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NITROGEN DYNAMICS IN SUGARCANE FIELDS

STIKSTOFDYNAMIEK IN SUIKERRIETVELDEN

by

door

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Table of contents

CHAPTER 1

GENERAL INTRODUCTION,

PROBLEM STATEMENT, THESIS HYPOTHESES,

OBJECTIVES AND EXPECTED OUTPUT

GENERAL INTRODUCTION, PROBLEM STATEMENT, THESIS HYPOTHESES, OBJECTIVES AND EXPECTED OUTPUT

1.1 Tanzania

In this chapter, information will be provided with regard to sugar production in Tanzania. The chapter finishes with the objectives, hypotheses and expected output of the carried out research.

1.1.1 A presentation of the country

In 1964, shortly after independence, Tanganyika and Zanzibar merged to give birth to Tanzania. Tanzania borders the Indian Ocean in the east, and Kenya and Uganda in the north; in the south it borders with Zambia, Malawi and Mozambique and in the west with the Democratic Republic of Congo (DRC), Burundi and Rwanda (Fig. 1.1).
Its climate varies from a hot and humid tropical type with a mean temperature of 26^0C along the coast to a temperate type with a mean temperature of 22^0C in the highlands. The greater part of the country is best described as a savanna, characterized by a short rainy season followed by a long dry period; it receives rainfall in the range of 500 to 1000 mm per year. Less than 10% of the country receives rainfall in excess of evapotranspiration.
The country has an area of 945 087 km^2 in which water occupies about 59 050 km^2 and land mass of 886 037 km^2 of which only 4% is arable. On this arable land

permanent crops occupy 1% and the rest is for other agricultural activities (Ministry of Agriculture, 2000). The peak of the Kilimanjaro Mountain is the highest point rising to 5 895 m above sea level.

KEY: SRI – Sugarcane Research Institute
TPC – Tanganyika Planting Company KSL – Kagera Sugar Limited
KSC – Kilombero Sugar Company
MSE – Mtibwa Sugar Company

Figure 1.1 Map of Tanzania showing sugarcane commercial estates and research centre

1.1.2 Agriculture in the Tanzanian economy

Tanzania, with a population of about 37 000 000 and growing at an annual rate of 2.6% is one of the poorest countries in the world. About 82% of the population lives in rural areas earning their living mainly from agriculture. Over 50% of Tanzanians are classifiable as poor; they have a per capita income of less than 1US $ day^{-1} (World Bank, 2000). The majority (over 80%) of these poor Tanzanians are located in rural areas. Agriculture is also the largest contributor to the GDP. Agriculture's share to the GDP for the period 1987-1990 averaged 48.2%, 48.4% for the period 1990-1993; 50% for period 1994-1998, and 50% for the period 1998-2000. Agriculture is the largest contributor to the country's foreign exchange earning ranging between 54% to 56%. Compared with other sectors, agriculture has the highest growth linkages (multiplier effects). Thus agriculture is the mainstay of the country's economic and social development (World Bank, 2000).

1.1.3 The Agricultural policy

The agricultural policy, as it now stands, intends to improve the wellbeing of the people whose principal occupation and livelihood is based on agriculture. The policy seeks to ensure that direction and pattern of development in the agricultural sector meets economical and social objectives and outputs. It emphasizes the importance of competitive markets and the conservation of the environment on a rational basis for agricultural development. The focus of the policy is on how the Government should deploy public goods and services to support the private sector in promoting growth

and commercialization in the agricultural sector. Thus the agricultural policy objectives are as follows (Ministry of Agriculture, 1995):

- to assure basic food security for the nation and to improve national standards of nutrition by increasing output, quality and availability of food commodities, and by increasing food crops through productivity and area expansion;
- to improve the standard of living in rural areas through increased income generation from agricultural production, processing and marketing;
- to increase foreign exchange earnings for the nation by encouraging the production and increased exports of cash crops;
- to produce and supply raw materials, including industrial crops, while also expanding the role of the sector as a market for industrial outputs through the application of improved production, marketing and processing technology;
- to develop and introduce new technologies which increase the productivity of labour and land;
- to promote integrated and sustainable use and management of natural resources such as land, soil, water and vegetation to conserve the environment;
- to develop human resources within the sector in order to increase the productivity of labour and to improve ability, awareness and morale;
- to provide support services to the agriculture sector, which cannot be provided efficiently by the private sector;
- to promote access by women and youth to land, credit, education and information.

1.1.4 The Government's vision of the agricultural sector

The nation envisages an agricultural sector, which by the year 2025 will be modernized, commercial, highly productive and profitable, using natural resources in an overall sustainable manner and offering effective inter-sectoral linkages.

1.1.5 The Government's strategic objectives in agriculture

In order to achieve the long-term Government vision by the year 2025, it will be necessary to transform the existing subsistence agriculture into a commercially profitable production system. The strategy is thus to create an enabling and conducive environment for improving profitability of the agriculture sector as the basis for improved incomes and poverty reduction. In the first five years, the main emphasis will be on laying the foundation of the transformation process by making agriculture profitable to all stakeholders in the production-consumption chain. This will create the necessary conditions for increased private sector participation. In this initial phase the government's emphasis will be on implementing the necessary institutional, legal and administrative policy changes as well as planning long–term investment programmes that will lead to further transformations. Strengthening the capacity of research, training and improving agricultural extension services are some of the key areas that will be addressed by the Ministry of Agriculture.

1.1.6 Agricultural sector targets

The agricultural sector development strategy summarized above is anticipated to lead to:

a. Growth targets
    1. An increase of the real annual agricultural growth rate from 3.6% to 5% by the year 2003 and 6% by the year 2005.
    2. An increase of the real annual growth rate of the export crops from 6.8% to 9% by the year 2005.

b. Poverty alleviation
    1. A reduction of the proportion of the population below the poverty line from 48% in the year 2000 to 42% in 2003, and 24% by the year 2010.
    2. A reduction of the proportion of rural population below the poverty line from 57% to 49.5% in the year 2003, and 29% in the year 2010.
    3. A reduction of the proportion of food deficit from 27% to 23% in the year 2003 and 14% in the year 2010.

1.2 World sugar situation

1.2.1 Production

According to the Sugar bulletin (2000), the world sugar production in 2001/02 was estimated at 133.9 million tons. This was an increase of 3.6 million tons against the previous year and it would arise from an increased production in Brazil of 5.3 million

tons, 1.29 million tons in Thailand and 1.02 million tons in China. On the other hand, the world sugar export in 2001/02 was estimated at 40.4 million tons, 2.8 million tons above the 2000/01 export. The world sugar production forecast for 2002/03 was set at 138.8 million tons, being 4.9 million tons more or 3.7% against the revised 2001/02 levels. The Brazilian production was forecast to increase for the second consecutive year, and in the year 2002/03 by 2.35 million tons. The EU was expected to rebound by 1.5 million tons from the previous year's (2001/02) low production of 16.2 million tons. The world sugar export in 2002/03 was forecast at 43.8 million tons, an additional 3.4 million tons or 8% against the revised 2001/02 estimates. Brazil was forecast to be the largest exporter, shipping 13.1 million tons, followed by the EU with 5.8 million tons, and Thailand with 4.6 million tons (Table 1.1).

1.2.2 Consumption

Between 1995 and 2005, global sugar consumption was projected to increase from an annual average of 110.2 million tons to about 137.2 million tons, giving an annual average growth of about 2%. The bulk of the increase in consumption would be in developing countries. By the year 2005, the developing countries' share of global sugar consumption would be in the order of 65.4%. Among the developing countries the highest growth in consumption was expected to be in Africa and the Far East by 3% annually, followed by the Near East by 2.8%, Oceania (Fiji) by 2.3%, Latin America and the Caribbean by 1.9%. (Table 1.2).

Table 1.1 World sugar production

Region	1993-1995 10^6 Tons	2005 Estimated 10^6 Tons	Annual Growth Rate 93-95 to 2005
Africa	5.5	5.8	2.8%
L. America	29.4	42.8	3.05%
Near East	2.8	3.7	2.5%
Far East	32.7	42.9	2.5%
North America	7.1	7.1	0.0%
W. Europe/EU	17.3	16.2	-0.6%
USSR&Misc.	6.5	4.9	-2.6%
Australia	4.8	6.4	2.6%
Japan	0.9	0.9	0.2%
South Africa	1.5	3.0	6.3%
World	112.5	137.7	1.9%

Source: Tanzania Sugar Board, 2003

USSR=Union of Soviet Socialist Republic
Misc. = Miscellaneous

Table 1.2 World Sugar Consumption

Region	1993-1995 10^6 Tons	2005 Estimated 10^6 Tons	Annual Growth Rate 93-95 to 2005
Africa	8.2	11.3	3%
L. America	20.7	25.5	1.9%
Near East	6.1	8.3	2.8%
Far East	31.9	44.4	3.0%
Fiji	0.09	0.12	2.3%
North America	9.6	10.9	1.2%
W. Europe/EU	14.1	15.5	0.9%
USSR & Misc.	14.2	15.1	0.5%
Australia	1.3	1.4	1.1%
Japan	2.6	2.9	1.1%
South Africa	1.4	1.7	2.0%
World	110.2	137.2	2.0%

Source: Tanzania Sugar Board, 2003

USSR=Union of Soviet Socialist Republic
Misc. = Miscellaneous

1.3 General review of the Tanzanian sugar industry

1.3.1 Sugar industry stakeholders

The Tanzanian sugar industry stakeholders comprise several groups: the large-scale sugar producers, the sugarcane outgrowers, the small-scale sugar producers, the high fructose corn syrup (HFCS) & sweeteners producers, the Sugarcane Research Institute, the National Sugar Institute and The Tanzania Sugar Board.

1.3.1.1 Large-scale sugar producers (companies)

These are identified as companies incorporated under the companies' ordinance Cap 212. They are engaged in the business of producing and marketing sugar. They are both cane growers and millers, owning sugar cane estates as well as sugar mills. There are at present four such sugar companies: Kilombero Sugar Company (KSC), Mtibwa Sugar Estate (MSE), Tanganyika Planting Company Limited (TPC) and Kagera Sugar Limited (KSL).

1.3.1.2 Sugarcane outgrowers

This is a diverse group of farmers who grow cane on an acre or less or more. They are attached to a sugar mill at KSC and MSE. TPC and KSL do not have outgrowers at present. Overall outgrowers command about 5,700 ha of cane and they total about 6,000 farmers.

1.3.1.3 Small-scale sugar producers

There are four categories of small-scale sugar producers operating in the country:

- Mini sugar plants: these are owners and operators of small sugar mills capable of producing 1 000 to 2 000 tons of sugar year^{-1}.
- Miniature sugar plants: these are owners and operators of commonly referred 'village level sugar plants'. A miniature plant has the capacity to crush 2.5 tons of cane per hour, and to produce between 100 to 600 kg sugar day^{-1}.
- Household level sugar producers: these producers crush sugarcane using manual cane crushers. Liming/boiling juice is done over open fire followed by slow cooling/crystallization and separation of sugar crystals from molasses through gravitational drainage. This programme is at an experimental stage by involving 11 women groups producing sugar at house level, and their production has yet to be determined.
- Producers of jaggery. Although jaggery is not granular free flowing sugar, this product can complement or substitute granular sugar and when exported, it is sometimes classified under tariffs applicable to raw sugar. It can also be treated as sugar. It is estimated that there are about 22 producers of jaggery, commanding an area of about 5 000 ha and producing 20 000 tons of jaggery.

1.3.1.4 High Fructose Corn Syrup (HFCS) & Sweeteners Producers

At present there is no HFCS production. As for sweeteners there is one company producing sweetened sugar. The process involves 'blending' normal sugar with high intensity sweeteners resulting in an extra sweet sugar.

1.3.1.5 Sugarcane Research Institute

There is only one Sugarcane research institute in the country. It is based at Kibaha. It is located 35 km west of Dar es Salaam just off the Dar-Morogoro highway opposite the former Tanzania Motor Manufacturing Company (TAMCO). The climate at Kibaha allows the sugarcane plant to flower and bear seeds, which are viable. Therefore it is a potential place for sugarcane hybridization. At the moment there is a germplasm collection of about 500 different varieties from all over the world.

1.3.1.6 National Sugar Institute

This is a training institute based at Kidatu, providing central training facilities for the sugar industry in key skills.

1.3.1.7 The Sugar Board

The sugar board is responsible for regulation, coordination and development of the sugar industry.

1.3.2 History of sugarcane research in Tanzania

Research on sugarcane in Tanzania is a relatively recently developed activity compared to other commercial and food crops. Research on sisal, cotton and coffee were initiated in Tanzania in the 1930's, while research on sugarcane was established in East Africa under the umbrella of the East African Agriculture and Forestry

Research Organization (EAAFRO) in the late 1960's in Kenya to cater for the whole region, originally known as the High Commission and subsequently as the East African Common Services Organization and the East African Community. The station was moved to Kibaha in Tanzania in 1972. The East African Community broke up in 1977, and the Sugarcane Research Institute at Kibaha has since come under the Ministry of Agriculture. The mandate inevitably has changed. The Institute is now broadly charged with the responsibility of carrying out and coordinating research on sugarcane in all aspects of development of the sugar industry in the country. The long-term objectives of the Sugarcane Research programme are:

- to service the sugar industry with superior high yielding adaptable clones resistant or tolerant to the prevailing disease and insect pest complex;
- to monitor the occurrence and distribution of sugarcane disease and insects and devise appropriate control strategies;
- to carry out basic studies on the biology and ecology of key pests (insects and disease);
- to study and recommend production practices which will lead to efficient utilization of limiting resources such as nutrients and water;
- to liaise with institutions outside Tanzania and exchange information and materials beneficial to the sugar industry;
- to maintain a living collection of local, exotic and new sugarcane genetic materials for the industry (Tanzania Department of Research and Training, 1991).

1.3.3 Importance of sugarcane and its prospects in Tanzania

As already indicated, the Tanzanian sugar industry revolves around five factories and estates owned by four companies, namely, the Tanganyika Planting Company (TPC), Mtibwa Sugar Estate (MSE), Kilombero Sugar Estate (KSE) and Kagera Sugar Limited (KSL). Now privatized, the government's share in each company is about 25%.

Sugarcane produced commercially is used mainly for the production of sugar and mollases together with filter cake as factory by-product during the sugar fermentation. Mollases are used either for the production of hard drinks (whisky) or mixed with hay as animal feed specially to cattle. On the other hand, filter cake is used both as a soil amendment and as a source of mineral N.

Sugar is an important commodity in Tanzania; it is not only a source of food but it also complements other key foodstuffs. Sugarcane production and processing generates direct employment to an average of 80 000 workers, of which one third is unskilled rural labour. This sub-sector is therefore very efficient in utilizing rural labour. However, it also provides indirect employment, which is not quantified in the following main areas:

- wholesale, sub-wholesale & retail trade in sugar with an annual turnover of around 50 million US $;
- provision of transport services valued at about 3 million US $;
- supplies of raw materials, for example lime, various spares and others;
- provision of social services in sugar townships (shops, bars, schools etc.), and
- indirect employment associated with purchase/sale & distribution of imported sugar.

Sugarcane production also generates an income to private small-scale sugarcane producers (outgrowers) who contribute twenty to thirty percent of total cane crushed per season. Presently sugarcane outgrowers earn about 4 million US $ a year from sale of sugarcane. When considered in the context of rural agriculture income, sugarcane is a major contributor in alleviating rural poverty. The spread of benefits covers a population of about 150 000 people.

The sub-sector also contributes significantly to the government tax revenue, which was 12.3 million US $ in 1999/2000. Through import substitution it fetched about 14 – 15 million US $ net of foreign exchange in 1995/96. This is a significant contribution toward the governmental budget essential for the development and maintenance of social services. As noted above sugar is produced mainly for local consumption and thus Tanzania imports only a fraction of its requirement; so that a considerable amount of foreign exchange is saved. For example in the year 2000/01, a total of 18.3 million US $ was saved. Sugar production can also be considered as one of the initial steps in the industrialization process in Tanzania. The sugar industry is thus in line with the overall agricultural development policy in the country whose objectives are:

- to attain food self sufficiency;
- to earn foreign exchange;
- to alleviate poverty; and
- to establish agriculture as a basis for industrialization.

The relative importance of sugar is best seen by comparing it with other major crops produced in Tanzania. In 1988, a comparison among crops was made in relation to coffee, cotton, tea, tobacco, sisal, cashew nuts, sugar, maize, rice and wheat. The production costs of these crops in economic terms were compared with economic

benefits gained. Crops with a cost-benefit (C-B) ratio greater than 1 indicate positive economic benefits and therefore a worthwhile crop for Tanzania. On the other hand, a C-B ratio of less than 1 would indicate that the crop would have little or no economic benefit to the country. Among the export crops, tobacco and sisal have a C-B ratio of less than 1 and thus are economically marginal. On food crops, only wheat has a C-B ratio of less than 1. Sugar has a ratio higher than maize and comes second to rice (Tanzania Sugar Board, 2003).

Table 1.3 The economic cost – benefit ratio

Export Crops	EC-B Ratio	Food Crops	C-B Ratio
Coffee	3.10	Rice	1.83
Cotton	2.50	Sugar	1.12
Tea	2.60	Maize	1.01
Cashew	1.80	Wheat	0.66
Tobacco	0.95		
Sisal	0.93		

Source: Impact of Taxes and Levies in the Agriculture Sector, 1998

The sugar industry in Tanzania is implemented through a ten-year development programme, which is divided into two phases of five years each. The first phase, which ends in the financial year 2004/05, has a production target of 271 000 Mt and the second one which ends in the year 2010 has a production target of 567 000 Mt. This plan aims at achieving the following objectives:

1) to attain self sufficiency in sugar by 2010;
2) to earn an annual foreign exchange (savings) of about 28 billion US $;
3) to create 81 360 jobs (employment opportunities);
4) to increase its contribution to the government revenue by 12.3 million US $;

5) to alleviate poverty of sugarcane outgrowers and small-scale producers, affecting 150 000 people who are projected to earn 4 million US $;
6) to promote environmental sustainability; and
7) to promote social and economic development in rural areas by building schools, hospitals, townships, roads and improving water supply in both rural and urban settlements.

1.4 Review of the performance of the sugar industry in Tanzania

1.4.1 General performance

Sugar production in Tanzania increased steadily from an annual average production of 40 000 tons between 1961 and 1965 to an annual average production of 115 200 Mt during the period 1976 to 1980. Over a period of 20 years, sugar production increased by more than 100%. However, considering that in 1980 the factory-installed processing capacity was about 165 000 Mt $year^{-1}$, the achieved high annual average production of 115 200 Mt represented only about 70% of the factory processing capacity. The period from 1981 to 1990 saw a decline in sugar production. The annual average production fell from the high 115 200 Mt of the period 1976 to 1980 to a lowest annual average production of 99 000 Mt for the period 1986 to 1990. That is a decline of 15%. The decline in production by then was a result of adverse economic situation prevailing in the country during that period. The industry was very badly affected by the lack of foreign exchange, which led to difficulties in procurement of essential inputs e.g. spares and consumables. During the period from 1981 to 1990, the installed factory processing capacity had increased to 230 000 Mt $year^{-1}$, thus the

overall utilization of built up capacity fell to a low of 43%. The period between 1990 and 2000 witnessed a very erratic production pattern as shown in Table 1.4 (Tanzania Sugar Board, 2003).

Table 1.4 Sugar production in metric tons at different sugarcane estates in 1990 – 2000

Year	KSC	MSE	TPC***	KSL	Total
1990/91	43 747	24 610	39 446	3 522	111 325
1991/92	53 674	25 565	32 681	5 284	117 204
1992/93	52 117	28 087	37 750	2 399	120 353
1993/94	54 059	30 635	37 854	3 073	125 621
1994/95	45 825	34 943	19 853*	4 200	104 821
1995/96	41 762	32 109	33 605	4 617	112 093
1996/97	38 981	32 584	39 435	5 300	116 300
1997/98	29 517	20 885	27 896	1 588	79 886**
1998/99	42 063	28 260	40 021	3 278	113 622
1999/00	50 236	32 111	34 580	-	116 927

Source: Tanzania Sugar Board, 2003

* Machinery breakdown no production most of the season
** Year of El nino
*** Performance of the estate where this study was conducted (TPC)

1.4.2 Production constraints/ Problem statement

Over the past ten years, sugar production in the country has stagnated at around 120 000 Mt year^{-1} as compared to the available total installed factory processing capacity of 230 000 Mt year^{-1}. With a domestic demand for sugar estimated to be well in excess of 360 000 Mt year $^{-1}$, local production provides less than 30% of the annual requirement. A proportion of this deficit is met through import and this is causing a serious economic drain of the foreign currency, which, being inadequate, is badly

needed in the country. Therefore, attainment of self-sufficiency in sugar is a primary objective.

