plants are not suitable for assessing the N nutrition of the plants, and in predicting sugar yields.

Although the relationship between sugar yield and leaf N concentration at four months age was highly linear, a quadratic response curve for the two parameters was plotted in order to estimate the optimum N concentration in the leaves of four months old plants (Fig. 5). Based on this curve, the leaf N concentration for maximum yield was found to be 2.20%. This value is comparable to that reported by Capo *et al.* (1955). These workers found N sufficient level for three months old sugarcane plants to range from 2.00-2.50%. It is also similar to that

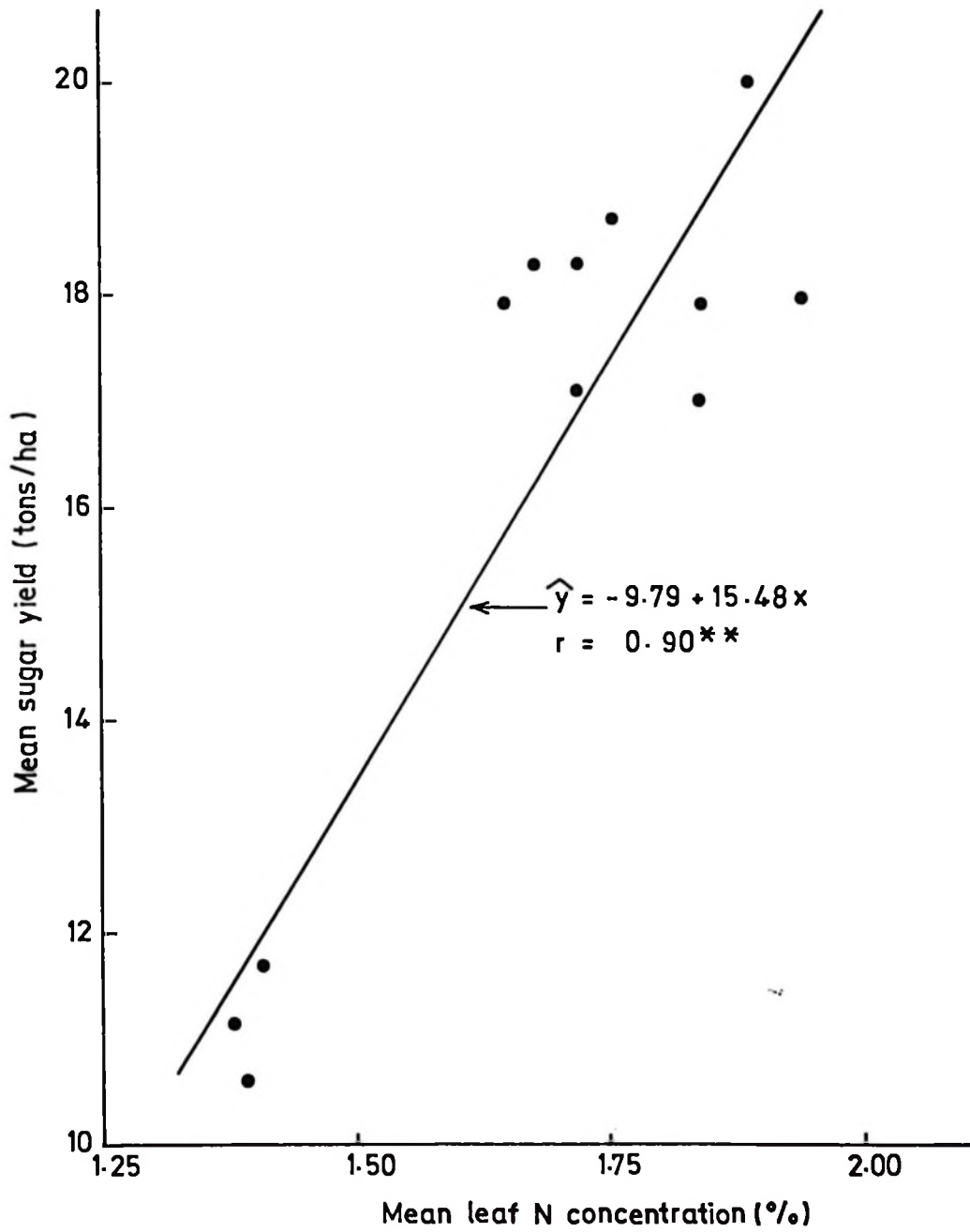


Fig. 4. Sugar yield as related to N concentration in sugarcane leaves at four months