The major problem the sugar industry is facing in the country is the gradual decline in sugar yield due to **low cane yield per unit area**. For example, Table 1.5 shows the production trend of cane ha^{-1} at the TPC estate. Mean cane yield decreased from 99.2 t ha^{-1} in 1990 to 73.6 t ha^{-1} in 2000 (Tanzania Sugar Board, 2003). Although this is partly linked to inadequate foreign currency reserve and local funds to purchase field inputs like irrigation equipment, other factors including pests, drought, salinity and lack of proper fertilizer management practices, are also important.

The presented study, however, focuses on the problems related to fertilizer management practices at the TPC estate as a model case study. The choice of this estate was due to the existence of both saline and non-saline soils. The problem of salinity is now increasingly becoming apparent also in other estates and in the fields of outgrowers. Consequently the TPC estate was the most suitable location for the proposed study.

Table 1.5 Annual production record at TPC estate from 1990/91 to 2000/01 growing seasons

Season	Hectare harvested	Tones Canes harvested	Tones of cane ha^{-1} (TCH)	Age in Month at harvest	% Pol
1990/91	4 302	426 758	99.2	12.3	12.8
1991/92	4 560	395 352	86.7	12.4	13.4
1992/93	4 920	403 932	82.1	13.1	13.1
1993/94	5 400	397 851	73.7	12.7	12.6
1994/95	3 319	225 600	73.1	15.8	12.0
1995/96	4 574	422 450	72.9	17.7	11.2
1996/97	5 244	424 530	68.8	13.9	12.0
1997/98	4 225	323 761	76.6	13.0	11.4
1998/99	4 715	428 251	66.8	14.7	12.7
1999/00	5 276	344 807	65.4	11.8	13.3
2000/01	5 323	371 773	73.6	12.6	11.1

Source: Agronomy department TPC estate
% Pol = The relative abundance of apparent sucrose in the cane juice

1.4.3 Research focus and justification

1.4.3.1 Fertilizer experimentation

Soils at the TPC estate, like other tropical soils, have a low organic matter content leading to deficiency of mineral N as a result of its low turnover (Smithson and Giller, 2002). Hence a proper fertilizer management practice on mineral N is the key issue for a successful and profitable production of sugarcane. Being the most limiting nutrient, mineral N is supplemented mainly by using inorganic and organic fertilizers. With regard to organic fertilizers, though not quite often, the use of filter cake, a factory by-product of processing sugar will be discussed. Levels of N to be applied have been determined using the traditional or conventional methods of measuring indirectly fertilizer use efficiency whereby N uptake in a unfertilized crop is deducted

from the uptake in a fertilized crop, divided by the amount of N applied to the fertilized plot. This technique can give misleading results through either overestimation or underestimation. Recommended rates have been high, sometimes up to more than 120 kg N ha $^{-1}$. Yet yields have remained very low at an average of 70 – 90 t ha^{-1}, although the potential yield at the TPC estate is as high as 120 t ha^{-1} (Wood, personal communication). Although the results of laboratory analysis of mineral N in the soil and plant tissue may sometimes show N levels below the threshold value in all tested fields, application of different rates of N may not necessarily result in significant yield increases (Isa, 1998; Isa and Kalimba, 2001). It emphasizes the need for a proper approach to study and to establish the fate of applied N in sugarcane fields and to review the estates' fertilization policy. The balance of applied mineral N in the soil under sugarcane cultivation influences subsequent crop response to fertilization (Ng Kee Kwong et al., 1999). Since the traditional or conventional methods do often not correctly allow the measurement of the effectiveness of different N sources in the soil, losses and balance of applied N at the end of the season, an alternative reliable technique is the use of labelled fertilizer material (^{15}N). Isotopic techniques allow the calculation of the contribution of various sources of N, utilization efficiency and the residue in the soil at the end of the season (Corbeels et al., 1998a; Corbeels et al., 1998b). If properly used, these techniques are more efficient than the traditional methodology in establishing the fate of N applied. A negative point of these techniques is the high cost and need for special analytical equipment.

1.4.3.2 Fertilizer recommendation versus soil characteristics

The TPC estate is divided in blocks of 10 to 15 ha each. In each block any of the 3 to 4 different commercial varieties is planted. Because soils at TPC are very heterogeneous in terms of their physico-chemical characteristics, the estate is divided into four main areas based on well-defined soil types. The northern part of the estate has a rather brownish to dark grey clay soil with neutral soil reaction. The eastern part of the estate has dark grey soils with a high water table, while the western part of the estate is generally dominated by soils that range in texture from sandy clay loam to silt clay loam; a few fields have sandy soils. The southern part of the estate, which accounts for 37% of the total area under sugarcane cultivation, is dominated by soils that range from saline to saline sodic. A survey of the pH and EC (1:5) of the different areas within the TPC estate is given in Table 1.6.

The fertilizer application regime depends on the results of a fertilizer trial conducted on one block and with one commercial variety (blanket recommendation is at 60 kg N ha^{-1}), without considering the possible varietal differences in response to fertilizer use efficiency, and to differences in physico-chemical soil characteristics existing in different blocks, such as salinity and concentration of cations and anions.

There is a distinct difference among plant species in their ion uptake and utilization efficiency (Greef et al., 1999). Verma et al. (1993) reported that different sugarcane varieties possess different abilities to consume fertilizer N. Some varieties have the capacity to use relatively high N rates with no quality deterioration at the end of the season, while others show very little response to N application. It is therefore apparent that some varieties are able to produce a satisfactory sugar yield in soils that would not be satisfactory for others.

Differences in soil physico-chemical characteristics are also an important parameter to be considered when recommending a fertilizer input. Different soil types require different fertilizer management practices (Ockerby et al., 1993). For example, the N requirement in two sites with a different level of organic N might differ significantly. Where the level of organic N in the soil is high, the N applied as fertilizer can be considerably lower than where organic N level is low (Yamamoto et al., 1993).

Sandy soils, which usually have a low water holding capacity and cation exchange capacity (CEC), require different fertilizer levels than clay soils in order to produce reasonably satisfactory yields. In addition, CEC is one of the dominant factors controlling volatilization (Freney and Simpsom, 1983). As ammonium ion reacts with cations in the soil, it reduces the amount of NH_4^+-N and NH_3 in solution at a given pH. Ammonia loss decreases as CEC increases. Losses of mineral N affect plant N uptake and underestimates the rate of fertilizer application. Consequently, two sites with a different CEC will require different levels of fertilizer application in order to produce a reasonably satisfactory yield.

Kanwar et al. (1989) reported that an efficient ion uptake and utilization depends on the variety, concentration of the nutrient, soil moisture, soil type and method of fertilizer placement. The Estate management is expected to apply rates, which are specific to a certain variety and site.

Table 1.6 Quantification of pH and EC levels on the TPC Estate

Location	pH (1:1)		*EC (1:5)*		Remarks
	Range	Mean	Range dS m^{-1}	Mean dS m^{-1}	
Northern area	6.7 – 7.7	7.2	0.06 – 0.18	0.11	Non-saline
Southern area	7.8 – 8.8	8.3	0.20 – 0.80	0.64	Saline
Western area	7.3 – 8.3	7.8	0.13 – 0.71	0.41	Saline
Eastern area	7.1 – 7.9	7.5	0.09 – 0.25	0.18	Non-saline

Source: Agronomy department TPC estate

1.4.3.3 Soil salinity versus type of fertilizer

At the TPC estate, the salt effect is actually the second agricultural setback, after the white grub infestation (Maro, 2001a). Out of 7 000 ha under commercial sugarcane, a total of 2 500 ha (about 37%) is salt affected in different categories as shown in Table 1.7. The TPC estate uses urea in the whole estate because it is cheap. Based on the current year (2003) fertilizer price, the unit price per kg urea is 0.40 US $ compared to 0.63 US $ for calcium nitrate and 0.75 US $ for ammonium sulphate. The use of urea is likely to be continued because of the economic benefit. Salinity together with high soil pH increases the potential for N loss due to volatilization of NH_3 especially when urea is used as a source of N (Byrnes and Freney, 1995). Recent work on the problems encountered with the use of urea has shown that together with the losses there is also a problem of phytotoxicity on seed germination and seedling growth from the NH_3 produced through hydrolysis of urea (Bremner, 1995). However, this occurs when a relatively large amount of N has been applied.

Furthermore, continuous use of urea increases soil alkalinity, and it might reach a level that is beyond the tolerance for sugarcane. The pH range for sugarcane is between 5.0 and 8.5 (Maro, 2001a). The estate management is expected to recommend the use of ammonium sulphate (AS) fertilizers. Losses of mineral N when AS is used are not large (Ellington, 1986) except in soils with high pH. On the other hand, AS can also help to reduce the level of soil alkalinity.

Table 1.7 Categories of salt-affected soils at the TPC estate

Soil description	pH (1:1)	EC (1:5) dS m^{-1}	Area covered ha	% of total arable land
Moderately saline, non-sodic soils	< 8.4	0.4 – 0.8	56.0	0.85
Saline soil	< 8.4	> 0.8	110.3	1.7
Non-saline soil, moderately sodic soils	8.4 – 9.0	< 0.4	981.8	14.9
Sodic soils	> 9.0	< 0.4	28.9	0.4
Moderately saline soil sodic soils	8.4 – 9.0	0.4 – 0.8	723.4	11.0
Highly saline sodic soil	> 9.0	> 0.8	539.3	8.2
Other soil (normal)	< 8.4	< 0.4	4160.5	63.0

Source: Agronomy department TPC estate.

1.4.3.4 Quality of water for irrigation versus type of fertilizer used

TPC estate uses irrigation to water its sugarcane fields. The main sources of water for irrigation at the TPC estate are the Weruweru river, which is considered to supply relatively good quality water (salt-free), and also the Kikuletwa river whose water contains a high content of soluble salts. The Kikuletwa River is the major source of irrigation water for the southern part of the estate. Occasionally bore holes are also

used as a source of irrigation water for other parts of the estate. Some boreholes also have relatively poor quality water especially those located in the southern part of the estate (Table 1.8).

Continuous use of saline water increases the soil electrical conductivity (salinity), Cl^-, SO_4^{-2} and Na^+ ions (Mostafa et al., 1992). Notwithstanding these observations, urea is used as a source of mineral N even in fields irrigated with water containing high levels of salt. Loss of mineral N as a result of NH_3 volatilisation is likely to be very high in those fields and hence N applied is not taken up effectively by the crop (Byrnes and Freney, 1995; Fleisher and Hagin, 1981).

High levels of Na^+ and Cl^- lead to toxicity of non-tolerant plants and also bring about nutrient imbalance in Ca^{++} uptake (Crane and Bowman, 1991). Furthermore, Sarig et al. (1993) reported that irrigation with saline water increases the accumulation of C and N in the microbial biomass, but decreases the rate of C and N mineralization, the carbohydrate content and soil aggregate stability. It appears that saline water reduces the carbohydrate produced by microorganisms and thus a reduction in soil aggregate stability, affecting the water holding capacity (Chang and Wann, 1993).

Table 1.8 Water analysis data from various sources of irrigation water for the TPC estate

Source	pH	EC dS m^{-1}	SAR
Karanga river	8.1	0.10	0.2
Weruweru river	8.1	0.16	0.3
Kikuletwa river	8.6	1.18	3.7
Borehole 5D	8.2	0.77	3.9
Borehole O3	7.4	0.74	2.3
Borehole BO3	7.6	0.61	1.8
Borehole Q3	7.6	0.72	5.2
Borehole N40	7.7	0.51	3.3
Borehole P4	7.8	0.70	2.9.
Borehole R3	7.8	0.69	3.0

Source: Agronomy department TPC estate
SAR = Sodium adsorption ratio
Threshold value = 0.4 dS m^{-1}

1.4.3.5 Climate at TPC versus fertilizer placement

The climate at the TPC estate is best described as semi arid, such that without irrigation the TPC estate would not exist. It is not uncommon to have a monthly moisture deficit even during the rain season. This is largely because of the high evapotranspiration that occurs throughout the year, with an average of 6.7 mm day^{-1}. Sometimes, on hot and windy days, evapotranspiration can be as high as 10 mm day^{-1}. The TPC estate experiences an annual rainfall average of about 600 mm and a daily temperature range from a minimum of 26^0C in July to a maximum of 33^0C in February (Table 1.9). Thus, high evapotranspiration prevailing at TPC is consistent with the climatic characteristics of the area.

The existence of saline soils, the saline water for irrigation and the fertilizer application method used, present special challenges to the TPC management. Urea is used all the time, as it is much cheaper. It is applied by hand on sugarcane stools after they have emerged. High evapotranspiration together with high soil surface temperatures are among the factors which speed up losses of mineral N as a result of hydrolysis (Bremner, 1995), and losses are even much higher if the soil is saline (Byrnes and Freney, 1995; Fleisher and Hagin, 1981). However, such losses could be minimized if ammonium sulphate was used instead of urea or if urea was buried in the soil rather than applied on the soil surface (Freney, 1997).

Table 1.9 Mean monthly climatic data at the TPC estate (ten years average -1990 to 1999)

	1	2	3	4	5	6	7	8	9	10	11	12
January	41.1	32.4	21.0	5.5	-140	26.0	2.7	8.4	251.1	8.6	77.0	49.3
February	35.4	32.9	20.7	4.9	-138	25.8	2.4	8.2	230.1	8.4	76.2	49.6
March	109.0	32.3	21.3	4.0	-126	26.1	2.6	8.1	245.3	7.3	81.3	54.5
April	229.1	29.9	21.2	2.7	-29	25.6	2.3	5.9	170.1	6.4	86.1	62.7
May	81.1	28.1	20.2	2.2	-72	23.9	1.8	5.2	160.9	5.5	86.3	64.9
June	5.0	26.9	18.4	2.0	-94	22.3	1.7	4.7	145.6	4.9	84.2	62.7
July	4.9	26.4	17.1	2.3	-100	20.5	1.7	5.7	155.9	4.9	81.2	59.6
August	4.7	27.8	17.6	2.6	-117	21.9	1.8	5.6	169.8	5.5	81.0	55.9
September	2.8	29.0	18.3	3.5	-140	22.7	2.6	6.9	271.3	7.3	76.4	54.1
October	19.1	30.8	19.5	3.7	-146	23.9	2.6	7.1	222.2	7.6	75.6	51.7
November	38.4	31.3	20.7	4.6	-128	26.1	2.8	7.3	226.5	7.6	76.5	50.0
December	29.6	31.7	20.9	5.4	-141	26.2	2.7	7.5	231.4	7.8	76.2	49.1
Total	600.2						27.4	80.6	2480.2	81.9		
Mean/ month	50	30.0	19.7	3.6	-114.3	24.3	2.3	6.7	206.7	6.8	79.8	55.3

Key: 1= Rainfall (mm) 4= Wind speed (km/h) 7= Radiation (kJ) 10= Sun shine hours

2= Temperature max. (^{0}C) 5= Soil moisture deficit (mm) 8= Pan evaporation (mm) 11= RH% morning

3= Temperature min. (^{0}C) 6= Soil temperature (^{0}C) 9= Evapotranspiration (mm) 12= RH% afternoon

1.4.3.6 The use of filter cake

Filter cake (FC), a factory by-product of the sugarcane fermentation, is often applied on fields around the factory as a soil amendment. However, information on the effect of FC on growth and quality of sugarcane at the TPC is very scanty. There is evidence that in soils which have the capacity to mineralize, relatively large amounts of N, presence of FC enhances the rate of mineralization, resulting in a luxury uptake of N by the crop and a consequent reduction in sugarcane juice quality at harvest (Rodella et al., 1990). This is perhaps the case at the TPC estate where, because of the high temperatures, the rate of decomposition of filter cake is likely to be very high. Filter cake also contains a lot of Ca^{++} so that, when applied on a saline soil, it displaces Na^{+} in soil colloids and reduces the salt effect. Thus it can be used as a soil amendment on saline soils. At the moment nothing has been done to evaluate the effect of FC on cane growth and yield.

Consequently, the aim of this study is to compare behavior of the mineral N applied on sugarcane grown on two main soil conditions, saline and non-saline, under the current management practices at the TPC estate.

1.5 Research objectives, hypotheses and expected output

1.5.1 Research questions

The study intends to answer the following research questions:

1. what is the potential of the native soil in supplying mineral N;
2. what is the fate of applied N fertilizer in a saline and non-saline soil;
3. how much of the applied N fertilizer remains in the soil and how much is lost;

4. what is the efficiency of N uptake by the variety under study;
5. what is the distribution of mineral N within the sugarcane plant and its effect on growth characteristics, yield and quality;
6. what is the influence of mineral N on chlorophyll content, stomatal conductance and photosynthesis, and
7. what is the potentiality of the filter cake (factory byproduct or waste) in supplying N.

1.5.2 General objective of the study

To obtain insight in the N behavior of a saline and non-saline soil, grown by sugarcane at the TPC estate of Tanzania.

1.5.3 Specific objectives

The specific objectives are:

1. to determine the fertilizer use efficiency by the variety used under saline and non-saline conditions;
2. to monitor the behavior of mineral N in the soil during the growing season;
3. to determine balances and losses of mineral N;
4. to determine the potentiality of the native soil and filter cake on mineralization;
5. to determine net photosynthesis at different levels of N.

1.5.4. Hypotheses

The current fertilization policy does not take into consideration:

1. the potential of the native soil in supplying mineral N;
2. the possible losses of N when urea is used on a saline soil;
3. the varietal differences in fertilizer use efficiency;
4. the enhancement of rate of mineralization following the addition of organic matter in the soil.

If the behavior of the mineral N in soil and crop is known, there is possibility of refining the fertilization policy and subsequently management practices. That will enhance an increased production per unit area.

1.5.5 Expected outputs

The expected outputs are:

1. the information obtained will be useful for refining the fertilizer recommendation in order to obtain high yields with high quality per unit area;
2. to shed more light on soil type * fertilizer interaction and N losses;
3. to assist the management to avoid the risk of polluting the environment through excessive use of fertilizers in soils with a high water table and prone to leaching;
4. to maintain soil fertility.

CHAPTER 2

LITERATURE REVIEW, GENERAL DESCRIPTION OF THE STUDY AREA, CHOICE OF METHODOLOGY AND RESEARCH APPROACH

LITERATURE REVIEW, GENERAL DESCRIPTION OF THE STUDY AREA, CHOICE OF METHODOLOGY AND RESEARCH APPROACH

2.1 Origin and domestication of sugarcane

From the scribes of Alexander The Great after his invasion of India in 327 BC, one found that the inhabitants chewed a marvelous reed, which produced a kind of honey without any help from bees (Ustimenko, 1983). This probably is the only evidence that sugarcane originates from India and was first brought out of India by Alexander The Great. Sugarcane was subsequently spread to Persia and then to Egypt through the Arab invasion. The use of sugar spread in Europe with the expansion of sugarcane growing in the Mediterranean region at the beginning of the 13th century (Maede and Chen, 1977). By the 16th century, sugar was an important item of trade between Europe and the producing countries India, Cuba, Brazil and Mexico (Irvine, 1977). It is now an important crop in the world, including Tanzania, which started to grow sugarcane commercially in 1930 (Tanzania Sugar Board, 2003).

2.2 Classification, botany and growth characteristics of sugarcane

Sugarcane is a gigantic grassy plant of the poaceae family (Ustimenko, 1983). It belongs to the genus *Saccharum* L. and, of the six species recognized, two are

considered to be wild, the other ones originated in cultivation. The most widely grown sugarcane is *S. officinarum* L. (2n = 80) or noble sugarcane, though in some parts of India both *S. barberi* J. and *S. sinense* R. are also cultivated (Fauconnier, 1993).

The root system is fibrous, situated in the 0 to 70 cm soil depth. Sometimes it can penetrate as deep as 150 cm. The stem is vertical, cylindrical and divided into internodes. The stem diameter is from 3 to 5 cm; its length is from 3 to 6 m. The leaves are lanceolate, composed of an axil, ligule and blade. There are 10 to 15 leaves on one stem. The inflorescence is a panicle of about 50 to 80 cm in length and silverish in color. The panicle branches have pairs of spikelets with two flowers in each spikelet. After fertilization the fruit is formed which ripens within 25 to 30 days. The fruit is a caryopsis (Ustimenko, 1983). However, not all varieties of sugarcane develop inflorescence.