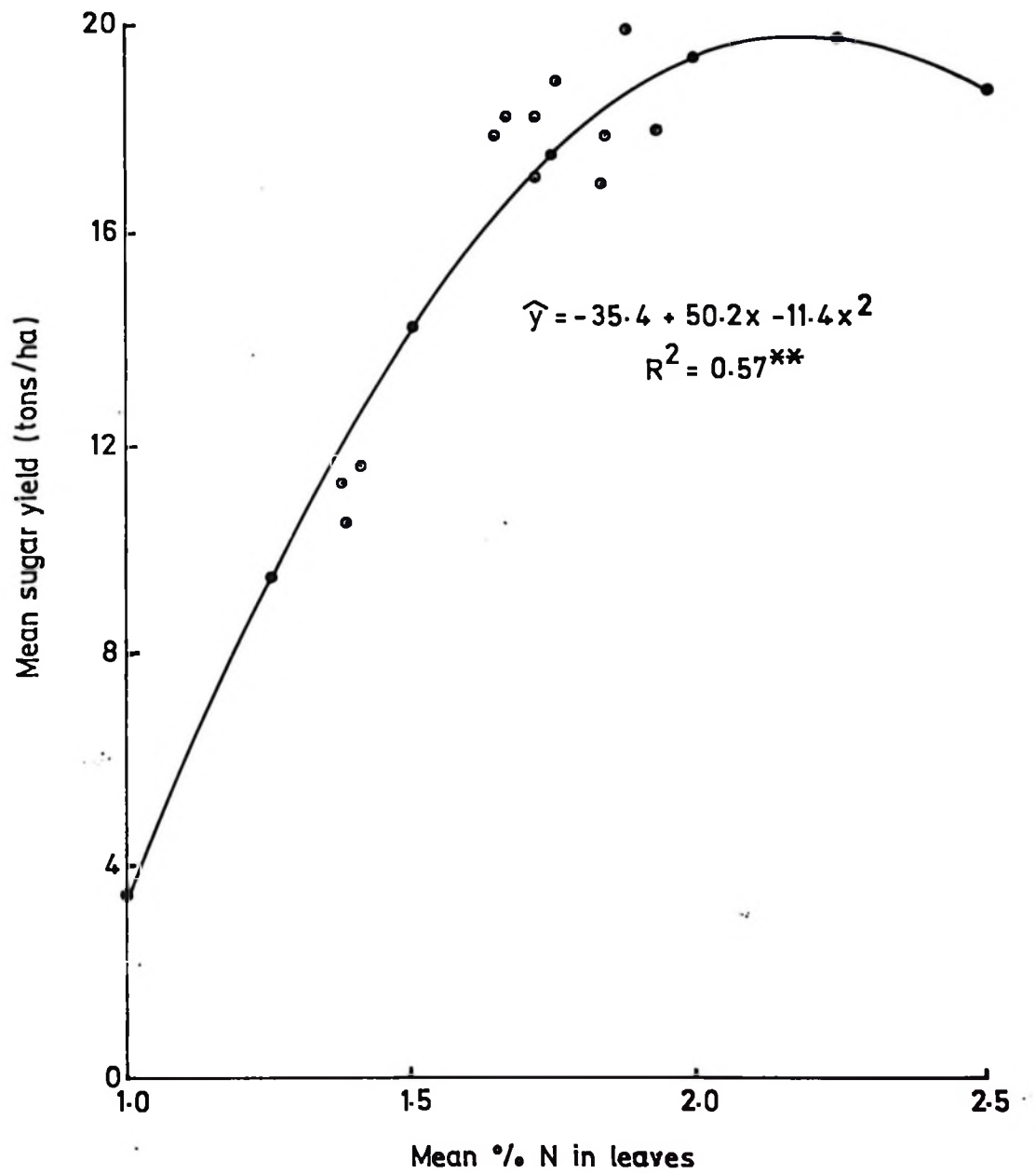


Fig. 5. Curvilinear relationship between leaf N concentration of four months old cane plants and sugar yield.

reported by Evans (1955) who found 2.2-2.3% N in leaves (midribs discarded) of four and half months old crop to be adequate. The value obtained in this study is however, higher than the 1.45-1.65% N reported by Du Toit (1955) for seven to eleven months old plants. And also higher than that reported by Clements (1953), i.e. 2.0% for six to eight months old plants. The difference with the results of the later workers is probably due to differences in age of the plants at sampling time.