Sugarcane is grown throughout the warm tropics. It requires a fertile, well-drained soil and abundant supply of moisture for successful growth. The vegetation period of sugarcane from planting to blossoming includes four basic stages: sprouting, tillering, intensive growth of shoots and ripening (maturation). A crop developed from planted stalks is known as a plant cane crop (Misra and Mathur, 1990). Sugarcane begins ripening in 2 to 3 months before harvesting (Blackburn, 1984). After harvest and field clearing, the underground stem emerges to give rise to the second cycle referred to as the first ratoon crop (Misra and Mathur, 1990).

2.3 Production practices

2.3.1 Crop requirement

Sugarcane belongs to the botanical family of the poaceae (Ustimenko, 1983), and it uses the C_4 cycle in its photosynthetic pathway. It is a tropical crop, which grows very well in hot, sunny areas. Consequently, temperature, light and moisture are the principal factors that affect sugarcane growth and yield (O'Leary, 2000). Normal growth is slow, with a delayed maturity at high altitude, where temperatures are low and the weather is cloudy (Cornland et al., 2001). Sugarcane grows very well in a wide range of soils preferably in medium heavy clay soils. Good yields are obtained in soils, which are well-drained, aerated and fertile, and have a minimal 60 cm rooting depth, with pH values ranging from slightly acidic to slightly alkaline.

The optimum temperature requirement ranges from 28-30^{0}C (Ebrahim et al., 1998) and rainfall of not less than 1000 mm year^{-1} is necessary. Irrigation therefore is necessary in areas receiving less than 800 mm year^{-1}. Sugarcane can survive several weeks of drought or waterlogging; in such circumstances, yield reductions are usually very severe (Ramesh, 2000). Yet drought conditions are necessary at maturity for cane to ripe (O'Leary, 2000).

2.3.2 General cultural practices

In Tanzania, sugarcane is grown commercially in estates where the crop is grown in monoculture either under irrigation or rainfed conditions. In areas

surrounding the Mtibwa Sugar Estate (MSE) and Kilombero Sugar Estate (KSC), there are also small-scale sugarcane growers, and it is estimated that they cultivate a combined total area of 100 000 hectares annually.

2.3.2.1 Land preparation

Soils are first tilled to the desired depth of 30-40 cm, through the use of subsoiling machineries. Usually one subsoil operation, one plough and two harrows are enough. Planting furrows are then made at distances of 1.45-1.50 m apart, and in the direction depending on whether the field is furrow irrigated or overhead irrigated.

2.3.2.2 Planting

In commercial production stalks are cut into parts, with two or three buds per part, technically known as setts and used as planting material (seed cane) (Guzman and Victoria, 1992). To ensure good germination, setts are put horizontally in the furrow such that the buds face sideways and with an overlap of approximately 6 cm. Depending on the variety used, 30 000 – 35 000 setts can be planted on one hectare. A crop developed from setts or cuttings is known as a plant cane crop (Misra and Mathur, 1990). For a rainfed crop, time of planting is just at the onset of rains, whereas in irrigated fields, planting can be done at any time of the year as long as maturity and ripening will occur during the dry periods of the year (Cornland et al., 2001). Young cane, usually 6 to 9 months of age and free from disease and insect attack, is selected as planting

material. To control fungal disease such as smut (*Ustilago scitaminea*) setts are treated with hot water and/or with fungicide (Guzman and Victoria, 1992). Varieties respond differently to the hot water treatment. So, it is necessary to experiment prior to adopting a specific practice. Water at 50^0C for 30 minutes is generally satisfactory for most varieties (Guzman et al., 1993). Sugarcane is usually grown in blocks of 10 to 15 ha, using any of the commercial cane varieties in each block. The TPC estate, where the experiments were carried out, grows at least 13 different varieties. The major ones are varieties B 52-313, EA 70-97, NCO 376, CO 1007, CO 421, EA 70-97 and NCO 310.

2.3.2.3 Weeding

Sugarcane is best grown on a well-drained fertile soil with a good supply of moisture and nutrients. Such conditions also favour intense and rapid growth of a wide range of weed species (Cardoso, 1997). Thus, weed infestation in sugarcane plantation is a major constraint in achieving higher yields. For example, Karim (1998) reported a reduction of 37% in cane yield when weeds were not controlled within the first six weeks after planting, and a reduction of 77% when the crop was not weeded for the whole season. Weeding is best done before the period of maximum growth known as the 'boom stage' of growth, which is from four to six months depending on the variety and various growth factors (Glaz et al., 1989).

The common methods of weed control are: hand hoeing, mechanical operation and use of selective herbicides. There is no single methodology, which can ensure permanent weed control, and therefore an ideal strategy is to use a

combination of two or more weed control measures (integrated weed control practices) (Mahadevaswamy et al., 1994). In plantations, however, the use of herbicides is considered to be the most effective approach (Hunsigi, 1993). The most common herbicides in use are the different combinations of Ametryne, Atrazine and 2,4-D Amine. Most of these herbicides are, however, not very effective against weeds such as *Rottboelia sp., Cyperus sp., Panicum sp.* and *Sorghum helepense*, which are now considered to be the major weeds in sugarcane plantations (Dissanayake et al., 1997). Herbicide products, which can control weeds for a period of 8 to 10 weeks, are recommended for use in sugarcane fields.

2.3.2.4 Fertilizer application

Because sugarcane consumes more nutrients than naturally present in the soil, fertilizer application is necessary for a sustainable production (Chandra and Sainu, 1998). The amount and type of fertilizer to be applied are based on soil and plant tissue analysis, in addition to the results obtained from fertilizer trials conducted on the estate (Rao et al., 1989; Weng and Chang, 1990).

Of the three major nutrients, NPK, N application is considered to be the most important one (Meinzer and Zhu, 1998). Nitrogen is usually applied by hand throwing on the cane stools three months after planting or emergence on both plant cane and ratoon crops (Weng and Chang, 1990). The highest yields cane are obtained with the highest amounts of N applied although too much N has adverse effects on cane quality as reported by Bangar et al. (2000). Phosphorus and K are applied when deficiencies exist, but they are always required in

sufficient quantities to maintain optimum levels for continuous cropping (Yadav, 1995).

2.3.2.5 Maturity and harvesting

Depending on the cycle of the crop, variety and cultural practices, sugarcane matures from 10 to 15 months after planting (Blackburn, 1984). As the cane plant approaches maturity, the numbers of active leaves diminish, growth slows down, and more reducing sugars already present in the cane are converted to sucrose. As ripening proceeds, the % of sucrose in the stalk gradually increases and correspondingly the % of glucose and fructose diminishes. Low temperature, moderate drought and N starvation are effective ripening agents (Cornland et al., 2001). However, low temperature is the most effective factor in inducing ripening even when the crop is supplied with ample N and soil moisture (Hunsigi, 1993). Pre-harvest sampling is important to determine prospects of maximum recovery of the sugar. A crop, which has matured and ripened (at highest % of sucrose) is burned, cut very close to ground level and sent to the factory as soon as possible to minimize dehydration and quality deterioration of the cane for processing (Schembri and Carson, 1997). After harvesting, the field is cleared and subsequently the underground stem emerges to give rise to the second cycle, which is referred to as the first ratoon crop (Misra and Mathur, 1990). Economic yields are obtained up to a crop cycle of six or eight ratoons. Thereafter the field must be uprooted and replanted to start a new cycle as a plant cane crop. Most of the soil under sugarcane cultivation suffers structural deterioration by puddling and compaction caused by

harvesting and other operations with heavy equipment. Therefore, the use of organic matter on sugarcane fields has been found to be important in reconditioning compacted and puddled soils (London, 1984).

2.4 The role of mineral N to plants

Growth and yield of a crop is influenced by factors such as light, temperature, CO_2, nutrients and biotic factors like pests and diseases (Brady and Weil, 1999). Plant mineral nutrient composition is in the order of 3% compared to 70% and 27% for water and organic matter, respectively (Mengel and Kirkby, 1978). Although minerals make up only a comparatively small proportion of the dry matter, they are essential for photosynthesis and other specific functions in plant metabolism and for building up organic matter. Depending on their influence on growth, minerals are either classified as macro or micronutrients (Marschner, 1995). Nitrogen, which has been found to be a major limiting factor in sugarcane production, is classified as a macronutrient.

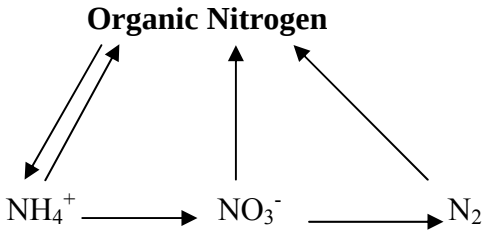
Nitrogen together with carbon (C), hydrogen (H), and oxygen (O) are major constituents of organic material. However, N constitutes 2 to 4% of the dry matter, and C about 40% (Mengel and Kirkby, 1978). Nevertheless, N is an indispensable element of numerous organic compounds of general importance (Pearcy et al., 1989). It occurs in the chlorophyll molecule and its presence in leaves increases the photosynthetic capacity of a plant (Tadahiko, 1997). As a constituent of organic compounds it combines with carbohydrates to form amino acids and proteins. When carbohydrates and nitrogenous compounds are abundant, plant growth is usually

rapid, more dry matter is produced and yield is far much greater. Marschner (1995) reported that the N required for optimum growth of a plant is 2 to 5% of the plant's dry weight, depending on the species. When N is deficient in the soil, poor growth and yield are realized. Several studies report an increase in yield with application of fertilizers N (Asfary et al., 1983; Gregory et al., 1984). But the influence of N on yield has limitations (Greenwood et al., 1980) and if not properly applied it affects the quality of the crop (Ng Kee Kwong et al., 1999) and other disorders such as rotting and discoloration of tissue (Greenwood et al., 1980). If mineral N is to be supplemented by inorganic fertilizers, the presence of moisture in the soil is important at the time of application (Hong et al., 2003). When N is in short supply to the plant, there is a reallocation of nitrogenous compounds from older tissue into young tissue. Yellowing which appears in older tissue is always associated with symptoms of N deficiency (Marschner, 1995; Mengel and Kirkby, 1978).

2.5 Mineralization and immobilization of soil organic N

Total soil N includes mineral N in the form of NH_4^+ and NO_3^-, fresh organic material including plant residues that have not passed through microbial transformations and soil humus or stable organic material that has at least once gone through a microbial transformation (Van Keulen, 1981). Assimilation of N by plants depends on the net formation of mineral N (Blackburn and Knowles, 1993; Roy and Singh, 1995). When N fertilizers are not used, soil N availability depends on the rate at which soil organic N can be converted to mineral N (Hong et al., 2003) through the process of mineralization.

NH_4^+ is an exclusive end product of mineralization (Blackburn and Knowles, 1993), but another school of thought is that ammonification and nitrification collectively constitute mineralization (Pilbeam et al., 1993). The whole process can be summarized as shown below (Blackburn and Knowles, 1993; Ellington, 1986; Pilbeam et al., 1993; Roy and Singh, 1995):



Although NH_4^+ is known to be the end product of mineralization, other chemical transformations of NH_4^+ also occur in the soil (Van Gestel et al., 1992). They include the nitrification process whereby NO_3^- is formed (Hart and Goh, 1980; Hatch et al., 1990), followed by the denitrification process producing N_2O and N_2 (Mosier and Schimel, 1993) and sometimes it undergoes volatilization to release NH_3 gas (Fleisher and Hagin, 1991; Freney et al., 1992). Fixation in clay minerals is another fate of NH_4^+ (Drury and Beauchamp, 1991). It comes about by a replacement of NH_4^+ for interlayer cations in the expanded lattice or clay minerals (Juang and Chen, 1993a). The clay minerals largely responsible for ammonium fixation are montmorillonite, illite and vermiculite (Mamo et al., 1993). It occurs to a greater extent in the subsoils than in the topsoils. The moisture content and temperature of the soil affects this process. Higher temperature, which may remove water molecules from the interlayer of clay minerals, increases the amount of fixed NH_4^+ (Juang, 1990). However, fixed NH_4^+ can be replaced by cations that expand the lattice such as Ca^{++}, Mg^{++} and H^+ (Juang and Chen, 1993b). Therefore, NH_4^+ fixation process can be regarded as an

alternative way of building N pool in the soil to optimize N crop recovery and minimize losses (Mamo et al., 1993).

The mineralization process is governed by a number of factors, such as microbial activity, temperature, moisture and the C/N ratio of the organic matter (Neale et al., 1997). The rate of decomposition is based on first order of kinetics (Van Keulen, 1981). However, various compounds have different decomposition rate constants; for example, proteins and sugars have the order of one day^{-1}; cellulose and hemicellulose 0.05 day^{-1} and 0.01 day^{-1} for lignin (Brady and Weil, 1999). During mineralization a diverse group of microorganisms is involved. Most of them utilize NH_4^+ and NO_3^- and very few utilize N_2, the so-called nitrogen-fixing bacteria (Byrnes and Freney, 1995; Srivastava, 1992; Blackburn and Knowles, 1993). During nitrification autotrophic bacteria known as *Nitrosomonas* and *Nitrobacter* (Mosier and Schimel, 1993) oxidize NH_4^+. Ammonium and O_2 control this process. However, the activity of microorganisms during the process of mineralization has been found to be influenced by other factors such as tillage operation (Van Gestel et al., 1992) and soil moisture (De Bruin et al., 1989; Hart and Goh, 1980). At moisture levels between field capacity and permanent wilting point both ammonification and nitrification may occur, but at a critical level of dryness NH_4^+ accumulates (Pilbeam et al., 1993). It appears that nitrifying and denitrifying bacteria can grow under hygroscopic humidity conditions (Nelida et al., 1993) and at an optimum pH range of 7 to 9 (Mosier and Schimel, 1993). Soil dryness has very often been associated with higher temperatures (Srivastava, 1992). However, there are microorganisms that are able to survive in extreme temperature and dryness.

Brady and Weil (1999) reported that the optimum range for nitrification is 30 to 35^0C and for ammonification 30 to 40^0 C. It seems that ammonification is a more

thermophilic process then nitrification. Closer to the soil surface where temperature can be high ammonification exceeds nitrification although nitrification might go on during the night. The reverse is true so that in deeper layers, where the soil temperature rarely exceeds 40^0 C, nitrification exceeds ammonification. Generally, soils with oxygen content above 5%, moisture near field capacity, temperature near 30 to 40 ^{0}C and soil reaction near neutral are ideal for mineralization (Brady and Weil, 1999).

Hebert et al. (1991) indicated that during decomposition of fresh organic matter, mineral N is released, and at the same time the N released is used to build up microbial tissue. This process is called immobilization. Net release of N depends on its total content in the substrate. That means that the kinetics of N immobilization and subsequent mineralization depends on the nature of the organic matter. This underscores the importance of the available mineral N in controlling plant residue decomposition under field conditions (Singh and Singh, 1993).

2.6 The C/N ratio

Through mineralization organic matter releases nitrogen, sulphur and phosphate as free ions (Singer and Munns, 1999). Microorganisms govern this process. In case of N mineralization, it releases N in the form of ammonium (Verhagen et al., 1993). Soil microorganism, like other organisms, require a balance of nutrients from which they build their cells. They need carbon for building essential organic compounds and obtain energy for life processes (Nicolardot et al., 1994). They also need N for their protein level e.g. synthesis of amino acids, enzymes and DNA (Zagal et al., 1993). On average, soil microorganism must incorporate into their cells about eight parts of

carbon for every one part of N (Brady and Weil, 1999). This requirement results in two extremely important practical consequences. First, the incorporation of high C/N ratio residues will deplete the soil's supply of soluble N causing a growing crop to suffer from N deficiency (Neale et al., 1997). Secondly it results in the so-called nitrate depression period (Brady and Weil, 1999), i.e. the period when N is not available to a growing crop. Once most of the crop residues are broken down, mineral N is released from the microorganism and is again made available to the growing crop.

With organic material of low C/N ratio, N is present to meet the needs of the decomposing organisms. Therefore, N from organic compounds is released into the soil solution (Compton and Boone, 2000). That means that net release or net immobilization can be predicted from the organic substrate's C/N ratio (Buamsha et al., 1998). At a C/N ratio below 20, N is released, but if it is much more above 20, N is likely to be immobilized causing a nitrate depression period to occur (Singer and Munns, 1999). Greatest immobilization occurs in soils with a C/N ratio more than 30 (Neale et al., 1997).

2.7 Nitrogen fertilization

A growing crop obtains its nutrients from the native soil and fertilizers. Another source of N to the growing crop can be the air, brought in by nitrogen-fixing bacteria (Boddey et al., 1995). In the case of sugarcane, it has been found that biological nitrogen fixation (BNF) can contribute to 38% of the N requirement (Asi-Constancio et al., 2002).

Nitrogen is the most limiting nutrient in tropical areas (Snapp, 1998). That it is due to the low levels of organic matter, and therefore, its conversion into N through mineralization is low (Broadbent, 1981). However, some agronomic practices contribute significantly to the deficiency of mineral N observed in the field (Hartemink, 1998a; 1998b). Inorganic and organic N fertilizers are usually applied in tropical soils to supplement the N requirement of a crop (Yadav, 1995).

Hartemink and Kuniata (1996) reported a decline of pH, P, K, total N and reduced biological activities in soils where sugarcane was grown for a long time under rainfed and monoculture conditions. Sugarcane depletes heavily the nutrient reserve as it removes a lot of soil nutrients at harvest (Coale et al., 1993).

Commonly used N fertilizers that provide readily available N include sulphate of ammonium, calcium ammonium nitrate, urea, mixed fertilizers with nitrogen phosphorus potassium (NPK), and di-ammonium phosphate (Brady and Weil, 1999). The less popular ones are nitrochalk, calcium cyanamide, and anhydrous ammonia. Most of the fertilizers are applied as a result of field trials and laboratory tests. However, the minimum amount of fertilizer needed for maximum financial yield is always recommended (Neeteson and Wadman, 1987).

In all places where sugarcane has been grown, field trials have been conducted to study the response of the crop to N fertilizer. Fertilizer recommendations have been based on climatic conditions including as well as the soil type (Weindenfeld, 1997). Numerous studies have shown that responses of sugarcane to N are not consistent. The cropping history, including previous crop and agronomic practices, influence the subsequent crop response to fertilization. But, such factors are rarely determined for sugarcane (Weindenfeld, 1997), even though it has been observed in some areas that the management of the previous crop primarily affects the yield and quality of the

cane. For example, the second ratoon fertilization is dependent on how much was applied to the first ratoon.

Considering that N fertilizer inputs are very high compared to those of P and K (Dobereiner et al., 1995) and fuel prices are escalating, N fertilizer application is economically unviable (Ng Kee Kwong et al., 1999). Consequently, efforts should now be made to study the conditions whereby fertilizer efficiency is as high as possible. That would avoid also groundwater contamination (Ng Kee Kwong et al., 1999). Using labelled ^{15}N techniques fertilizer N efficiency can easily be studied.

2.8 Uptake, assimilation and distribution of N in sugarcane

Plants assimilate mineral N in either NH_4^+ or NO_3^- form (Blackburn and Knowles, 1993). Several scientists who studied the uptake of nutrients by plants showed that most plant nutrients are taken up through roots (Brady and Weil, 1999). The movement of the ions to the root surface is by mass flow and diffusion. The presence of a fine root biomass at the nutrient site also supports this hypothesis (Nadelhoffer et al., 2002).

The carrier ion and ion pump theories are considered to explain the uptake of ions through the root cell membrane (Singer and Munns, 1999). In both processes energy is required. The theory is that active and passive processes are involved and these depend on the electrochemical potential gradient. However, selectivity in ion uptake has been observed whereby certain mineral elements are taken up preferentially while others are excluded (Marschner, 1995). Although there is a distinct difference among plant species in ion uptake characteristics (Greef et al., 1999), the rate of nutrient uptake by a plant depends on plant demand and external nutrient concentration, soil

moisture (Abreu et al., 1993), soil type and agronomic practices such as amount and method of placement of fertilizer applied (Meine and Siebe, 1996). It has further been observed that accumulation of N is proportional to the relative growth rate (Duli et al., 2003). However, from the soil solution, plants can take NO_3^- and NH_4^+, NO_3^- being much more preferred. The differences in NH_4^+ and NO_3^- uptake are due to pH levels; NH_4^+ is taken up efficiently in a neutral medium and decreases as pH goes down, while NO_3^- uptake is highest at low pH values (Mengel and Kirkby, 1978). Any form of N taken up by plants is then translocated through the xylem to the upper plant parts.