The same curve (Fig. 5) was used to estimate the critical level of N in the sugarcane leaves. Assuming the critical concentration as the concentration giving 90% of the maximum yield as suggested by Braud (1972), the critical concentration of N in the leaves of four months old plants was 1.78%. This value is close to that of 1.6% reported by Wahhab (1961), but higher than the levels reported by Schmehl and Humbert (1964) and Cotteni^e (1980). The later workers reported critical N concentrations as being 1.0% and 1.0-1.5%, respectively.

5. SUMMARY AND CONCLUSIONS

A field study on the effects of rate and time of N application on growth and yield of sugarcane (Saccharum officinarum) variety N.Co. 3/6 was made during the 1982/83 cropping season. The experiment was done at Msolwa estate of Kilombero Sugar Company Limited, in Morogoro region. The study was conducted using a plant cane crop in a randomized block design.

The treatments tested were four levels of N viz: 0, 100, 200 and 300 kg N/ha applied as ammonium sulphate, and three times of application. These were (i) all the N applied in the furrows at planting, (ii) all the N applied as a side dressing at three months of age, and (iii) N applied in two split doses; half at planting and the rest at three months of age. The crop was irrigated during periods of extended dry spells, and the appropriate agronomic practices recommended for the estate were followed. This included roguing of smut infected stools, weeding, and draining of excessive water in the field.

To assess growth and development of the crop the following parameters were observed: germination, stalk population, and heights of the plants at two, three, four and five months of age. The nutrition of the crop, specifically the N, P, Ca, and Mg nutrition, was assessed by analysing leaves sampled at the age of two and four months, respectively.

The crop was harvested at the age of twelve months, and cane yield as well as sugar yield were determined. In addition, a number of parameters used to assess the quality of the crop such as the pol, brix, purity and sucrose content in the plants were determined.

The germination of the crop was high and was not affected by treatments. The heights of the plants and stalk population in the plots were significantly increased by increase in N levels applied. The rates of growth were highest in February, and lowest in March when the crop was four and five months old, respectively.

Nitrogen application significantly increased the concentration of N in leaves at both ages of leaf sampling. For the two months old plants, the concentration ranged from 1.87% to 2.27%. At this age the effect of N application was not significant when the rate of N was below 100 kg/ha. In the four months old plants, the leaf N concentration ranged from 1.38% to 1.94%. The increase in leaf N concentration when N levels were increased was due to the increase in N uptake due to increase in N supply. Nitrogen fertilization also affected the concentration of P, K and Mg in the leaves sampled at both ages. The effect of the fertilizer on leaf Ca concentration was only significant when the leaves were sampled at the age of four months.

The effect of time of N application on the concentration of the nutrients in the leaves was significant for P, Ca, and Mg. Application

of N at planting increased the concentration of P, and reduced the concentration of Ca and Mg in the leaves of the four months old cane. Nitrogen and P concentrations in the leaves decreased with increase in the age of the plants. The results of leaf analysis data generally showed that the concentrations of P, K, Ca, and Mg in the leaves were within the adequate range for the crop.

Nitrogen fertilization highly affected the yield and the quality of the crop at harvest time. Increasing the level of fertilizer N applied decreased the brix from 4.88% in the unfertilized plots to 4.38% in plots applied with 200 kg N/ha. The same increase in the level of the fertilizer also decreased the pol from 4.16% to 3.66%. The juice purity was decreased from 85.1% to 79.4% when the N level increased from 0 kg to 300 kg/ha. The sucrose content in the plants decreased from 13.3% in the control plots to 10.8% in plots applied with 300 kg N/ha. On the other hand, application of N increased cane yield as well as sugar yield over the control. Application of N increased cane yield from 82.0 tons/ha in the unfertilized plots to 170.3 tons/ha in plots treated with 300 kg N/ha. The increase in sugar yield due to N application was observed only when the fertilizer was applied at 100 kg N/ha. At this level the increase in yield was 7.5 tons sugar/ha. Application of N above that level did not cause further increase in yield. The fibre contents in the plants were not significantly affected by N application.