For nitrate to be incorporated into the organic structures and to fulfill its essential functions as a plant nutrient, it has to be reduced to ammonium (Marschner, 1995). It is first reduced to NO_2^- in the cytoplasm then to NH_4^+ in the chloroplasts (Marschner, 1995; Mengel and Kirkby, 1978). NH_4^+ is further converted to amino-acids and proteins. When nitrate remains in the shoots, organic acid anions are stored in the vacuole. Ammonium can either be assimilated in shoots, root nodules and leaves.

The demand for mineral N varies from organ to organ but is controlled by the existing N concentration in the organ (Van Keulen, 1981); eventually it decreases as the organ approaches maturity.

Several reports indicate that N taken up by the plant is distributed to roots and shoots proportional to their demands. However, since the root system is very close to the source it will be satisfied first before being transported to the aboveground parts (Van Keulen, 1981), where it is further distributed to the leaves and non-leaf tissue according to their deficiencies. In flowering plants, which bear seeds after flowering, mineral N is translocated from the vegetative tissue to the seeds. It is assumed that all nitrogenous compounds in seeds must have passed through the vegetative tissue first

and that the importance of N uptake by plants after flowering is negligible (Penning de Vries et al., 1979).

Mineral N fed to sugarcane plants through the soil is rapidly absorbed, distributed and assimilated into proteins and mobile amides, amino acids and peptides (Fauconnier, 1993). Synthesis of proteins appears to occur in the foliar tissue, meristem and roots. Excess N is stored in the basal joints as ammonium, amides, amino acids and peptides. When N is in short supply, proteins are hydrolysed and the resulting amino acids are redistributed in young tips and leaves (Mengel and Kirkby, 1978).

2.9 Losses of mineral N from the soil

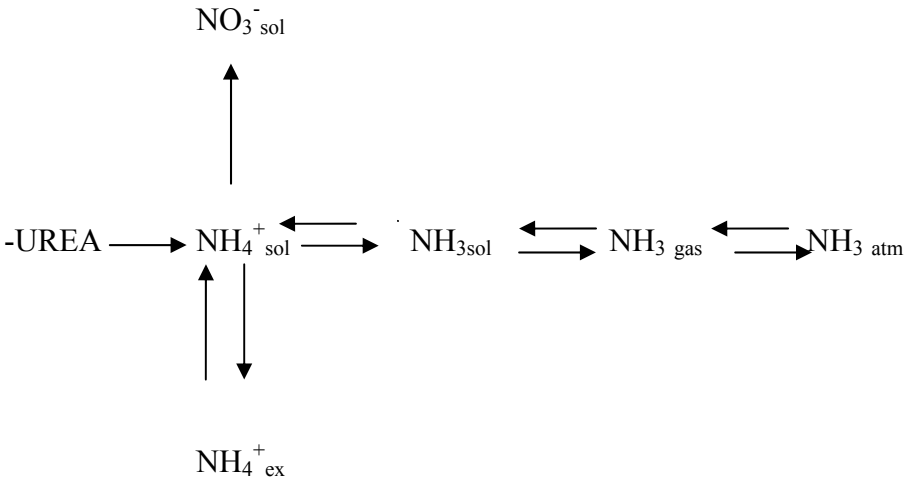
Volatilization of NH_3, biological denitrification, chemodenitrification, and leaching of NO_3^- are the main processes leading to losses of N from the soil (Blackburn and Knowles, 1993; Bremner, 1997). The nature and extent of loss depends on temperature, agronomic practices, soil moisture, micro organisms involved and soil type (Follet and Hatfield, 2001).

2.9.1 Ammonia loss

Byrnes and Freney (1995) reported that over 40% of the fertilizer consumed in the world is in the form of urea as it has a high N nutrient content and is cheap. However, when urea is not incorporated into the soil during its application, ammonia gas can be liberated at high surface soil temperature and high microbial activity. It harms the plant and crop and N losses occur (Bremner, 1995). It is different when ammonium sulphate is used. Losses are lower; and they are less connected to the meteorological variables, rate of application or incorporation into the soil (Ellington, 1986).The soil

enzyme urease is partly responsible for NH_3 loss (Byrnes and Freney, 1995) through pH increase upon urea hydrolysis. Loss of NH_3 in the field can also be as a result of a high pH value (Mengel and Kirkby, 1978) and lack of enough soil moisture. Freney et al. (1992) observed that surface application of urea to trash covering sugarcanes with a minimal amount of rains resulted in heavy losses of ammonia. The loss was reduced to 17% with addition of more water to dissolve all fertilizers into the soil; losses were further untailed to less than 1.8% when urea was substituted by ammonium sulphate.

The fate of urea applied to the soil has been reported by several scientists and can be presented as follows:



Where,

sol: in the soil solution

ex: on the exchange sites

gas: in the gas phase

atm: in the gas phase, the atmosphere above soil.

The use of improved management practices such as drip fertigation (Ng Kee Kwong et al., 1999) could slow down the losses observed in the field; others suggest that coating of urea with inert material or by binding urea with acid anions, such as sulfate and phosphate generates a low pH, and slows down the volatilization process.

However, this technique has been discouraged as it is costly and it decreases the N content of the product (Fleisher and Hagin, 1981). A more promising and developed technique is the use of urease inhibitors, slowing down the urea hydrolysis.

2.9.2 Biological Denitrification

Denitrification is the biological conversion accomplished by a large group of microorganisms when the soil becomes O_2-limited. Denitrifying bacteria such as *Pseudomonas stutzeri*, *Streptomyces thioluteus* and *Thiocillus denifricans* are responsible for the denitrification process (Shouni et al., 1998), resulting into formation of mostly N_2, N_2O and NO (Mosier and Schimel, 1993). These gases volatilize from the soil into the atmosphere. The process starts with NO_3^-. Under limited O_2 conditions the denitrifying bacteria use NO_3^- as electron acceptor, the organic matter being the electron donor (Fillery et al., 1986). Warm temperatures, saturated soils, slightly acidic soils, nitrate supply and sufficient carbon are favourable conditions for denitrification. Low temperature, limited presence of readily available C and minimum biological activity decrease the denitrification process (Van Cleemput, 1998). Different enzymes are catalyzing the process. The nitrate reductase is responsible for the reduction of NO_3^--N to NO_2^--N (Bedzyk et al., 1999), nitrite reductase for the reduction of NO_2^--N to nitric oxide (Shouni et al., 1998), nitric oxide reductase for the reduction of NO (Vollack and Zumft, 2000) and nitrous oxide reductase for the reduction of N_2O (Hole et al., 1996).

Usually the denitrification process is rapid and it can lead to extensive gaseous N loss. If all conditions are optimal, denitrification is a zero-order process. Estimates of total loss by denitrification on cropped lands average 10 – 20% of fertilizers N (Singh and

Singh, 1993). In extreme conditions losses can be as much high as 40 – 60% or rates up to 60 - 70 kg ha^{-1} $year^{-1}$ as reported by Van Cleemput (1998).

2.9.3 Chemodenitrification

Initially it was assumed that biological denitrification was the only process responsible for N_2O and N_2 production (Bremner, 1997). However, several studies have provided strong evidence that significant gaseous loss from fertilizer N can occur through chemical reactions of NO_2^- formed by nitrification of NH_4^+ and NH_4^+ forming fertilizers in mildly acidic soils (Bremner, 1997; Schulz et al., 1994). However, this process is more important in the ocean, where it occurs in the suboxic zones of marine sediments (Gruber and Sarmiento, 1997). It is also an important loss mechanism in suboxic environments where there is a source of Fe^{2+} and/or Mn^{2+} (Schulz et al., 1994; Van Cleemput, 1998). Like in biological denitrification, both NO_3^- and NO_2^- may undergo chemodenitrification (Thorn and Mikita, 2000). Since NO_2^- is an intermediary compound formed during nitrification as well as during denitrification, it plays a key role in chemodenitrification (Van Cleemput and Samater, 1996). Nitrate as well as nitrite are very mobile, and can move from a nitrification to a denitrification zone and vice versa (Van Cleemput, 1998). Soil pH controls abiotic nitrite decomposition. At pH less than 5.5, nitrous acid decomposes to NO and N_2O. At the same time NO_2^- also undergoes reactions with metallic cations, especially Fe^{2+} and with organic matter to form NO, N_2O, NO_2 and CH_3ONO (Thorn and Mikita, 2000; Van Cleemput and Samater, 1996). At high pH and heavy application of NH_3, NO_2^- may accumulate due to inhibition of nitrification. This inhibition is presumed to result from NH_3 toxicity to *Nitrobacter* (Thorn and Mikita,

2000). However, nitrite accumulated in sites of high pH can easily move to sites of low pH where it can undergo a number of reactions (Van Cleemput, 1998). With normal agricultural practices on slightly acidic soils, nitrite instability does not lead to economically important N losses. However, gasses produced are linked to environmental problems such as tropospheric ozone formation, acid rain, the greenhouse effect and the destruction of the stratospheric ozone.

2.9.4 Leaching

The nitrate ion is the most readily leached form of N (Chan and Weng, 1988). Although both NH_4^+ and NO_3^- ions are soluble in water, the NH_4^+ ion is better held to cation exchange sites and it resists better to leaching. Losses of NO_3^- increase as the quantity of percolating water increases and when there is little or no growing cover crop to absorb the nitrate as rapidly as it is produced (Miller and Donahue, 1995). Nitrification inhibitors may provide some protection by slowing down nitrification and keeping more of the ammonium present in the soil for a longer period of time (Ginestet et al., 1998).

Occasionally, plant characteristics can lead to substantial losses of N, as is the case of leaching of mineral N out of the sugarcane leaf.

2.10 Nitrogen balance studies using ^{15}N labelled technique

Insufficient N supply by the soil for maximum crop production is found all over the world (Buresh et al., 1982). Therefore, any system aiming at increasing crop production must include inputs of N and improvement of the efficiency of N

utilization (Christianson et al., 1990). Because of the N fertilizer prices (Zapata and Van Cleemput, 1986a), and since much uncertainty exists about the causes of variation in crop response and yield to N fertilization, efforts are directed to enhance effectiveness of N fertilizer and to reduce N loss in the fertilization process. Quite a good number of studies have been carried out on this subject.

A growing crop is known to derive its N from the soil, biological fixation, and applied fertilizer N (Boddey et al., 1995). Research carried out to monitor the behaviour of mineral N includes, N uptake, fertilizer use efficiency, mineralization studies and losses. In these studies, different techniques have been used (Moraghan et al., 1984). Buresh et al. (1982) reported that the traditional method of measuring fertilizer use efficiency, whereby N uptake in a fertilized crop is deducted from the uptake in an unfertilized crop, divided by the amount of N applied to the fertilized plot, gave often misleading results, due to either overestimation or underestimation. Still much of the fertilizers used in developing countries is at present wasted because of difficulties in forecasting and adjusting levels and methods of application (Neeteson and Wadman, 1987). Huge differences occur between sites, years and agronomic practices with regard to the uptake of native organic N and the nature of plant response to fertilizers.

The use of ^{15}N-isotope techniques has been found to be very effective in studying these problems (Vallis et al., 1996). It allows calculation of the contribution of different sources and their effective utilization by the crops as well as the N remaining in the soil at the end of the growing season (Meisinger et al., 1995). This gives a clue on the residual effect on the forth coming crop or a ratoon crop as in the case of sugarcane (Ng Kee Kwong and Deville, 1987).

Although the International Atomic Energy Agency (IAEA) started in 1962 to coordinate several studies on the use of isotopes to determine fertilizer use efficiency, the technique has not caught on in developing countries like Tanzania and therefore the information about the effectiveness of fertilizer applied to the soil is missing. On the other hand, there is already a lot of information from developed (and few from developing countries) on fertilizer use efficiency, losses, and recovery of N, using ^{15}N isotopes. There are examples with maize (Khanif et al., 1984); wheat (Van Cleemput et al., 1981); rice (Zia and Waring, 1987); faba bean (Zapata and Van Cleemput, 1986a); sugarbeet (Moraghan et al., 1984); sorghum (Zapata and Van Cleemput, 1986b); winter rye (Harmsen and Moraghan, 1988), sugarcane (Ng Kee Kwong and Deville, 1994; Ng Kee Kwong et al., 1987) and other crops. The use of labelled fertilizers in determining fertilizer use efficiency has proven to be accurate (Buresh et al., 1982). In general, the isotopic analysis has been used in measuring specific pathways related to N in agriculture (Blackburn and Knowles, 1993). That includes also the loss process of N as ammonia, and of N_2O and N_2 by denitrification (Broadbent, 1981).

There are two stable isotopes of N, ^{14}N and ^{15}N, occurring naturally at a (constant) ratio of 272 to 1 and a radioactive ^{13}N isotope (Blackburn and Knowles, 1993), which can also be used to some extent. The drawbacks of ^{13}N are that it has a half life time of only ten minutes (Weidner et al., 2002).

Naturally occurring N contains 0.366 atom % ^{15}N. Any material with a higher or lower ^{15}N content than the natural abundance of 0.366 atom % can be used as a tracer (Hauk and Bremner, 1976). The N content of a material can be expressed as atom % ^{15}N or atom % ^{15}N excess. The atom % ^{15}N excess is the atom % ^{15}N minus 0.366 (Buresh et al., 1982; Pilbeam et al., 1993). Addition of ^{15}N enriched materials to a

system will increase the ^{15}N concentration in the various parts of the system proportional to the movement of the N compounds in the soil reaction or plant growth through fertilizer enrichment. Therefore, the amount of ^{15}N, which cannot be accounted for during the analysis, serves as a measure of fertilizer N loss from the plant/soil system (Moraghan et al., 1984; Zia and Waring, 1987).

Tracers used in agricultural N-isotopic studies are $^{15}NH_4^+$, $^{15}NO_3^-$, $^{15}N_2$ and ^{15}N organic compound (Mulvaney, 1993). $^{15}NH_4^+$ and $^{15}NO_3^-$ are commonly used.

There are two commonly methods used for ^{15}N isotope analysis: the optical emission spectrometry and mass spectrometry (Blackburn and Knowles, 1993; Buresh et al., 1982; Mulvaney, 1993). Originally, emission spectrometry was the most useful equipment at least in developing countries, as it required very small samples of only 1 to 10 μg for analysis (Caroline and Preston, 1993; Mulvaney, 1993). However, new mass spectrometers can use even smaller samples containing low concentrations of N (Mulvaney, 1993). Therefore, it is common nowadays to measure the ratio $^{15}N/^{14}N$ by mass spectrometry (Buresh et al., 1982; Mulvaney, 1993). For effective determination of the efficiency of labelled fertilizers, the fertilizer must be applied evenly and accurately (Caroline and Preston, 1993) together with an appropriate sampling technique. Also the enrichment of labelled fertilizers must be high enough in order that after dilution with the large pool of unlabelled N in the soil, the ^{15}N content of the soil will be measurable and different from 0.366 atom % at the time of sampling (Buresh et al., 1982). The ^{15}N isotopic method does not have healthy hazards and no radiation effects on the biological system (Buresh et al., 1982; Hauk and Bremner, 1976).

2.11 Nitrogen and water use efficiency

Several scientists have defined “water use efficiency”. It is the ratio of dry matter production and evapotranspiration (Van Keulen, 1981). Addition of N to the soil with adequate soil moisture increases the total water use by increasing the depth of water extraction from the soil and therefore it increases yield and water use efficiency (Gregory et al., 1984; Halitligil et al., 1984).

A lower protein content in N-stressed plants is associated with a lower respiration rate and a lower assimilation rate (Van Keulen, 1981). Also, when the mineral N is deficient, the top to root weight ratio decreases, followed by a greater reduction in leaf growth, then in stems and in sheaths. These processes are not favourable to a high water use efficiency as there is an increase of non-photosynthesizing tissue, thereby changing unfavorably the assimilation ratio. Also when N is deficient, losses due to soil surface evaporation are larger especially in the tropics as the dry matter production will be slow, leading to slow coverage of the soil surface by canopy (Van Keulen, 1981).

On the other hand, when moisture stress exists, there is limitation in transportation of nutrients and metabolites (Singer and Munns, 1999). Although the effect of N application to crops depends on the availability of water (Singh et al., 1998), there must be a proper balance of N and available water. When soil moisture is inadequate, increasing N levels increases drought stress and becomes detrimental to crops (Nielsen and Halvorson, 1991)

The young sugarcane plant, given excess N and water, will produce vigorous vegetative growth but store little sugar. After the boom stage of growth, the growth rate subsides and more sugars are stored in the stalk (Ramesh, 2000). As sugarcane

approaches its normal harvesting age, its moisture and N level drops and its reducing sugars are converted to sucrose. Too much water and N at this stage have detrimental effects. They delay maturity of sugarcane, affect the quality of cane juice and sometimes they cause lodging of the crop (Ng Kee Kwong et al., 1999).

2.12 Salinity in sugarcane

Normally, salt-affected soils often occur under natural conditions (Maro, 2001a). They are abundant in semi-arid and arid regions where the amount of rainfall is insufficient for substantial leaching (Marschner, 1995). Groundwater contains salt leached from soil and rock layers. As a result of evaporation and evapotranspiration, salts are left behind and increase their concentration in the groundwater and soil surface. Important salinity problems in agricultural areas arise as a result of irrigation (Maro, 2001a). Irrigation causes the level of water table to rise and if the drainage system is not effective, salts tend to accumulate on the soil surface. Furthermore, if the salt content is high in the irrigation water, it is likely to add more salt to the system and further salinize the groundwater (Roy, 1999).

Soils are considered to be saline if they contain soluble salts in quantities sufficient to interfere with the growth of most crop species (Plaut et al., 2000).

Depending on the level of Na^+ and electrical conductivity saline soils are categorized in three major groups;

Saline soils: they contain an excess of neutral soluble salts, mainly bicarbonates, chlorides and sulphate of K, Na, Ca and Mg. They have high EC values (> 4 dS m^{-1} for saturated paste). Usually the pH is less than 9.0 and the exchangeable Na^+ is less than 15%.

Sodic soils: they are low in total salt content and electrical conductivity. The % exchangeable Na^+ is more than 15% of the CEC.

Saline-sodic soils: they contain an excess of both total soluble salts and sodium adsorbed on the soil. Electrical conductivity is higher than 4 dS m^{-1} and they have more than 15% exchangeable Na^+ (Brady and Weil, 1999; Singer and Munns, 1999).

In saline soils, Na^+ and Cl^- are usually dominant. Although Cl^- is a micronutrient in higher plants, and Na^+ is a mineral nutrient for many halophytes and some C_4 species, concentration of Cl^- and Na^+ in a saline soil exceeds demand by far, and leads to toxicity with non-tolerant plants (Plaut et al., 2000). Stunted growth as a result of drought stress and imbalance in Ca^{++} uptake are typical characteristics of plants grown on saline soils (Crane and Bowman, 1991). Also the rate of mineralization and decomposition of organic matter decreases in saline soils. However, ammonification is less sensitive to salts then nitrification (Singh and Bajwa, 1986). It appears that microbial activity is less pronounced in saline soils than in non-saline ones (Reddy and Sithunathan, 1985).

Chloride, sodium and bicarbonate ions are toxic to sugarcane when present in high concentrations. Furthermore, it affects the growth of sugarcane in two other ways. Salts reduce the rate and quantity of water that can be absorbed by plant roots (Plaut et al., 2000) as it results in a progressive increase in osmotic pressure. Retardation of growth is virtually linear with increasing osmotic pressure and is largely independent of the kinds of salt present (Plaut et al., 2000). Salinity also brings about unfavourable physical conditions of the soil. The structure of the soil deteriorates, thus impeding the movement of water and air. When dry, the soils crust, and when tilled they break into hard clods which are unfavourable to the preparation of a desirable seedbed for sugarcane (Rozeff, 1995). Sugarcane harvested from saline soils exhibits a withered

appearance, is usually pithy, and gives juice of very poor quality. A high salt content in juices increases scale deposition in the evaporators (Maede and Chen, 1977), causing processing problems in the mill.

Reclamation in its broad sense means modifying land to make it suitable for cropping. Like in any other crop, reclaiming saline soils in a sugarcane field requires a good quality source of water, large irrigation water, appropriate means of application and an effective drainage system (Roy, 1999). Saline sodic soils need a soil amendment to replace Na^+ prior to the leaching process. Gypsum is often the cheapest amendment for saline sodic soils, but a large amount is required and the process is slow (Maro, 2001a). Breeders and physiologists should now include various physiological mechanisms such as K^+ and Na^+ uptake and selectivity for salinity tolerance (Plaut et al., 2000; Roy, 1999).