The effect of timing of N application on yield and quality of the crop was not significant.

The sucrose content in cane as well as cane and sugar yields were correlated with the concentration of N in leaves of the plants. However, the correlation coefficients were higher when the leaves were sampled at four months than at two months of cane growth. Using the linear relationships between leaf N concentration at four months and the three parameters, it was found that an increase of 1% N in the leaves is associated with an increase of 158.2 tons of cane and 15.5 tons of sugar per hectare. While the sucrose content in the plants decreased by 4.85% over the same change in leaf N concentration. By using a curvilinear relationship between leaf N concentration for the four months old plants and sugar yield, the critical N concentration in the leaves was found to be 1.78%.

According to the above results it is apparent that the Ruaha area of Msolwa estate has a high potential for sugar production; and that N is the major limiting nutrient in the production of the crop in the area. The data show that under the present agronomic practices a rate of 100 kg N/ha can tentatively be recommended for use but there is need to evaluate the effects of lower rates of N especially in combination with other nutrient elements. In addition, N fertilizers can be applied in furrows at planting in single doses without adverse effects on yield. It is concluded also that leaf N concentrations obtained from four months old cane can be used in the assessment of N sufficiency for the crop.

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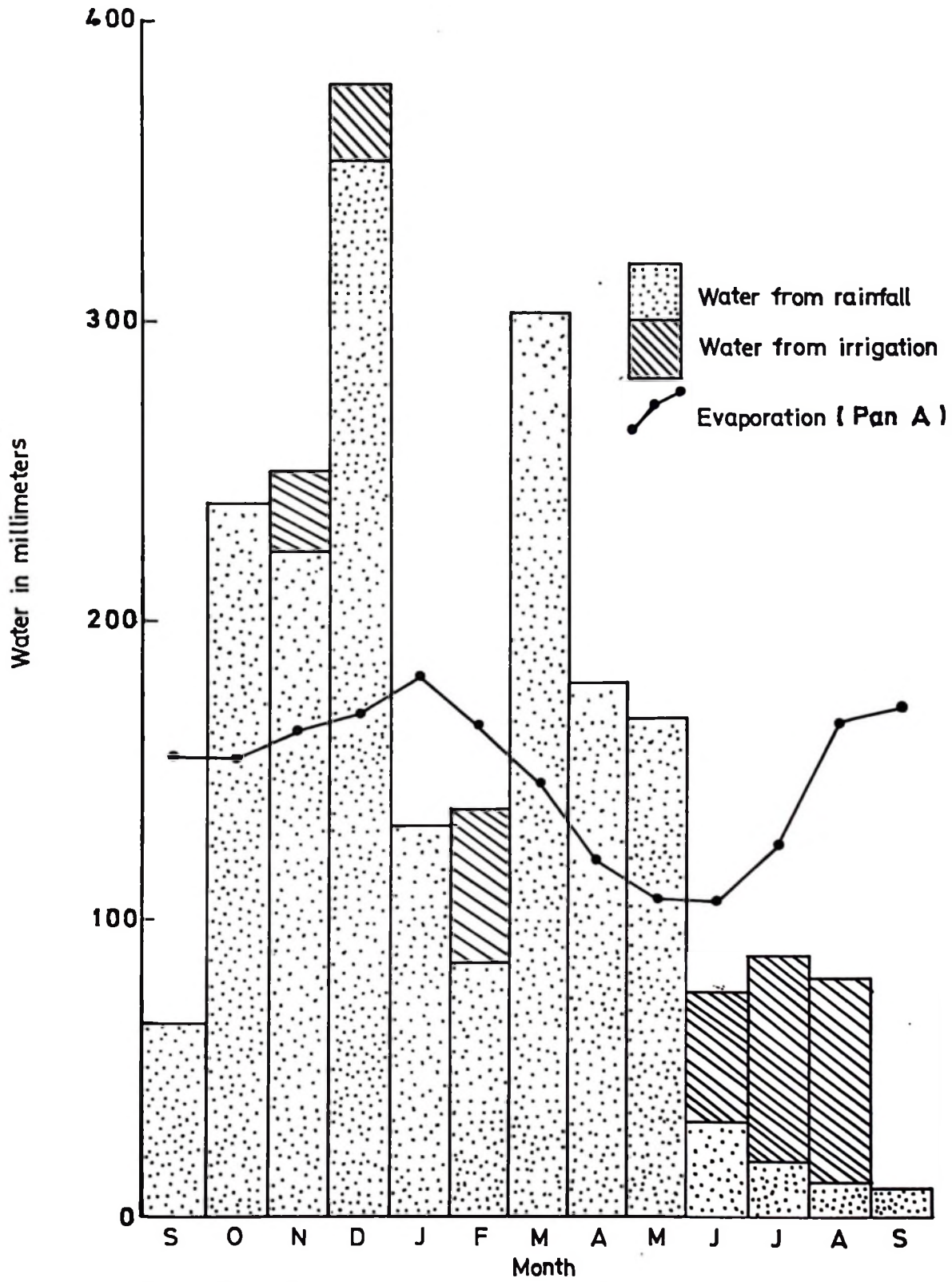
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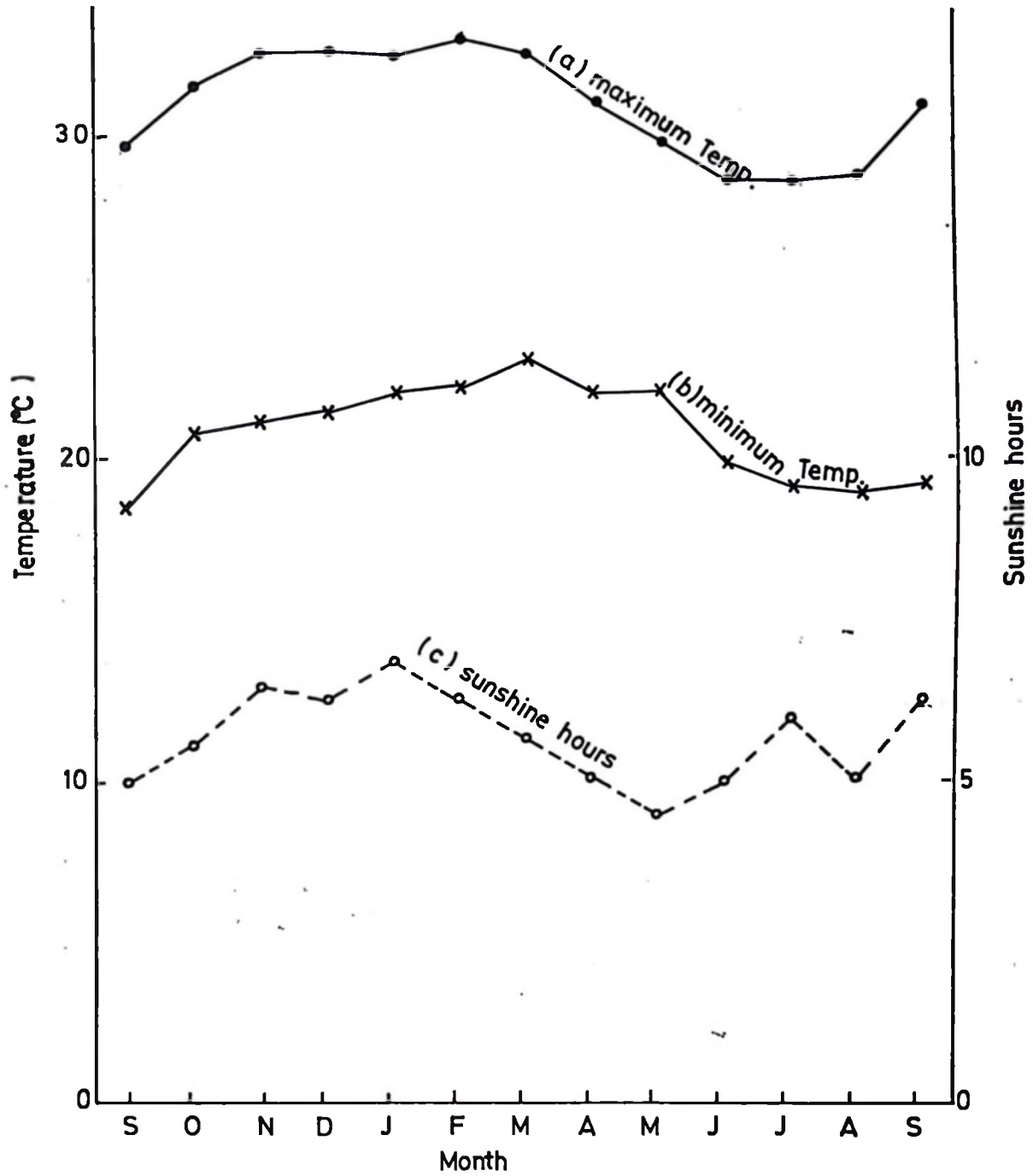
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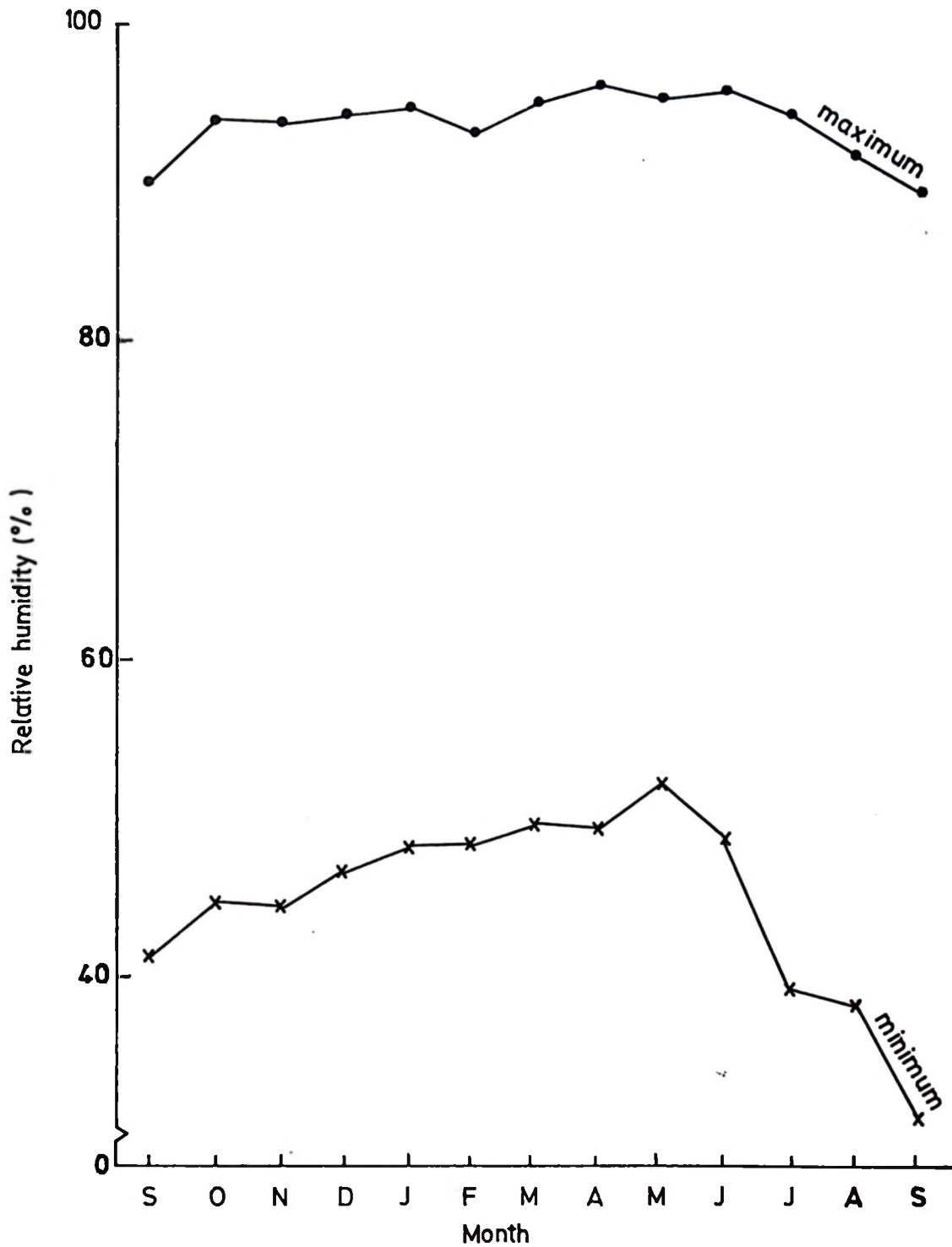
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Appendix 1. Water balance sheet during the experiment