2.13 Location and climatic conditions of the experimental fields

2.13.1 The Tanganyika Planting Company (TPC) estate

A small review of history, location and climatic condition

The TPC estate was established in 1930 by a Danish ship-owner. He started with other crops, and sugarcane came in as subsidiary crop. Later on, sugarcane overtook the other crops and by 1936, a significant area of virgin land was opened for cane. Currently, the whole of the exploited land of the estate is under sugarcane cultivation.

The TPC estate is situated in the Moshi district, Kilimanjaro Region in northern Tanzania. It lies between latitudes $3^0$30’ and $3^0$40’ south of the equator, and the longitudes $37^0$20’ and $37^0$30’, east of Greenwich. Its altitude is about 700 m above sea

level. The general land topography comprises a low-lying plain (slope < 2% running north to south) at the foot of Mt. Kilimanjaro. Climatically, it is a semi-arid area with a total annual rainfall rarely exceeding 600 mm, a high evapotranspiration rate of 206.7 mm per month, a mean monthly evaporation pan B of 6.7 mm day^{-1}, a mean monthly temperature of 30.0 ^{0}C (max.), a mean monthly soil temperature of 24.3 ^{0}C, a mean monthly soil moisture balance of –114.0 mm and a mean monthly radiation of 2.3 kJ.

The estate has a gross area of 14 164 ha but grows sugarcane on about 7 000 ha of the land. One half is furrow-irrigated and the other half is sprinkler-irrigated. The grub infestation problem exists in some areas of the estate: the southern part of the estate is highly infested by white grubs, while the northern part of the estate is the least grub-infested area.

2.13.2 Physico-chemical characteristics of the experimental site

The experiments related to the presented study were conducted on a saline and a non-saline soil. The horizon description of both soils is given in Table 2.1 and 2.2. The physico-chemical characteristics of the experimental sites are given in Table 2.3.

2.13.2.1 Site one: the non-saline soil

Site description

Location: Tanzania, Kilimanjaro, TPC Limited Estate, Field P2S, southeast corner, near P4 borehole pump, ± 50 m from the border road P2S/P4N.

Elevation: 701 m above sea level (±1)

Landform: Plain (slope about 1%)

Vegetation: Weeds, mainly *Panicum maximum*, and scattered *Ricinus communis*, etc.

Land use: Fallow farmland originally planted with cane. Re-opened for cane during the 2000/01 growing season. Cropping system is irrigated monoculture.

Climate: Mean annual temperature: 26 ^{0}C; precipitation year^{-1}: 500 mm

Parent material: Alluvial, formed through deposition and enrichment

Drainage: Well-drained

Moisture condition: Dry at the time of description

Ground water table: >120 cm

Erosion: Minimum to none

Flooding/ponding: Once in 5 years, 7-14 days, April to May, 10 to 30 cm

Soil group classification: Lixisols (FAO, 1998).

Table 2.1 Horizon description (non-saline soil)

Code	Symbol	Depth (cm)	Description
1	Ap	0-25	Dark greyish brown (10YR 3/2 dry, 2/2 moist); silty loam, fine to medium granular; soft, friable; few fine to medium roots, clear smooth boundary.
2	A2	25-55	Brown (10YR 4/3 dry, 4/2 moist); silty loam, massive friable to moderately firm, few fine roots, abrupt smooth boundary
3	E	55-85	Light yellowish brown (10 YR 5/6 dry, 5/4 moist); fine sand loam; massive; very friable, very few very fine roots, abrupt smooth boundary.
4	Bt	85-120+	Brown (10YR 5/3 moist) sandy clay loam, massive, moderately friable to firm, very thin and patchy cutans; no roots

FAO guidelines, 1998.

This site has a soil with a sandy gravel texture. Through the depth, pH is increasing from 7.8 at the 0 to 25cm layer to 8.2 at the 85 to 120 cm layer. The electrical conductivity (EC) is far below 0.4 dS m^{-1} (threshold value for salinity) and the sodium adsorption ratio (SAR) < 1. The soil is therefore considered 'normal' (non-saline, non-sodic) (Singer and Munns, 1999)

2.13.2.2 Site two: the saline soil

Site description

Location: Tanzania, Kilimanjaro, TPC Limited estate, Field R5N, North of the field, 100 m ± 5 m east of Weruweru River bank, 250 m ± 10 m west of R camp.

Elevation: 700 m above sea level (± 1).

Landform: Plain (slope about 1%).

Vegetation: Weeds, mainly *Portulaca oleracea*, and scattered *Ricinus communnis*, etc.

Land use: Fallow farmland originally planted with cane. Re-opened for cane during the 2000/01 growing season. Cropping system is irrigated monoculture.

Climate: Mean annual temperature: 26 ^{0}C; precipitation $year^{-1}$: 500 mm

Parent material: Alluvial, formed through deposition and enrichment

Drainage: Moderately well-drained

Moisture condition: Dry at the time of description

Ground water table: > 120 cm

Erosion: minimum to none

Flooding/ponding: Once in 5 years, 7 – 14 days, April to May, 10 to 30 cm

Soil group classification: Cambisols (FAO, 1998).

Table 2.2 Horizon description (saline soil)

Code	Symbol	Depth (cm)	Description
1	Ap	0-30	Very dark brown (10YR 2/3 dry, 7.5YR 3/2 moist); silty loam; moderate fine to medium granular; very friable; few very fine to fine pores, few fine roots, slightly calcareous, abrupt wavy boundary.
2	B1	30-50	Dark greyish brown (10YR 5/4 dry, 7.5YR 4/3 moist); silty loam; massive; moderately strong, friable; few very fine pores, few fine roots, slightly calcareous, abrupt smooth boundary.
3	B2	50-65	Very dark greyish brown (10YR 2/3 dry, 7.5YR ¾ moist) with few fine distinct clear mottles 7.5YR 3/2; silty clay loam, subangular blocky; moderately strong and firm; thin parchy cutans; few fine pores, few fine roots, moderately calcareous, abrupt smooth boundary.
4	B3k	65-120+	Very dark brown (10YR 2/3 dry, 3/2 moist) with few fine distinct clear mottles (7.5YR 3/3); silty clay loam; subangular bloky; thin patchy cutans; very few fine pores; very few medium roots; strongly calcareous

On this site, the salinity was found to decrease with depth while the reverse was true for sodicity. Through the depth, pH is generally well over 8.4, the minimum level for soils categorized as saline soil (Singer and Munns, 1999). The EC of the surface horizon shoots to 1.08 dS m^{-1} (highly saline), while the subsoil shows to stabilize at around the threshold value of 0.4 dS m^{-1} (Singer and Munns, 1999). High levels of, K^{+}, Mg^{++} and Na^{+} are experienced, while Ca^{++} level is relatively lower than in the non-saline soil.

At both sites, P and K are at acceptable levels for sugarcane cultivation whereas N is deficient (Maro, 2001b).

Table 2.3 Physico-chemical characteristics of the experimental sites

Site	Soil Depth (cm)	pH (1:1)	EC (1:5) dS m^{-1}	P mg kg^{-1}	K^+ mg kg^{-1}	Ca^{++} mg kg^{-1}	Mg^{++} mg kg^{-1}	Na^+ mg kg^{-1}	OC %	Total N %	C/N	SAR
Non-saline soil												
Ap	0-25	7.8	0.07	15.1	3077	2640	384	200	1.31	0.19	7.1	0.3
A2	25-55	7.9	0.07	20.6	2976	2240	384	251	0.76	0.14	5.4	0.4
E	55-85	8.3	0.07	17.5	1127	2240	372	400	0.54	0.029	18.6	0.7
Bt	85-120	8.2	0.10	19.3	1743	3280	360	550	0.32	0.013	24.6	0.8
Saline soil												
Ap	0-30	8.8	1.08	17.5	4001	2480	888	1700	0.75	0.06	11.6	2.4
B1	30-50	9.2	0.46	16.5	6568	1960	720	1999	0.16	0.01	14.5	3.1
B2	50-65	9.2	0.30	13.6	4310	1520	576	1296	0.09	0.008	11.3	2.3
B3k	65-120	9.2	0.45	11.2	5132	1760	792	1699	0.05	0.003	16.7	2.8

Total nitrogen was analyzed using the Macro-Kjeldahl method, organic carbon by the Walkley-Black method, available P by the Olsen method, Na^+ and K^+ by flame photometry, Ca^{2+} and Mg^{2+} by the EDTA titrimetry method and anions were first extracted from soil by water followed by titration using the procedure outlined in the National Soil Laboratory Centre (1989). Texture was determined by the Bouyoucos hydrometer method using the USDA triangle classification model.

2.14 Thesis outline/research approach

In order to meet the objectives of the study, the actual research involved four field experiments and one laboratory experiment. A fifth field experiment involved was the testing of a model constructed to predict the N requirement of sugarcane. The model has been integrated using part of the data obtained from field experiments.

The thesis is divided into the following seven different chapters/parts.

Chapter 1: The introduction. This part is essentially an overview of information on Tanzania in terms of weather, agricultural policy, importance of sugar, and its prospects and problem statement. It includes also the research questions, objectives and expected outputs.

Chapter 2: Literature Review. This part gives a detailed review of the sugarcane crop itself, including its origin, botany, classification, and agronomic practices. The mineral N itself has been reviewed in detail including its uptake, importance and N transformations e.g. losses. Also in this chapter there is a review covering the history, location and climatic condition of the experimental field i.e. the TPC estate, as well as the thesis/research outline.

Chapter 3. Uptake and loss of mineral N applied to sugarcane. This was a field study conducted on both the saline and non-saline soil using labelled urea and ammonium sulphate as source of mineral N. In this study, it was possible to monitor the fate of mineral N in relation to two soil properties (saline and non-saline soils) in sugarcane fields i.e. losses, uptake, and balance at the end of the season.

Chapter 4. Dry matter production and percentage utilization of fertilizer N of two commercial sugarcane varieties grown in Tanzania. This was a field experiment conducted on the non-saline soil using labelled urea; it involved two commercial

varieties EA 70-97 and B 52 313. The fate of mineral N applied was also monitored, though the interest was to determine the fertilizer use efficiency of the two varieties studied.

Chapter 5. The effect of different levels of urea, and urea plus filter cake (FC) on growth, yield and quality of sugarcane. Field experiment conducted on both the saline and non-saline soil to determine the impact of urea and urea plus FC on growth, yield and quality of sugarcane. There is a detailed discussion of the effect of N on yield and quality of sugarcane, as well as on the use of FC as a soil amendment.

Chapter 6. The effect of different levels of urea and urea plus filter cake on the chlorophyll content, stomatal conductance and net photosynthesis. The field experiment described in chapter 5 was used to collect the data for this chapter. The possible reasons for differences in yield between the two contrasting soil types, saline and non-saline, have been explained and hence the recommendations for agronomic practices to be followed, especially on the saline soil.

Chapter 7. Potential N mineralization of soils under sugarcane cultivation. This is a laboratory experiment in which soil samples of varying properties were incubated at room temperature for 90 days. There is a detailed discussion on the mineralization potential of the two contrasting native soil types, saline and non-saline, and a discussion on the filter cake as a soil amendment.

Chapter 8. A mathematical model for estimating the N fertilizer requirement of a sugarcane crop. Part of the results of this study were integrated into a model designed to predict the ‘optimum’ level of fertilizer N required in sugarcane. There is a discussion on the performance of the predicted level and its shortcomings.

Chapter 9. Summary, general conclusion and recommendations for future research.

The thesis finishes with the list of references and curriculum vitae.

CHAPTER 3

UPTAKE AND LOSS OF MINERAL NITROGEN APPLIED TO SUGARCANE

UPTAKE AND LOSS OF MINERAL NITROGEN APPLIED TO SUGARCANE

Abstract

The use of labelled N fertilizer has been proven to be very effective in studying fertilizer use efficiency. During the 2000/01 and 2001/02 cropping seasons, a study was conducted at the Tanganyika Planting Company (TPC) estate in Tanzania, to investigate the uptake, loss, leaching and balance of mineral N applied as urea (60 kg ha^{-1}) and ammonium sulphate (40 kg ha^{-1}) on a saline and a non-saline soil. In each block, i.e. non-saline and saline block, two plots of 5 * 1.5 m^2 (microplots) were marked and used for this study. At harvest, the plot was divided into five subplots of (1 * 1.5 m^2). Samples containing ^{15}N, enrichment was determined by mass spectrometry. During the 2000/01 growing season, on the non-saline soil, with urea as N source, total plant recovery of ^{15}N was 94%, 0.14% was recovered from the soil and 5.9% could not be accounted for. During the 2001/02 growing season, total plant recovery of ^{15}N was 91%, 0.19% was recovered from the soil and 8.7% could not be accounted for. In the saline soil, on the other hand, during the 2000/01 growing season, total plant recovery of ^{15}N was 37%, 0.11% was recovered from the soil whereas 62.7% could not be accounted for. During the 2001/02 season, total plant recovery of ^{15}N was 34%, 0.09% was recovered from the soil 65.7% could not be accounted for. During the 2000/01 growing season, on the non- saline soil with ammonium sulphate, total plant recovery of ^{15}N was 96%, 0.2% was recovered from the soil and 4.3% could not be accounted for and during the 2001/02 growing season,

total plant recovery of ^{15}N was 94%, 0.16% was recovered from the soil and 5.7% could not be accounted for. In the saline soil, during the 2000/01 growing season, total plant recovery of ^{15}N was 79%, 0.14% was recovered from the soil and 21.2% could not be accounted for and during the 2001/02 growing season, total plant recovery of ^{15}N was 76%, 0.13% was recovered from the soil and 23.7% could not be accounted for. Losses that occurred in the saline soil using urea as source of N were explained by volatilisation of ammonia. There was a very big difference in performance between urea and AS on the saline soil. Dry matter production in plots treated with urea was 50% of that in the plots treated with AS. Also, non-accounted for N from urea was very high (63-66%) compared to AS (21-24%).

KEY WORDS: nitrogen, ^{15}N, ^{15}N recovery, loss, leaching, balance, urea, ammonium sulphate, uptake, volatilisation, denitrification, nitrification, chemodenitrification

3.1 Introduction

In Tanzania, sugarcane is grown on estates of at least 4000 to 6000 ha, subdivided into blocks of 15 to 20 ha for management purposes. Each block is planted by any one of the 3 to 4 commonly used commercial varieties. The policy of fertilizer management in these estates is somehow complicated. The common practise is the use of blanket recommendations without considering possible varietal differences in response to fertilizer use or differences in physico-chemical soil characteristics among different sites, such as salinity levels ranging from normal to highly saline levels (Maro, 2001a). Urea fertilizer is mostly used as source of N, regardless of soil type, because it is least expensive.

For quite a long time, the determination of N efficiency on sugarcane fields has been conducted using the traditional method of relating the amount of N fertilizer applied to yields obtained (Mkodo, personal communication). Thus, the efficiency of N applied was measured indirectly without determining whether or not the source of N is the soil reserve or the applied N (Buresh et al., 1982). Also, by using this method it is not possible to determine the actual fertilizer use efficiency of a specific variety, N losses, or the balance of applied nutrients at the end of the season. This has resulted in the fact that recommended fertilizer rates were very high, sometimes up to more than 120 kg N ha^{-1}, with the yield still remaining very low, at an average of 70 – 90 t of cane ha^{-1} (SUDECO, 1996). The potential sugarcane yield at the Tanganyika Planting Company (TPC) is estimated to be as high as 120 t of cane ha^{-1} (Wood, personal communication). Although results of laboratory analysis may sometimes show N levels in soil and plant tissue far below the threshold value in all tested fields, the application of different rates of N may not result in significant yield increases (Isa, 1998).

Nonetheless, numerous studies with sugarcane have shown that efficient N fertilization depends on a number of factors such as soil, crop, source of N and climate. Likewise, fertilization of the second ratoon crop, for example, would depend on how much was applied during the first crop and the balance of mineral N at the end of the first ratoon (Weindenfeld, 1997). These observations indicate that there is a need for using other techniques to fine-tune the fertilizer recommendations in sugarcane plantations in Tanzania. The use of ^{15}N in fertilizer trials has been found to be effective in measuring different sources of N taken up by the plant, the efficiency in utilization, losses and the N balance in the soil at the end of the growing season (Khanif et al., 1983; Corbeels et al., 1998a; Corbeels et al., 1998b and Van Cleemput

et al., 1981). Although this technique is new in Tanzania, it has been in use in other countries for quite a long time.

Given this observation, the objectives of the present study were to determine the uptake and loss of applied mineral N from urea and ammonium sulphate in saline and non-saline soils using a commercial variety currently being used at the TPC estate. The loss of applied N was calculated from the balance.

This information will shed more light on variety * soil type * fertilizer interactions and hence assist the estate management and outgrowers to fine-tune their fertilizer recommendations, at the same time minimizing the risk of polluting the environment through excessive use of fertilizers in soils with high water table and prone to leaching.

3.2 Materials and methods

This study was conducted in Tanzania at the TPC estate on a non-saline soil as well as on a saline soil, under overhead irrigation, on the plant cane and first ratoon crop during two consecutive years 2000/01 and 2001/02. A standard variety, EA 70-97, and two different sources of nitrogen (urea and ammonium sulphate) were used. In each block, i.e. non-saline and saline block, two plots of 5 * 1.5 m^2 (microplots), were marked and used for N uptake and balance study. In these plots, care was taken to ensure that they received the same agronomic treatments as applied across the whole field. Prior to fertilizer application, soil samples were collected down to a depth of 1 m to determine the physico-chemical properties of the experimental site such as pH, EC, P, K^+, Ca^{++}, Mg^{++}, Na^+, OC%, N%, C/N and SAR.

Urea fertilizer, labelled with 10-atom % ^{15}N excess, was applied in plots marked for the uptake and balance study in accordance to the recommended rate (60 kg N ha^{-1}) while the ammonium sulphate (AS), also labelled with 10-atom % ^{15}N excess, was applied at 40 kg N ha^{-1} on the same day with the rest of the field. In order to retain the floodwater, metal sheets of 30 cm high isolating the ^{15}N treated plot, were pressed 20 cm deep into the soil and left 10 cm above the soil. At harvest, the plot was divided into five subplots of (1 * 1.5) m^2.

Plant samples including roots and soil samples up to 90 cm depth were collected from each subplot. Roots from the top 50 cm were dug out and separated from the soil by wet sieving. Above-ground samples were separated into leaves, sheaths and stalks. Senescing and dead leaf tissues were carefully collected and included in the leaf part at sampling. Thereafter, each part was weighed separately and dried at 70^0C till constant weight was reached. Dried samples were weighed and ground to pass through a 0.5 mm sieve. Collection of soil samples was done at 30 cm interval to a depth of 90 cm. Three sub-samples for each layer were collected and pooled together to get one bulk sample per layer per subplot.

In the samples containing ^{15}N, the enrichment was determined by mass spectrometry. The % of ^{15}N in the plant derived from the fertilizer and in the soil samples was calculated using the formula of Hauck and Bremner (1976):

$$\%\ ^{15}N \text{ recovery from fertilizer} = N_{sample}(c - b) * 100 / R (a - b) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where,

Nsample: total nitrogen content of the sample;

a: ^{15}N abundance of the applied fertilizer;

b: ^{15}N abundance of an untreated sample (background level);

c: ^{15}N abundance of the treated sample;

R: rate of applied fertilizer.

The % of N in the plant derived from the fertilizer (% Ndff) was calculated using the following formula:

$$\% Ndff = (c-b)*100/(a-b) \quad \ldots\ldots (2)$$

The % of N in the plant derived from the soil was made up by the difference:

$$\% Ndfs = 100 - \% Ndff \quad \ldots\ldots (3)$$

To check whether information from the plots treated with ^{15}N urea can be extrapolated to the rest of the field, the technique published by Khanif et al. (1983) was used. Therefore, an equal number of subplots were harvested at random outside the ^{15}N-treated plot. Data from a plot treated with labelled ammonium sulphate at 40 kg N ha^{-1} were compared with those obtained from another plot of the same size just adjacent to it, in which ordinary non labelled fertilizer was applied at the same rate. Five sub-samples were harvested from each plot. The means of uptake of these samples were compared with those from the ^{15}N sub-samples using the t-test, and their variances using the two-tailed F- test (Khanif et al., 1983).

3.3 Results

Physico-chemical characteristics of the experimental sites are given in Table 3.1. The non-saline soil is a soil with a sandy to gravely texture. In the saline soil, salinity was found to decrease with depth while the reverse was true for sodicity. At both sites P, K and Ca were at acceptable levels for sugarcane cultivation. However, N was deficient (Maro, 2001b).