Appendix 2. Mean maximum and minimum temperature and mean sunshine hours during the experiment



Appendix 3. Mean relative humidity during the experiment

Appendix 4: Soil inorganic N (ppm) as determined from plots with 3 months old cane just before second N application

| Block | Time of application | Depth (cm) | N rate (kg/ha) | | | |
|-------|-------------------------------|------------|----------------|------|------|------|
| | | | 0 | 100 | 200 | 300 |
| 1 | at 3 months | 0-30 | 4.68 | 3.85 | 3.14 | 4.95 |
| | | 30-60 | 3.39 | 3.11 | 3.35 | 5.07 |
| | $\frac{1}{2}$ at planting and | 0-30 | 3.78 | 4.44 | 6.18 | 7.56 |
| | $\frac{1}{2}$ at 3 months | 30-60 | 4.56 | 4.57 | 6.87 | 6.43 |
| 2 | at 3 months | 0-30 | 3.95 | 5.28 | 4.72 | 3.38 |
| | | 30-60 | 4.34 | 5.40 | 4.45 | 3.74 |
| | $\frac{1}{2}$ at planting and | 0-30 | 3.66 | 3.31 | 6.15 | 7.62 |
| | $\frac{1}{2}$ at 3 months | 30-60 | 3.37 | 4.40 | 5.65 | 6.58 |
| 3 | at 3 months | 0-30 | 4.07 | 3.61 | 5.00 | 5.89 |
| | | 30-60 | 3.37 | 3.91 | 4.10 | 5.90 |
| | $\frac{1}{2}$ at planting and | 0-30 | 3.50 | 5.27 | 5.11 | 6.37 |
| | $\frac{1}{2}$ at 3 months | 30-60 | 3.10 | 4.88 | 4.63 | 6.72 |

Appendix 5 : Mean monthly growth rate (cm/month) as related to rate and time of N application

| Time of application | N. rate (kg/ha) | | | | | | | | | | | | | | |
|---|-----------------|------|------|------|----------|------|------|------|-------|------|------|------|------|------|------|
| | January | | | | February | | | | March | | | | | | |
| | 0 | 100 | 200 | 300 | Mean | 0 | 100 | 200 | 300 | Mean | 0 | 100 | 200 | 300 | Mean |
| at planting | 54.0 | 68.0 | 70.0 | 72.0 | 66.0 | 43.0 | 61.0 | 86.0 | 136.0 | 81.5 | 17.0 | 22.0 | 50.0 | 27.0 | 29.0 |
| at 3 months | 58.0 | 60.0 | 67.0 | 64.0 | 62.3 | 43.0 | 59.0 | 90.0 | 133.0 | 81.3 | 16.0 | 26.0 | 50.0 | 26.0 | 29.5 |
| $\frac{1}{2}$ at planting, and $\frac{1}{2}$ at 3 months | 58.0 | 64.0 | 68.0 | 75.0 | 66.3 | 43.0 | 53.0 | 90.0 | 104.0 | 72.5 | 8.0 | 32.0 | 52.0 | 46.0 | 34.5 |
| Mean | 56.7 | 64.0 | 68.3 | 70.3 | 64.8 | 43.0 | 57.7 | 88.7 | 124.3 | 78.4 | 13.7 | 26.7 | 50.6 | 33.0 | 31.0 |

Appendix 6 : Number of smut infected stools destroyed during the
first six months of cane growth (counts/plots)

| Time of application | N. rate (kg/ha) | | | | Mean |
|--|-----------------|-----|-----|-----|------|
| | 0 | 100 | 200 | 300 | |
| at planting | 4.0 | 1.0 | 1.0 | 1.0 | 1.7 |
| at 3 months | 2.0 | 0.0 | 0.0 | 8.0 | 2.3 |
| $\frac{1}{2}$ at planting and $\frac{1}{2}$ at 3 months | 0.0 | 0.0 | 7.0 | 0.0 | 1.7 |
| Mean | 2.0 | 0.3 | 2.7 | 3.0 | 2.0 |

Appendix 7 : Concentrations of nutrient elements in leaves of two months old sugarcane plants as affected by N applied at planting

| Element | N applied (kg/ha) | | | | | | Mean | CV (%) |
|---------|-------------------|--------|--------|-------|-------|-------|------|--------|
| | 0 | 50 | 100 | 150 | 200 | 300 | | |
| N | 1.90bc | 1.87c | 1.93bc | 2.28a | 2.08b | 2.29a | 2.06 | 4.84 |
| P | 0.22b | 0.25a | 0.25a | 0.25a | 0.26d | 0.24c | 0.25 | 1.74 |
| K | 1.66b | 1.78ab | 1.87a | 1.92a | 1.85a | 1.83a | 1.82 | 4.32 |
| Ca | 0.15a | 0.15a | 0.16a | 0.14a | 0.15a | 0.14a | 0.15 | 6.17 |
| Mg | 0.16a | 0.17d | 0.16a | 0.14b | 0.15c | 0.14b | 0.15 | 3.40 |
| Na | 0.09a | 0.08a | 0.10a | 0.11a | 0.10a | 0.11a | 0.10 | 14.94 |

Means with a common letter in the same row are not statistically different at $P = 0.05$ by Duncan's multiple range test.

Appendix 8: Relationship between K and Ca concentration in leaves of four months old cane plants and rates and time of N applied

| Time of application | N applied (kg/ha) | | | | | | Mean | Ca % in leaves | | | |
|--|-------------------|-------|-------|-------|-------|-------|----------|----------------|-------|-------|-----|
| | 0 | 100 | 200 | 300 | Mean | 0 | | | 100 | 200 | 300 |
| at planting | 1.74 | 1.96 | 1.93 | 1.68 | 1.83b | 0.16 | 0.16 | 0.14 | 0.13 | 0.15a | |
| at 3 months | 1.72 | 1.88 | 1.78 | 1.91 | 1.82b | 0.17 | 0.16 | 0.15 | 0.15 | 0.16b | |
| $\frac{1}{2}$ at planting and $\frac{1}{2}$ at 3 months | 1.73 | 1.87 | 1.85 | 1.96 | 1.85b | 0.16 | 0.15 | 0.13 | 0.13 | 0.14c | |
| Mean | 1.73c | 1.90a | 1.85a | 1.85a | 1.83 | 0.16e | 0.16e | 0.14d | 0.14d | 0.15 | |
| | cv 3.55% | | | | | | cv 5.33% | | | | |

Means with a common letter in the same row/column are not statistically different at $P = 0.05$ by Duncan's multiple range test.

Appendix 9: Leaf Mg and Na concentration at four months as affected by rate and time of N application

| Time of application | N. applied (kg/ha) | | | | | Mean | Na % |
|--------------------------------|--------------------|-------|-------|-------|-------|-------|------------------|
| | 0 | 100 | 200 | 300 | Mean | | |
| | | | | | | | |
| at planting | 0.16 | 0.18 | 0.15 | 0.15 | 0.16c | 0.10 | 0.10 0.11 0.10b |
| at 3 months | 0.16 | 0.19 | 0.18 | 0.18 | 0.18d | 0.10 | 0.11 0.10 0.10b |
| at planting and at 3 months | 0.16 | 0.19 | 0.16 | 0.13 | 0.16c | 0.11 | 0.10 0.11 0.11b |
| Mean | 0.16a | 0.19b | 0.16a | 0.15a | 0.17 | 0.10a | 0.10a 0.11a 0.10 |
| | | | | | | | cv 16.14% |
| | | | | | | | cv 9.10% |

Means with a common letter in the same row/column are not statistically different at $P = 0.05$ by Duncan's multiple range test.