Table 3.1 Physico-chemical characteristics of the experimental sites

Site	Soil Depth (cm)	pH (1:1)	EC (1:5) dS m^{-1}	P ($mg\ kg^{-1}$	K^+	Ca^{++}	Mg^{++}	Na^+	OC %	Total N %	C/N	SAR
								mg kg^{-1})				
Non saline soil												
Ap	0-25	7.8	0.07	15.1	3077	2640	384	200	1.31	0.19	7.1	0.3
A2	25-55	7.9	0.07	20.6	2976	2240	384	251	0.76	0.14	5.4	0.4
E	55-85	8.3	0.07	17.5	1127	2240	372	400	0.54	0.029	18.6	0.7
Bt	85-120	8.2	0.10	19.3	1743	3280	360	550	0.32	0.013	24.6	0.8
Saline soil												
Ap	0-30	8.8	1.08	17.5	4001	2480	888	1700	0.75	0.06	11.6	2.4
B1	30-50	9.2	0.46	16.5	6568	1960	720	1999	0.16	0.01	14.5	3.1
B2	50-65	9.2	0.30	13.6	4310	1520	576	1296	0.09	0.008	11.3	2.3
B3k	65-120	9.2	0.45	11.2	5132	1760	792	1699	0.05	0.003	16.7	2.8

Total nitrogen was analyzed using the Macro-Kjeldahl method, organic carbon by the Walkley-Black method, available P by the Olsen method, Na^+ and K^+ by flame photometry, Ca^{2+} and Mg^{2+} by the EDTA titrimetry method and anions were first extracted from soil by water followed by titration using the procedure outlined in the National Soil Laboratory Centre (1989). Texture was determined by the Bouyoucos hydrometer method using the USDA triangle classification model.

A balance sheet showing the distribution of dry matter (DM), the harvested N content and the recovery of applied N in plant and soil as well as the total amount of N that could not be accounted for is given in Tables 3.2 to 3.5.

From these tables, it is clear that the differences in dry matter production and fertilizer N recovery depend on soil type and type of N source in both years.

Dry matter production on the non-saline soil during the 2000/01 and 2001/02 growing seasons, with urea as source of N was 70 t ha^{-1} and 65 t ha^{-1} respectively and on the saline soil it was 34 t ha^{-1} in year one and 30 t ha^{-1} in year two. Also, during the 2000/01 growing season, in the non-saline soil with urea as source of N, the total plant recovery of ^{15}N was 94%, 0.14% was recovered from the soil to a depth of 90 cm and 5.9% could not be accounted for. During the 2001/02 growing season, the total plant recovery of ^{15}N was 91%, 0.19% was recovered from the soil to a depth of 90 cm and 8.7% could not be accounted for. On the saline soil, on the other hand, during the 2000/01 growing season, the total plant recovery of ^{15}N was 37%, 0.11% was recovered from the soil to a depth of 90 cm and 62.7% could not be accounted for, while during the 2001/02 growing season, the total plant recovery of ^{15}N was 34.7%, 0.09% was recovered from the soil to a depth of 90 cm and about 66% could not be accounted for.

In case of application of ammonium sulphate, dry matter production during the 2000/01 and 2001/02 growing seasons, on the non-saline soil, was 60 t ha^{-1} and 58 t ha^{-1} respectively and on the saline soil it was 55 t ha^{-1} in year one and 53 t ha^{-1} in year two. Also during the 2000/01 growing season, on the non-saline soil, with ammonium sulphate as a source of N, total plant recovery of ^{15}N was 95.5%, 0.2% was recovered from the soil to a depth of 90 cm and 4.3% could not be accounted for. During the 2001/02 growing season, the total plant recovery of ^{15}N was 94.1%, 0.16% was

recovered from the soil to a depth of 90 cm and 5.7% could not be accounted for. In the saline soil, on the other hand, during the 2000/01 growing season, the total plant recovery of ^{15}N was 78.7%, 0.14% was recovered from the soil to a depth of 90 cm and 21.2% could not be accounted for. During the 2001/02 growing season, the total plant recovery of ^{15}N was 76.2%, 0.13% was recovered from the soil to a depth of 90 cm and 23.7% could not be accounted for. In both cases and years, the amount of applied labelled N recovered from the soil was very small, less than 0.5%.

In order to verify if the data obtained from the labelled plots can be extrapolated to the whole field, a statistical technique was used as described by Khanif et al. (1983). The means of uptake ^{15}N for the plots treated with labelled urea were compared to the means of uptake for samples taken at random outside the ^{15}N-treated plots using the t-test at 5% and their variances using the two-tailed F-test as outlined by Robert and Torrie (1980). Those treated with labelled ammonium sulphate were compared with another plot, which was applied with ordinary fertilizer AS at 40 kg N ha^{-1}. A total of four sub-plots in 2000/01 and five sub-lots in 2001/02.

In both seasons, the results show that there was no statistical difference ($P<0.05$) in N uptake between plots treated with ^{15}N and those treated with ordinary fertilizer N (Table 3.2 and Table 3.3). Hence, the results from plots treated with ^{15}N can be extrapolated to the rest of the field.

Table 3.2 The DM (t ha^{-1} and % distribution) and harvested N content (kg ha^{-1} and % distribution) as well as statistical information (mean of four sub-plots) on total N-uptake during the 2000/01 growing season

	Urea				Ammonium sulphate			
Parameters	Non-saline soil		Saline soil		Non-saline soil		Saline soil	
Plant DM								
	(t ha^{-1})	% distr.	(t ha^{-1})	% distr.	(t ha^{-1})	% distr.	(t ha^{-1})	% distr.
Stalk	46.0	66	17.6	51	34.6	57	22.6	41
Leaves	11.7	17	8.0	23	15.2	25	21.0	38
Sheath	10.0	10	6.7	19	8.4	14	9.7	17
Roots	2.0	3	2.0	6	1.8	3	1.9	4
Total	70±2.0	100	34±1.4	100	60±1.9	100	55±1.8	100
Plant N content	(kg ha^{-1})	% distr.	(kg ha^{-1})	% distr.	(kg ha^{-1})	% distr.	(kg ha^{-1})	% distr.
Stalk	280	63	88	40	200	50	170	50
Leaves	120	27	96	43	160	40	140	42
Sheath	37	8	30	13	30	7	22	6
Roots	3.7	2	8.8	4	10	3	3	2
Total	440	100	220	100	400	100	335	100
	±		±		±		±	
SE	8		13		10		16	
t. calc.	2.5^{ns}		1.4^{ns}		2.0^{ns}		1.13^{ns}	
t. $tab._{0.05}$	2.5		2.5		2.5		2.5	
CV (%)	2.0		6.0		3.7		5.8	
F calc.	1.8^{ns}		2.4^{ns}		1.6^{ns}		1.8^{ns}	
F $tab._{0.05}$	15.1		15.1		15.1		15.1	

Table 3.3 Labelled N recovery (%) in the plant parts and the soil (mean of four sub- plots) during the 2000/01 growing season

Parameter	Treatment			
	Urea		Ammonium sulphate	
	Non-saline soil	Saline soil	Non-saline soil	Saline soil
N recovery in the plant (in %)				
Stalk	60.0	15.0	46.4	36.5
Leaves	25.0	16.0	41.0	33.3
Sheath	8.0	5.0	7.3	7.0
Roots	1.04	1.2	0.8	1.5
Sub-total	94.0±2.3	37.2±1.6	95.5±1.4	78.7±2.3
N recovery in the soil (in %)				
0-30cm	0.07	0.078	0.15	0.1
30-60cm	0.07	0.023	0.035	0.02
60-90cm	0.007	0.01	0.018	0.017
Sub total	0.14±0.012	0.11±0.008	0.20±0.009	0.14±0.006
Total recovery	94	37	96	79
Non accounted for N	6	63	4	21

Table 3.4 The DM (t ha^{-1} and % distribution) and harvested N content (kg ha^{-1} and % distribution) as well as statistical information (mean of five sub-plots) on total N-uptake during the 2001/02 growing season

	Urea				Ammonium sulphate			
Parameters	Non-saline soil		Saline soil		Non-saline soil		Saline soil	
Plant DM								
	(t ha^{-1})	% distr.	(t ha^{-1})	% distr.	(t ha^{-1})	% distr.	(t ha^{-1})	% distr.
Stalk	42.4	65	17.0	56	34.6	60	28.3	55
Leaves	11.1	17	7.8	26	12.1	21	13.4	24
Sheath	7.8	12	4.9	16	9.2	16	8.8	17
Roots	3.9	6	0.6	2	1.7	3	2.1	4
Total	65±2.2	100	30±1.1	100	58±1.9	100	53±1.1	100
Plant N content	(kg ha^{-1})	% distr.	(kg ha^{-1})	% distr.	(kg ha^{-1})	% distr.	(kg ha^{-1})	% distr.
Stalk	190	48	90	46	190	51	160	52
Leaves	180	45	88	43	150	40	120	40
Sheath	20	5	14	7	20	6	20	6
Roots	10	2	8	4	10	3	10	2
Total	400	100	200	100	370	100	310	100
	±		±		±		±	
SE	10		9		10		10	
t. calc.	2.0^{ns}		2.2^{ns}		1.2^{ns}		1.7^{ns}	
t $tab._{0.05}$	2.31		2.31		2.31		2.31	
CV (%)	3.6		7.4		5.8		6.7	
F calc.	2.3^{ns}		2.15^{ns}		2.9^{ns}		1.5^{ns}	
F $tab._{0.05}$	9.6		9.6		9.6		9.6	

Table 3.5 Labelled N recovery (%) in the plant parts and the soil (mean of five sub- plots) during the 2001/02 growing season

Parameter	Treatment			
	Urea		Ammonium sulphate	
	Non-saline soil	Saline soil	Non-saline soil	Saline soil
N recovery in the plant (in %)				
Stalk	44.3	15.4	47.4	38.1
Leaves	40.6	14.5	37.4	30.3
Sheath	4.4	3.2	6.5	5.4
Roots	1.8	1.2	2.7	1.4
Sub-total	91.1±1.9	34.31±1.2	94.1±2.0	76.2±1.4
N recovery in the soil (in %)				
0-30cm	0.14	0.06	0.10	0.09
30-60cm	0.04	0.02	0.04	0.03
60-90cm	0.005	0.01	0.02	0.01
Sub-total	0.19±0.006	0.09±0.002	0.16±0.006	0.13±0.004
Total recovery	91	34	94	76
Non accounted for N	9	66	6	24

Generally, results on non-accounted for N, uptake of N and dry matter in each treatment during the 2000/01 cropping season were almost similar to the results obtained in the second year (2001/02).

3.4 Discussion

Biological denitrification, volatilisation of NH_3, runoff and leaching of NO_3^- are the main processes, which can lead to N losses from the soil (Blackburn and Knowles, 1993; Freney and Simpson, 1983). Recent research on sources of nitrous oxide in the soil has indicated that little nitrous oxide is produced and lost by chemical processes such as chemodenitrification (Bremner, 1997; Freney, 1997). Losses occur from mineral N produced in the soil as a result of mineralization, or when inorganic fertilizers are applied (Follet and Hatfield, 2001). The mechanism and magnitude of loss depends on a combination of biological, chemical and physical factors (Freney and Simpson, 1983). In this experiment, labelled N was measured to a depth of 90 cm and showed a recovery of less than 0.5% in all cases. The very low recovery of labelled N in the soil is most probably due to the high nutrient demand of the crop, exploring the full soil profile. The N deficit reported in this paper when urea was used as source of N in the saline soil was quite high, and could be due to ammonia volatilization, a process catalysed by the urease enzyme (Yameogo et al., 1993). Though biological denitrification, chemodenitrification and leaching processes can also occur. Runoff could be excluded because metal sheets used prevented N loss during the entire period of the experimentation.

The experiment was conducted in a tropical area where soil temperature and biological activity at the soil surface are high, conditions which are favourable for rapid hydrolysis of urea to ammonia (Byrnes and Freney, 1995). Bearing in mind that the common practise at TPC is to apply urea just on the soil surface and sometimes on sugarcane trashes left on the soil surface, it is possible that this may cause a very high microbial activity, responsible for volatilisation of ammonia gas as reported by Bremner (1995). Similarly, because of the high pH observed in the saline soil, the rate of ammonium hydrolysis is also bound to increase together with the alkalinity of the solution, a condition ideal for volatilisation loss (Freney and Simpson, 1983). Ellington (1986) reported similar results. Furthermore, at higher concentrations of Na^+ and Cl^- in saline soil, the rate of nitrification is reduced leaving a bigger pool of ammonium, resulting in more volatilisation loss (Singh and Bajwa, 1986). It appears that the acceleration of the nitrification process leads to a rapid lowering of the ammonium concentration, resulting in less ammonia loss by volatilisation. Subsequently, carbonates and bicarbonates formed as a result of urea hydrolysis on a saline soil, provide a buffering capacity at high pH at the site where ammonia is released, facilitating further loss of NH_3 gas (Byrnes and Freney, 1995).

With regard to the use of ammonium sulphate, losses reported on saline soils could be due to biological denitrification, chemodenitrification and/or volatilisation of ammonia gas. It has been observed that all commonly used NH_4^+ fertilizers applied to the soil can release ammonia (Greenwood, 1981). This means that losses observed after the application of AS on a saline soil can also be partly the result of volatilisation of ammonia (Ng Kee Kwong and Deville, 1987). Because of salinity and high pH values, the process of nitrification is decelerated leaving a pool of ammonium, which is further subjected to volatilisation. Similarly salinity brings about unfavourable

physical soil conditions such as the deterioration of soil structure, impeding the movement of water and air, and creating anaerobic conditions leading to denitrification (Fillery et al., 1986). Consequently, part of ammonium that has been nitrified to nitrate can move to anaerobic microsites where it is denitrified to form nitrous oxide and nitrogen gas (Weir et al., 1996).

The differences in performance between urea and AS on the non-saline soil was very small, though urea was applied at a rate of 60 kg N ha^{-1} and AS at 40 kg N ha^{-1}. It was also observed that although pH values on the non-saline soil were also high, still the non-accounted for N was very small, even with urea. This is due to the absence of Cl^-, Na^+ and HCO_3^- at high concentration compared to the saline soil as reported by Maro (2001a). A combination of these cations and anions together with a high pH accelerates urea hydrolysis and volatilisation of ammonia. It was also found that soil root development in non-saline soils was well established compared to the saline soil because of salt injury.

Because of the differences in rates of application, it appears that AS on the non-saline soil was used quite efficiently compared to urea. This leads to the suggestion that there is a possibility of substituting the use of urea by AS. This might help to reduce soil alkalinity (Freney and Simpson, 1983), which is already on the high side as a result of continuous use of urea.

The differences in performance between urea and AS on the saline soil was relatively quite substantial. DM production in the plots treated with urea was almost 50% of that in the plots treated with AS. Non-accounted for N from urea was also very high (63-66%) compared to AS (21-24%). It is said that losses of mineral N occur when inorganic fertilizer is applied to the soil. But the nature and extent of loss depend on several factors including soil type, soil moisture, agronomic practices and type of

fertilizer used (Ng Kee Kwong and Deville, 1994). However, when AS and urea are applied to the soil, losses from AS are not large and are not connected to the agronomic practices (Ellington, 1986), and whereas for urea it is the reverse of what happens with AS and losses could go up to 60% (Follet and Hatfield, 2001).

Recent research on the problems encountered with the use of urea has shown that together with the losses, which affect the efficient use of mineral N, there is also a problem of phytotoxicity on seed germination and seedling growth by NH_3 produced through hydrolysis of urea (Bremner, 1995). The differences of dry matter production reported in this study, when urea was applied to the saline and non-saline soil, explain further the findings reported by Bremner (1995).

3.5 Conclusion

It is known that the effectiveness of a fertilizer depends on several factors such as type of the crop, soil, climatic conditions and management practices. Therefore, the optimum fertilizer practice for any fertilizer must be adapted to local conditions, crops and soils.

Many soils at TPC have pH values in excess of 8.5 (Maro, 2001a), making them very potential for N loss due to volatilisation when urea is used as source of N; therefore, also affecting the fertilizer use efficiency. Results from this study show that differences in DM production between urea and AS on a non-saline soil were very small while in the saline soil it was substantial, though urea was applied at 60 kg N ha^{-1} and AS at 40 kg N ha^{-1}. The use of urea in the saline soil led to a reduction of more than 50% in DM. Following the results of this study the use of ammonium

sulphate in both soil types is scientifically recommended and considered to be a better alternative.

Nevertheless, if urea is to be used because of its economic benefit, care should be taken to avoid losses and to increase fertilizer efficiency. Thus, it is recommended, where overhead irrigation is used, to broadcast urea fertilizer and to irrigate immediately. If it is done under surface irrigation, urea should be applied in furrow and irrigated immediately while controlling the water flow so that the fertilizer is not washed to the ends of the rows as observed by Wood (personal communication). Alternatively, supplying fertilizer with the irrigation water can be recommended (Freney, 1997). It is also recommended to bury urea in the soil to minimize volatilisation of ammonia gas. Further research is required to determine the most suitable combination of soil urease and nitrifying inhibitors to reduce N loss and to increase the efficiency of fertilizer N use in sugarcane cropping fields. Meanwhile it is recommended that in future, fertilizer recommendation in sugarcane fields must be specific to a soil type.

CHAPTER 4

DRY MATTER PRODUCTION AND PERCENTAGE OF FERTILIZER N UTILIZATION BY TWO COMMERCIAL SUGARCANE VARIETIES GROWN IN TANZANIA

DRY MATTER PRODUCTION AND PERCENTAGE OF FERTILIZER N UTILIZATION BY TWO COMMERCIAL SUGARCANE VARIETIES GROWN IN TANZANIA

Abstract

In sugarcane estates, fertilizer recommendations are generally based on results of fertilizer trials conducted with one commercial variety. These blanket recommendations are made without considering possible varietal differences in ion uptake and utilization of the applied fertilizer by the crop. In this study the fertilizer use efficiency of two commercial varieties, namely EA 70-97 and B 52-313, was verified. The study was conducted at the Tanganyika Planting Company (TPC) estate in Tanzania during the 2001/02 and 2002/03 growing seasons. Two plots of 10 * 10 m^2 were marked adjacent to one another and planted with the two varieties. In each plot five microplots of 0.5 * 1.5 m^2 were marked randomly on which urea fertilizer, labelled with 10 atom% ^{15}N excess was applied. Commercial non-labelled fertilizer was applied to the rest of the field. At harvest, plant samples including roots and soil samples down to 90 cm depth were collected from each of the two microplots. Data collected included dry matter production (DM), harvested N content and percentage fertilizer N utilization (% FNU). Mean values of DM, N content and % FNU observed with variety EA 70-97 were higher and significantly different ($p<0.05$) from values obtained with variety B 52-313 using a t-test analysis. The differences in ion uptake and its utilization between the two varieties suggest that, in the future, N fertilizer recommendations in sugarcane must be specific to the variety.

KEY WORDS**:** Sugarcane, fertilizer efficiency, nitrogen, urea, variety

4.1 Introduction

In Tanzania, commercial sugarcane production is carried out in estates. For practical management purposes, and also to avoid unexpected calamities such as diseases and pest infestation, different varieties are planted in field blocks of 15 to 20 ha. For example, at least 13 varieties have been growing at the TPC estate. The major varieties, EA 70-97 and B 52-313, occupy 25% and 52%, respectively, of the area planted with sugarcane. Other commercial varieties include NC0 376 and NC0 310, which comprise only 7% and 2%, respectively, of the planted area (Mkodo, personal communication). As a matter of policy, fertilizer use is based on the results of fertilizer trials conducted on only one commercial variety (blanket recommendation), which is at 60 kg N ha^{-1}.

However, crop varieties possess different abilities to effectively use N fertilizers, as reported by Carranca et al. (2001) with spinach, Chanda et al. (2002) and Peng et al. (2002) with rice, and Lopez et al. (2002) with wheat and soyabean rotation systems. Even in sugarcane, some varieties have the capacity to grow and increase the cane tonnage with heavy application of N without adverse effects on their juice quality, yet in others excess N deteriorates juice quality (Chandra and Saini, 1998). Varietal differences in mineral uptake have also been reported with regard to P, K, Fe and Zn (Zdenko, 2002). Actually, little is known about the percentage fertilizer N utilization (% FNU) of commercial sugarcane varieties of Tanzania. Consequently, the objective of this study was to evaluate the % FNU of the two most popular commercial varieties using the ^{15}N-

enriched fertilizer technique. The hypothesis was that the current recommended rate of N fertilizer (60 kg N ha^{-1}) does not apply to all varieties grown at the estate.

4.2 Materials and methods

This study was conducted at the TPC estate in Tanzania during the 2001/02 and 2002/03 growing season.

On a field of more than 15 ha on which sugarcane was planted, two plots of 10 * 10 m^2 were marked on a non-saline soil, which was under overhead irrigation. For this study, two commercial varieties, EA 70-97 and B 52-313, were used. On each plot five microplots of 0.5 * 1.5 m^2 were marked randomly on which urea fertilizer, labelled with 10 atom % ^{15}N excess, was applied according to the recommended rate, and used for the uptake and balance study. The rest of the field was treated with ordinary fertilizer at the same rate of 60 kg N ha^{-1}. Prior to planting, 25 kg P ha^{-1} and 25 kg K ha^{-1} were applied to ensure fertility levels of these nutrients necessary for optimal yield. Care was taken to ensure that the microplots received the same agronomic treatments like the rest of the field. In order to control irrigation water, sheet metal frames of 30 cm high were pressed 20 cm deep into the soil and left 10 cm above the soil, thus isolating the microplots.

At harvest, plant samples including roots and soil samples to a depth of 90 cm were collected from each of the microplots. Roots from the top 60 cm were dug out and separated from the soil by wet sieving. Above-ground plant samples were separated into leaves, sheath and stalks. Senescing and dead leaf tissues were carefully collected and

included in the leaf part at sampling. These were dried at 70^0 C till constant weight was reached, then weighed and ground to pass a 0.5 mm sieve.

Soil samples were collected at 30 cm interval to a depth of 90 cm. Of each layer three sub-samples were collected and pooled together to get one bulk sample per layer per microplot.

In samples containing ^{15}N, the enrichment was determined by mass spectrometry. The % ^{15}N recovered from the fertilizer in the plant and soil samples was calculated according to Hauck and Bremner (1976):

% ^{15}N recovery from fertilizer (FNU) = Nsample(c-b) *100 /R (a-b)….(1)

Where,

Nsample: total N content of the sample;

a: ^{15}N abundance of the applied fertilizer;

b: ^{15}N abundance of an untreated sample (background level);

c: ^{15}N abundance of the treated sample;

R: rate of applied fertilizer.

The % of N in the plant derived from the fertilizer (% Ndff) was calculated using the following formula:

% Ndff = (c-b)*100/(a-b)……………………………………………….(2)

The % of N in the plant derived from the soil was made up by the difference:

% Ndfs = 100 - % Ndff…………………….………………………….(3)

and the percentage fertilizer N utilization (%FNU), a measure of fertilizer use efficiency (Brian et al., 1995; IAEA, 1976), was calculated as

$$\textit{\% FNU = \%Ndff * sample total N / fertilizer rate} \quad \text{..... (4)}$$

This is, in fact, the same formula as the one developed by Hauck and Bremner (1976).
Prior to fertilizer application, soil samples were collected to determine the physico-chemical properties of the soil such as, pH, P, K, N, EC and sodium adsorption ratio (SAR).

Total nitrogen was analyzed using the Macro-Kjeldahl method, organic carbon by the Walkley-Black method, available P by the Olsen method, Na^+ and K^+ by flame photometry, Ca^{2+} and Mg^{2+} by the EDTA titrimetry method and anions were first extracted from soil by water followed by titration using the procedure outlined in the National Soil Laboratory Centre (1989). Texture was determined by the Bouyoucos hydrometer method using the USDA triangle classification model.

Differences in DM, harvested N content and % FNU between the two varieties were tested using the t-test for their means according to the procedure described by Mead et al. (1993). Differences were declared significant at $P<0.05$.

4.3 Results

A summary of the physico-chemical characteristics of the experimental site is given on Table 4.1. The site can be regarded as a neutral soil, non-saline and non-sodic loam. It is deficient in N, but well supplied with P and K, and therefore it is a highly potential soil that could yield well, provided there is an appropriate fertilizer management practice, especially on N (Maro, 2001b).

Table 4.1 Physico-chemical characteristics of the experimental site (non-saline soil)

Depth (cm)	pH	P	K^+	Ca^{++}	Mg^{++}	Na^+	SAR	EC (1:5) dS m^{-1}	Total N %	Texture
		{	———	mg kg^{-1}	———	}				
0-30	7.8	15.4	3077	2640	384	200	0.3	0.07	0.19	Clay loam

SAR = Sodium Adsorption Ratio

A balance sheet for both varieties and for both experimental years showing the distribution of N, labelled N, and % FNU between above-ground plant parts and the soil (0 to 90 cm depth) is given in Table 4.2, 4.3, 4.4 and 4.5. The % FNU at the end of the season for the variety EA 70-97 during the 2001/02 and 2002/03 growing seasons was 86% and 90%, respectively. For the variety B 52-313 the % FNU was 56% and 60%, respectively. Non accounted for N for the variety EA 70-97 during the 2001/02 and 2002/03 growing seasons was 14% and 10%, respectively, and for the variety B 52-313 it was 44% and 40%, respectively. Total DM production for the variety EA 70-97 was 65 t ha^{-1} and 67.3 t ha^{-1} for season one and season two, respectively. For variety B 52-313 total DM production for the two seasons were 50.0 t ha^{-1} and 53.4 t ha^{-1}, respectively. Total harvested N content harvested from variety EA 70-97 was 410 kg ha^{-1} and 400 kg ha^{-1} for season one and season two respectively, and for variety B 52-313 it was 330 kg ha^{-1} and 360 kg ha^{-1} in season one and season two, respectively. With both varieties the sequence of distribution of DM in the different parts of the plant was almost similar. The highest amount of DM was found in the stalks, followed by the leaves, sheath and roots. The same trend of distribution of the N content was observed.

Higher % FNU, DM production and N content were observed with variety EA 70-97 than with B 52-313. Significant differences ($p < 0.05$) were observed in both seasons with all

parameters tested when the means of the two varieties were compared using the t-test, with the exception of the N content which did not show significant differences (P>0.05) in season two (Table 4.6).

Table 4.2 A balance sheet showing the distribution of N, labelled N (in the plant parts and the soil), % FNU, DM and harvested N content for the variety EA 70-97 during the 2001/02 growing season (mean of five microplots)

Plant part	Stalk	Leaves	Sheath	Roots	Total
DM (t ha^{-1})	42.9±2.5	11.1±1.7	9.1±1.0	2.0±0.2	65.1±4.1
% distribution	66	17	14	3	
Harvested N content (kg ha^{-1})	260±20	110±20	30±3	10±1	410±20
% distribution	63	27	8	2	
% FNU	54	23	6	3	86.0
% Ndff	12.5	12.5	12.5	17	
% Ndfs	87.5	87.5	87.5	83	
Soil part	0 - 30cm	30- 60cm	60 - 90cm		
% Ndff	0.35	0.77	0.15		
% Ndfs	99.7	99.2	99.8		
% Recovery ^{15}N	0.04	0.05	0.03		0.12
Total N recovery: Plant part = 86.0 % Soil part = 0.12 % Non accounted for N = 13.9 %					

Table 4.3 A balance sheet showing the distribution of N, labelled N (in the plant parts and the soil), % FNU, DM and harvested N content for the variety EA 70-97 during the 2002/03 growing season (mean of five microplots)

Plant part	Stalk	Leaves	Sheath	Roots	Total
DM (t ha^{-1})	43.7±2.6	12.1±1.5	9.4±1.4	2.0±0.2	67.3±4.0
% distribution	65	18	14	3	
Harvested N content (kg ha^{-1})	260±20	100±50	30±3	10±2	400±20
% distribution	65	25	8	2	
% FNU	60.0	20.8	6.7	2.6	90.1
% Ndff	13.8	12.5	13.5	15.6	
% Ndfs	86.2	87.5	86.5	84.4	
Soil part	0 - 30cm	30 - 60cm	60 - 90cm		
% Ndff	0.7	0.5	0.4		
% Ndfs	99.3	99.5	99.6		
% Recovery ^{15}N	0.05	0.015	0.005		0.07

Total N recovery:
Plant part = 90.1 %
Soil part = 0.07 %
Non accounted for N = 9.93 %

Table 4.4 A balance sheet showing the distribution of N, labelled N (in the plant parts and the soil), % FNU, DM and harvested N content for the variety B 52-313 during the 2001/02 growing season (mean of five microplots)

	Stalk	Leaves	Sheath	Roots	Total
DM (t ha^{-1})	27.0±2.3	11.5±1.7	10.0±1.6	1.5±0.06	50.0±3.8
% distribution	54	23	20	3	
Harvested N content (kg ha^{-1})	140±10	140±20	50±4	6±0.1	330±30
% distribution	42	42	14	2	
% FNU	25.1	22.7	8.0	0.0001	55.8
% Ndff	10.7	9.7	9.7	0.001	
% Ndfs	89.3	90.3	90.3	99.9	
Soil part	0-30cm	30-60cm	60-90cm		
% Ndff	0.8	0.35	0.14		
% Ndfs	99.2	99.7	99.9		
% Recovery ^{15}N	0.07	0.011	0.002		0.083

Total N recovery:
Plant part = 55.8 %
Soil part = 0.08 %
Non accounted for N= 44.9%

Table 4.5 A Balance sheet showing the distribution of N, labelled N (in the plant parts and the soil), % FNU, DM and harvested N content for the variety B 52-313 during the 2002/03 growing season (mean of five microplots)

Plant part	Stalk	Leaves	Sheath	Roots	Total
DM (t ha^{-1})	29.2±1.5	11.2±1.3	10.7±0.9	1.6±0.1	53.4±2.9
% distribution	56	21	20	3	
Harvested N content (kg ha^{-1})	180±3	120±12	50±5	10±2	360±50
% distribution	50	33	14	3	
% FNU	29.2	23.6	5.5	2.2	60.5
% Ndff	9.7	11.8	6.6	6.6	
% Ndfs	90.3	88.2	93.4	93.4	
Soil part	0 - 30cm	30 - 60cm	60 - 90cm		
Ndff	0.56	0.35	0.15		
Ndfs	99.4	99.7	99.9		
% Recovery ^{15}N	0.04	0.02	0.002		0.062
Total N recovery: Plant part = 60.5 % Soil part = 0.06 % Non accounted for N = 39.9					

Table 4.6 A summary of statistical analysis (t-test), mean of five microplots

Variety	Mean	T value	Prob.	Std dev.
% FNU during the 2001/02 growing season				
EA 70-97	86.0	10.8	0.0004*	2.7
B 52 313	55.8			
% FNU during the 2002/03 growing season				
EA 70-97	90.1	13.6	0.0002*	2.2
B 52 313	60.5			
DM production (t ha^{-1}) during the 2001/02 growing season				
EA 70-97	65.1	4.2	0.013*	3.5
B 52 313	50.0			
DM production (t ha^{-1}) during the 2002/03 growing season				
EA 70-97	67.3	5.6	0.005*	2.5
B 52 313	53.4			
Harvested N content (kg ha^{-1}) during the 2001/02 growing season				
EA 70-97	410	4.4	0.012*	0.02
B 52 313	340			
Harvested N content (kg ha^{-1}) during the 2002/03 growing season				
EA 70-97	400	1.4	0.23^{ns}	0.03
B 52 313	360			

* = Significant differences ($P<0.05$)
^{ns} = not significant

4.5 Discussion

There are differences among plant species in ion uptake and utilization efficiency. Several scientists including Kanwar et al. (1989) with sugarcane and Reed and Hageman (1980) with maize reported similar findings. Crop response to fertilizer application depends not only on the level of available plant nutrients in the soil but it is also related to crop physiology and morphology (Larry, 1997). Some plant species and genotypes, therefore, may consequently have the capacity to grow and yield well even on soils of low fertility (Hynes, 1992). Genotypes which are considered to grow and yield on nutrient-deficient soils have specific physiological mechanisms that allow them to gain access to sufficient quantities of nutrients and utilize them quite efficiently. Plant growth characteristics including roots, root morphology and root metabolism vary among genotypes as well as species and are considered to be among the physiological mechanisms, which cause differences in ion uptake between plant species and genotypes (Dong et al., 1995; Sattelmacher et al., 1997; Staunton et al., 2003). It becomes a general practice that for many cultivated crops, plant nutrients are supplied at rates which are in accordance with to the growth rates of the crop. A cultivar with low growth rate will absorb sufficient nutrients from a soil with a low or medium nutrient status so that fertilizer application will have little effect on yield production. Consequently, cultivars with high growth rates are unable to attain plant nutrients in adequate amounts under low soil fertility conditions as they require a higher rate of nutrients per unit soil surface (Mengel, 1983). That is why the higher yielding variety or crop species responds more readily to fertilizers. Also, cultivars, which are bulky with more extensive root systems, would increase the volume of soil to be explored for N and hence increase the pool of available N, as reported by

Mekonnen et al. (1997) in a study conducted on the uptake of mineral N. Furthermore, the extent to which plant roots are capable of exploiting the soil for plant nutrients is also important. In these respects considerable differences between species and cultivars occur as reported by Ghosh and Kashyap (2003). Such differences include physiological differences in the capacity of the root cells to take up nutrients in the plasma membrane and differences in nutrient affinity (Hynes, 1992).

Also the higher percentage of fertilizer N utilization in a crop like sugarcane is strongly associated with the greater partitioning of leaf N into chlorophyll and ribulose 1,5-bisphosphate-carboxylate oxygenase (Rubisco) (Ranjith and Meinzer, 1997). It might be possible to further improve the already high fertilizer N utilization of sugarcane by screening genotypes for differences in partitioning of leaf N into components of the photosynthetic apparatus such as chlorophyll and Rubisco. Consequently, because of the differences in partioning of leaf N, which results into differences in growth rate among species and genotypes, it is implicit that time of fertilizer application should be specific to a variety. In the sugarcane estate, the common practice is to apply N at three months after planting. For those varieties, which grow fast, that could be the right time. But for others, which grow slowly, that may not be the right time. With the latter the danger is that at that time the root system is not well developed, increasing the susceptibility for loss of NO_3^--N through leaching.

Different plant species and genotypes within species influence differently the quantitative and qualitative composition of the microbial population and plant nutrients in the rhizosphere. The nature of root exudates that might be involved in promoting or inhibiting growth of various bacteria in the rhizosphere and their effect

on nutrient composition and concentration is the subject of current research in various places (Van Overbeek et al., 1997). For example, Baon et al. (1994) reported that a rye genotype with short root hairs was more dependent on mycorrhizal colonization for growth in a P deficient soil than a genotype with long root hairs.

According to the results obtained from our study, variety EA 70-97 was more efficient in utilizing mineral N than variety B 52-313. Both varieties were planted on the same day, the same site and had the same time of fertilizer application, but they differed in total dry matter, % FNU and N content. The reason could be due to differences in root growth characteristics. The roots harvested for variety EA 70-97 were 2.0 tons in both seasons, while for variety B 52-313 the root harvests were 1.5 and 1.6 tons in season one and two, respectively. It appears that variety EA 70-97 was more efficient because of the extensiveness and bulkiness of the root system. It had more volume of the soil to be explored for mineral N, which increased the pool of available N (Otegui et al., 2002). Extensiveness and bulkiness of the root system also reduces the loss of NO_3^- through leaching.

At the estate, it has been observed that the current varieties do not yield to the expectations (Maro, personnal communication). There is a decline in mean yield for the past ten years from 99 t ha^{-1} to 73. t ha^{-1}. This can be explained by the low affinity of the variety to nutrient uptake (Graham & Rengel, 1993), loss of genetic potential in yield of current commercial varieties and lack of effectiveness of fertilizer applied which might be limited by chemical and biological reactions, topsoil drying, and disease interactions.

Meanwhile, according to the balance sheet, which shows the distribution of N and labelled N, the percentage of N derived from fertilizer (% Ndff) was on average 12.5% and the percentage of N derived from the soil (% Ndfs) 87.5% for variety EA

70-97, while for variety B 52-313, % Ndff was on average 10% and % Ndfs 90%. Generally, the values of % Ndff appear to be very small as compared to various reported results. On the other hand, also other scientists have reported results somewhat similar to ours. Weng and Chan (1990) reported values of % Ndff of 18%, 11% and 15% using ammonium sulphate, urea and potassium nitrate respectively as source of N in sugarcane. Vallis et al. (1996) reported values of % Ndff in sugarcane ranging from 20% to 40%. The possible reason for the relatively lower values of % Ndff could be the nature of the crop itself. Though the main sources of N to a growing plant are both the soil and the fertilizer applied. For a sugarcane crop, N can also come from biological N fixation (BNF) as reported by Biggs et al. (2002) and Kennedy et al. (1997). Associative N_2 fixing bacteria have been isolated from fields where sugarcane is grown and it has been reported that fixation contributes potentially significant amounts of N to plant growth and development. The bacteria *Acetobacter diazotrophicus* and *Herbaspirillum spp.* are mentioned to be responsible for N_2 fixation in sugarcane (Urquiaga et al., 1992). Sugarcane cultivars grown in association with N_2 fixing bacteria, are either independent to fertilizer application or do not highly respond to fertilizer application (Muthukumarasamy et al., 1999) or low application rates of chemical fertilizers stimulate high uptake of soil N and biological N fixation (Cao et al., 2002). Contribution of BNF could go to 38% (Asis-Constancio et al., 2002). Another reason, which could support the possibility of BNF is that the amount recommended for N application at the moment, 60 kg N ha^{-1}, is low according to the world record of recommended rates in sugarcane production (Keating et al., 1997). It appears that both varieties, EA 70-97 and B 52 313, are not responding favourably to fertilizer application due to their association with N_2 fixing bacteria (Kennedy et al., 1997).

According to literature, N accumulation in sugarcane occurs during a period of 150-200 days (Wood et al., 1996). Fertilizer is applied 90 days after planting and it will probably take not more than ten days before it has completely been taken up by the plant. Still there are 100 days whereby the sugarcane crop continues to accumulate N. Meanwhile the sources of N become both the soil and BNF. According to experiments conducted in the laboratory to evaluate the potential of the native soil to N mineralization (chapter 7), it is shown that mineralization in the field under study is limited and eventually only just for a short period, 3 to 4 months only. That means that for the rest of the growing period the crop will accumulate N from the soil but also from BNF.

Simultaneously with fertilizer application, farmers need to consider technologies that increase the efficiency of N application. This can be done through the use of varieties with greater affinity to nutrients (Lynch, 1998). On the other hand, because of the costs involved in the production of chemical fertilizers especially N fertilizers, the use of varieties which can fix atmospheric N, could be a possible alternative (Roy et al., 2002).

4.5 Conclusion

Results from this experiment have shown that there is a difference in % FNU between the two varieties tested. It is therefore strongly recommended to the estate management to review its fertilization policy. It is further recommended that fertilizer application be specific to the variety. Future research on improving FNU of the sugarcane crop in Tanzania should focus on improving cultivars' N responsiveness, optimizing the rate of N application based on the cultivars' N status, time for

optimum fertilizer application and the introduction of varieties which can fix atmospheric N (biological N fixation). As a short-term solution, it is also recommended to import, test and identify other varieties, which are most suited and adaptable to the local environment.

CHAPTER 5

THE EFFECT OF DIFFERENT LEVELS OF UREA AND UREA PLUS FILTER CAKE ON GROWTH, YIELD AND QUALITY OF SUGARCANE

EFFECT OF DIFFERENT LEVELS OF UREA AND UREA PLUS FILTER CAKE ON GROWTH, YIELD AND QUALITY OF SUGARCANE

Abstract

A field experiment was conducted at the Tanganyika Planting Company (TPC) sugar estate, Tanzania, during the 2000/01 and 2001/02 growing seasons. The objective of this study was to evaluate the effect of different levels of urea and urea plus filter cake (FC) on growth, yield and quality of sugarcane grown on a saline and a non-saline soil. The randomised complete block design (RCBD) was used with four replications and plots made up of five rows of 8 m long. Treatments consisted of four levels of N (0, 30, 60 and 90 kg N ha^{-1}) and a mixture of 15 kg N ha^{-1} plus FC applied at 50 t ha^{-1}. Tons of cane ha^{-1} (TCH), sucrose (%) and tons of sugar ha^{-1} (TSH) on the non-saline soil increased with increasing N levels up to 60 kg N ha^{-1} and decreased at 90 kg N ha^{-1}. High levels of N affected the quality of sugarcane resulting into reduced TCH, sucrose (%) and TSH. The 60 kg N ha^{-1} and 15 kg N ha^{-1} plus FC treatments gave the best results and are therefore recommended for use on a non-saline soil. On the saline soil the treatment 15 kg ha^{-1} plus FC performed better than any other treatment on all parameters recorded. It appears that most of the urea applied to the saline soil might have been lost by volatilisation. The treatment 15 kg N ha^{-1} plus FC was able to supply mineral N slowly for quite a long time and is therefore recommended for use on a saline soil.

KEY WORDS**:** nitrogen, filter cake, sugarcane, urea, quality, pol, brix, purity, sucrose, saline, non saline

5.1 Introduction

Insufficient native N is a characteristic of soils for crop production all over the world and it is even worse in arid regions where soils have low organic matter content (Broadbent, 1981). Snapp (1998) has reported that N is the most limiting nutrient in tropical areas where organic matter is very low and its turnover into nitrogen through mineralization is also low. Therefore any system designed to increase crop production in tropical areas must include inputs of N and improvement in the efficiency of its utilization. In most agricultural systems where sugarcane is grown, the amount of N readily available is usually insufficient to support high crop productivity (Anderson et al., 1995).

Estimating the requirement of sugarcane for major elements (NPK) for variety COS 767, Chandra and Saini (1998) reported a maximum cane yield of 75.1 t ha^{-1} and uptake of 227.9 kg N ha^{-1}, 89.6 kg P $ha^{-1}$and 364.3 kg K ha^{-1}. These observations clearly show that the high nutrient demand of sugarcane could cause fast deterioration of soil fertility status especially when the crop is grown under monoculture conditions (Coale et al., 1993), even when these nutrients are supplied through chemical fertilizers (Yadav and Prasad, 1992). It is therefore recommended that for best sugarcane production, it is a principal prerequisite to draw a proper and timely fertilization policy.

Although research on this subject has shown that yield increases with application of N fertilizers (Asfary et al., 1983), the response has limitations (Greenwood et al., 1980),

especially on quality parameters. In the brewing industry, for example, the quality of barley for brewing malt is strongly related to fertilization (Carreck and Christian, 1993). Similarly in the sugar industry, sugar concentration in sugar beet was found to be a function of nutrient management (Smith et al., 1995). Ng Kee Kwong et al. (1987) reported that excess mineral N in sugarcane fields is not only wasteful but it also depresses sucrose content of sugarcane.

Until now N has proven to be the only main limiting nutrient at the Tanganyika Planting Company (TPC) (Isa, 1998). Sources of mineral N in the estates have been inorganic fertilizers and filter cake (FC). Filter cake is a factory by-product of the sugarcane fermentation, which at present is often returned to the soil as fertilizer (organic waste). For N application, the common practice has been a blanket recommendation at a rate of 60 kg N ha^{-1} (Mkodo, personal communication), using urea, without considering physico-chemical soil characteristics such as salinity, existing in several areas. Sometimes in areas, which are within the vicinity of the factory, urea at a rate of 15 kg ha^{-1} mixed with filter cake at a rate of approximately 50 t ha^{-1} is applied on cane fields as a blanket recommendation regardless of differences of soil physico-chemical characteristics. About 37% of total land in use at TPC is salt-affected, being mostly saline and saline sodic (Maro, 2001a). Nitrogen management should differ substantially between saline and non-saline soils (Freney and Simpson, 1983). Urea fertilizer is not suitable in saline soils, but growers in the estates apply it because it is the most affordable type of N fertilizer.

Information on the relationship between yield and quality of sugarcane on various soils with salinity problems and application of urea as source of mineral N at TPC is very scanty. In addition the interaction between urea, salinity and quality of the sugarcane crop

is not known and/or whether the recommended rate of 60 kg N ha^{-1} is also appropriate to a saline soil. However, it is known that losses of mineral N when urea is applied on saline soil are usually very high (Freney and Simpson, 1983). The salt of saline soils affects the rate and quantity of water that can be absorbed by plant roots, and it subsequently reduces yield and juice quality (Lingle and Wiegand, 1997; Lingle et al., 2000).

Furthermore, information on the effect of filter cake, applied on saline and non-saline soils, on yield and quality of sugarcane grown at TPC is also very scanty. Nonetheless there is evidence that in soils, which have the capacity to mineralize relatively large amounts of nitrogen, the presence of filter cake enhances the rate of mineralization, resulting in luxury uptake of N by the plant and a consequent reduction in sucrose content and sugar (Moberly and Meyer, 1978). Likewise, FC applied on a saline soil reduces the effect of salt injury to a growing crop (Sen and Maji, 1994).

Therefore, the objective of this study was to evaluate the effects of different levels of urea and urea plus FC on growth, yield and quality of sugarcane grown on a saline and non-saline soil.

5.2 Materials and methods

A field experiment was conducted at the TPC sugar estate, Moshi, Tanzania. Two sites were chosen for their contrasting soil characteristics during two consecutive years, 2000/01 to 20001/02, involving one plant cane and the first ratoon crop. The commercial variety EA 70-97 was used. The experiment was laid out in a randomised complete block design (RCBD) with four replications. Plots were made up of five rows of 8 m long and a

spacing of 1.45 m between rows. The treatments consisted of four levels of N (0, 30, 60 and 90 kg N ha^{-1}) applied as urea and one level of urea at 15 kg N ha^{-1} plus filter cake (FC) at 50 t ha^{-1}, equivalent to 65 kg N ha^{-1}. When determining the amount of N to add in the mixture it was assumed that 50% of the total N in the decomposed FC would be available to the plants (Moberly and Meyer, 1978). The treatment containing FC was broadcasted and disced into the soil at planting. The age of the FC used in the experiment was four weeks.

Prior to fertilizer application, soil samples were collected to a depth of 120 cm to characterize the physico-chemical properties of the experimental site. Total nitrogen was analyzed using the Macro-Kjeldahl method, organic carbon by the Walkley-Black method, available P by the Olsen method, Na^+ and K^+ by flame photometry, Ca^{2+} and Mg^{2+} by the EDTA titrimetry method and anions were first extracted from soil by water followed by titration using the procedure outlined in the National Soil Laboratory Centre (1989). Texture was determined by the Bouyoucos hydrometer method using the USDA triangle classification model. Also a detailed analysis of the chemical characteristics of the filter cake was done separately. The timing of fertilizer application, including P and K both at 25 kg ha^{-1}, and other agronomic practices such as weeding, were done in accordance to estate recommendations.

Data collection was made on the three middle rows. In each plot the second row was specifically divided into four subplots of 1.5*1.5 m^2 and used for the determination of dry matter which was done periodically at 6, 9 and 12 months after planting. Plant and root samples were collected at each time. Roots from the top 50 cm depth were dug out and separated from the soil by wet sieving. Above-ground parts were separated into leaves,

sheaths and stalks. Thereafter, each part was weighed separately and dried at 70^0C until constant weight. Dried samples were weighed and ground to pass through a 1mm sieve and stored in plastic bags till analysis of total N. The % distribution of dry matter and total N uptake were calculated on the basis of t ha^{-1}.

At harvest, the 3rd and 4th row was used to measure agronomic characteristics such as plant height, stalk weight and cane yield. A total of ten samples were picked randomly from the 3rd and 4th row and used for determination of the percentage of soluble solutes in juice (% brix), the relative abundance of apparent sucrose in the cane juice (% pol), the % ratio of pol to brix (% purity), sucrose content and sugar yield using the procedures outlined by Maro (2001b).

Means of data collected were subjected to statistical analysis using the Mstat C programme, version 2.00.

5.3 Results

Physico-chemical characteristics of the experimental site and filter cake are given in Table 5.1.

The non-saline soil is a soil with a sandy gravel texture. pH through the depth range from 7.8 at the 0 to 25 cm layer to 8.2 at the 85 to 120 cm layer. The electrical conductivity (EC, 1:5) was far below 0.4 dS m^{-1} the threshold value for salinity (Singer and Munns, 1999) and sodium adsorption ratio (SAR) < 1. The soil is therefore considered ‘normal’ (non saline, non sodic) (Singer and Munns, 1999).

In the saline soil, the pH through the depth was generally above 8.8 with all sub-surface horizons well over 9.0. The EC of the surface horizon shot to 1.08 dS m^{-1} (highly saline) (Singer and Munns, 1999), while the sub-soil showed to stabilize at about the threshold of 0.4 dS m^{-1}. High levels of, K^{+}, Mg^{++} and Na^{+} were experienced, while the Ca^{++} levels were relatively lower than in the non-saline soil.

At both sites, P and K were at acceptable levels for sugarcane cultivation, although N was deficient (Maro, 2001b).

Table 5.1 Physico-chemical characteristics of the experimental sites as well as of the filter cake (FC).

Site	Soil Depth	PH	EC (1:5)	P	K^+	Ca^{++}	Mg^{++}	Na^+	OC %	Total N %	C/N	SAR
	(cm)	(1:1)	dS m^{-1}	(mg kg^{-1}				mg kg^{-1})				
Non-saline soil												
Ap	0-25	7.8	0.07	15.1	3077	2640	384	200	1.31	0.19	7.1	0.3
A2	25-55	7.9	0.07	20.6	2976	2240	384	251	0.76	0.14	5.4	0.4
E	55-85	8.3	0.07	17.5	1127	2240	372	400	0.54	0.029	18.6	0.7
Bt	85-120	8.2	0.10	19.3	1743	3280	360	550	0.32	0.013	24.6	0.8
Saline soil												
Ap	0-30	8.8	1.08	17.5	4001	2480	888	1700	0.75	0.06	11.6	2.4
B1	30-50	9.2	0.46	16.5	6568	1960	720	1999	0.16	0.01	14.5	3.1
B2	50-65	9.2	0.30	13.6	4310	1520	576	1296	0.09	0.008	11.3	2.3
B3k	65-120	9.2	0.45	11.2	5132	1760	792	1699	0.05	0.003	16.7	2.8
Filter cake		5.7	0.05	16.2	14781	9940	1344	644	4.2	0.20	21.0	0.29

5.3.1 Dry matter accumulation, N content, stalk count, plant height and tons of cane ha^{-1} (TCH)

Results for the above-mentioned parameters during the 2000/01 and 2001/02 growing season are summarised in Tables 5.2 and 5.3.

Dry matter (DM) yields show a strong response to N application at all sampling stages, sites and seasons. During the 2000/01 growing season, on the non-saline soil, total dry matter (TDM) yields at harvest differed significantly ($p > 0.05$), whereby the 90 kg N ha^{-1} treatment had the highest TDM yield (64 t ha^{-1}). This did not differ significantly (LSD0.05) with 60 kg N ha^{-1} (60 t ha^{-1}) and 15 kg N ha^{-1} plus FC (57 t ha^{-1}) treatments. The differences were significant with the 0 (37 t ha^{-1}) and 30 kg N ha^{-1} (45 t ha^{-1}) treatments. Similar observations were made during the 20001/02 growing season, though the DM yields were higher during the 20001/02 growing season. During the 2000/01 growing season, the 15 kg N ha^{-1} plus FC treatment on the saline soil had the highest TDM (44 t ha^{-1}) which was statistically not different from the 90 kg N ha^{-1} (44 t ha^{-1}) and 60 kg N ha^{-1} (36 t ha^{-1}) treatments. This observation was more or less consistent with that of the 2001/02 growing season. TDM yields on the saline soil were lower than those on the non-saline soil.

The N content data show a similar pattern of results as with the total dry matter yield at harvest. Raising the level of N increased total dry matter content in all plant parts and therefore increasing the total amount of N harvested. During the 2000/01 growing season, the 15 kg N ha^{-1} plus FC treatment on the non-saline soil was statistically the same as the total amount of N harvested (0.367 t ha^{-1}) with the 60 kg N ha^{-1} (0.351 t ha^{-1}) and 90 kg N

ha^{-1} (0.381 t ha^{-1}) treatments which differed significantly from the 0 (0.222 t ha^{-1}) and 30 kg N ha^{-1} (0.278 t ha^{-1}) treatments. In year two, on the non-saline soil, the 15 kg N ha^{-1} plus FC treatment harvested 0.375 t ha^{-1} of total N being statistically the same as with the 60 kg N ha^{-1} (0.365 t ha^{-1}) and 90 kg N ha^{-1} (0.389 t ha^{-1}), which differed from the 0 (0.225 t ha^{-1}) and 30 kg N ha^{-1} (0.286 t ha^{-1}) treatments. Similar patterns of observation were experienced in the saline soils in both seasons whereby the total N content on the saline soil was lower than on the non-saline soil.

A similar trend was observed with the data obtained on stalk count and plant height on the non-saline soil and saline soil in both seasons. At both sites and seasons, 0 and 30 kg N ha^{-1} treatments had the lowest values in stalk count and plant height, differing significantly (LSD0.05) from the other treatments. On the non-saline soil, the 60 kg N ha^{-1} had the highest number in stalk count (385/plot in year one and 396/plot in year two), while the 90 kg N ha^{-1} had the highest value of plant height in season one (297 cm), and the 15 kg N ha^{-1} plus FC treatment (290 cm) in season two. On the saline soil, the 90 kg N ha^{-1} gave the highest stalk count and plant height, which did not differ significantly from the 60 kg N ha^{-1} and the 15 kg N ha^{-1} plus FC treatment. Like with other parameters already discussed, values of stalk count and plant heights were higher on the non-saline soil than on the saline soil in both years.

The final yield in TCH also shows a similar response to N application. During the 2000/01 growing season the highest TCH was obtained with the 60 kg N ha^{-1} (121 t ha^{-1}) on the non-saline soil, being not significantly different from the 90 kg N ha^{-1} (117 t ha^{-1}) and 15 kg N ha^{-1} plus FC (117 t ha^{-1}) treatments. The same observation was recorded in the second growing season of the experiment whereby the highest TCH was obtained

with 60 kg N ha^{-1} (129 t ha^{-1}) which did not differ significantly from the 90 kg N ha^{-1} (121 t ha^{-1}) and the 15 kg N ha^{-1}plus FC (120 t ha^{-1}) treatments. On the saline soil the 15 kg N ha^{-1} plus FC treatment produced the highest TCH (90 t ha^{-1} and 95 t ha^{-1}) in both years. This did not differ statistically from the 60 kg N ha^{-1} treatment which produced 74 t ha^{-1} in year one and 80 t ha^{-1} in year two and the 90 kg N ha^{-1} treatment, which produced 83 t ha^{-1} in year one and 88 t ha^{-1} in year two.

TCH from the saline soil was relatively lower than those obtained from the non-saline soil in both years.

Table 5.2 The effect of different levels of urea and urea plus filter cake on growth and yield of sugarcane grown on a non-saline soil during the 2000/01 and 2001/02 growing seasons

| | 1st sampling DM in t ha^{-1} (six months old) | | | | 2nd sampling DM in t ha^{-1} (nine months old) | | | | 3rd sampling DM in t ha^{-1} (twelve months old) | | | | | | |)
Treatment	stalk	leaves	sheath	roots	stalk	leaves	sheath	roots	stalk	leaves	sheath	roots	TDM	N content in t ha^{-1}	Stalk count/ plot	Plant/ Height (cm	TCH
2000/01																	
0 kg N ha^{-1}	16.4b	4.25c	3.5b	0.56	20.7c	5.3c	3.9b	0.9c	25.3b	6.0d	4.3c	1.14c	37b	0.222b	190c	190b	75.2b
30 kg N ha^{-1}	26.1a	6.0b	5.3a	0.59	27.5b	7.0b	6.0ab	1.12bc	29.5b	7.6c	6.4bc	1.35bc	45b	0.278b	200c	205b	87.7ab
60 kg N ha^{-1}	27.8a	7.4a	6.2a	0.75	33.2ab	8.8a	8.0a	1.5ab	39.6a	10.2b	8.4ab	1.80ab	60a	0.351a	385a	285a	121.4a
90 kg N ha^{-1}	31.6a	8.2a	6.7a	0.85	37.3a	9.6a	7.5a	1.7a	42.9a	11.5a	9.9a	1.95a	64a	0.381a	269b	297a	116.6a
15 kg N ha^{-1} plus FC	29.5a	7.6a	6.2a	0.76	34.5a	8.5a	7.3a	1.6a	37.0a	9.5b	8.6a	1.78ab	57a	0.367a	285b	276a	117.1a
LSD 0.05	6.7	1.37	1.7	ns	6.7	1.24	2.8	0.04	6.7	1.2	2.2	0.5	8.7	0.062	62.8	56.3	34.6
CV (%)	12.9	10.4	15.5	17.0	11.1	8.05	21.4	15.1	9.8	6.6	14.8	16.6	8.4	6.76	12.0	11.5	17.0
2001/02																	
0 kg N ha^{-1}	10.5c	7.0c	5.0	1.7c	15.4c	8.7	5.6d	2.0d	19.4c	9.6	6.3b	2.3c	37.6d	0.225b	199c	195b	77.8b
30 kg N ha^{-1}	16.1bc	9.3bc	5.4	2.0c	23.0bc	10.0	6.1dc	2.4c	28.0b	10.8	7.4b	2.5bc	48.7c	0.286b	213c	209b	90.9b
60 kg N ha^{-1}	22.6ab	10.1b	7.3	2.4b	30.1ab	11.5	8.5ab	2.8b	37.9a	12.3	8.8ab	3.0b	62.0ab	0.365a	396a	289a	129.4a
90 kg N ha^{-1}	24.3a	c	8.6	2.8a	31.4a	13.1	10.5a	3.5a	39.0a	14.7	11.1a	4.7a	69.5a	0.389a	277b	274a	121.2a
15 kg N ha^{-1} plus FC	21.5ab	12.1a	7.1	2.3b	30.7ab	10.1	8.0bc	2.5c	35.7a	11.8	8.6ab	2.9b	59.0b	0.375a	290b	290a	120.1a
LSD 0.05	6.7	b	ns	0.61	7.9	ns	2.0	0.19	7.1	ns	3.3	0.58	8.8	0.06	38.7	42.2	23.8
CV (%)	17.9	14.3a	27.4	13.9	15.5	25.2	13.7	3.7	11.4	22.9	19.1	9.6	8.2	10.9	7.1	8.5	11.2
		3.7															
		17.7															

* Data followed by the same letter within a column are statistically not different (P>0.05).

Table 5.3 The effect of different levels of urea and urea plus filter cake on growth and yield of sugarcane grown on a saline soil during the 2000/01 and 2001/02 growing seasons

	1st sampling DM in t ha-1 (six months old)				2nd sampling DM in t ha-1 (nine months old)				3rd sampling DM in t ha-1 (twelve months old)								
Treatment	stalk	leaves	sheath	roots	stalk	leaves	sheath	roots	stalk	leaves	sheath	roots	TDM	Nconten t in t ha^{-1}	Stalk count /plot	Plant/ Heigh t (cm)	TCH
2000/01																	
0 kg N ha^{-1}	5.0d	2.1c	1.9d	0.6c	7.6d	3.6b	3.0c	0.9c	9.5b	4.3c	3.7d	1.1b	18.6c	0.121c	76b	150b	38.2b
30 kg N ha^{-1}	7.8c	3.5bc	3.1cd	0.9bc	10.3cd	4.6b	3.8c	1.2bc	12.4b	4.5c	4.7cd	1.4ab	23.0c	0.141c	84b	175ab	47.3b
60 kg N ha^{-1}	10.8b	4.7ab	3.8bc	1.2ab	15.4bc	7.5a	6.6b	1.4ab	21.4a	7.1bc	6.1bc	1.6ab	36.2b	0.210b	110a	186ab	74.4a
90 kg N ha^{-1}	13.0b	c	5.1ab	1.5a	17.4ab	7.9a	6.9b	1.7a	22.5a	9.1ab	7.1ab	1.8a	40.5a	0.256ab	121a	198a	83.2a
15 kg N ha^{-1} plus FC	16.2a	5.6ab	6.1a	1.6a	20.6a	9.5a	8.3a	1.8a	23.6a	10.6a	7.8a	1.9a	b	0.286a	130a	210a	90.2a
LSD 0.05	2.4	7.0a	1.3	0.5	5.1	2.8	1.3	0.5	5.1	3.5	1.6	0.68	43.9a	0.062	22.9	39.7	16.9
CV (%)	11.7	2.7	17.1	23.7	18.3	21.7	11.9	18.0	14.6	24.7	14.2	22.3	6.3	8.9	11.2	11.0	12.9
		31.0											9.8				
2001/02																	
0 kg N ha^{-1}	6.7c		2.2c	0.7b	8.3d	3.6d	2.3d	0.9d	10.6e	4.4d	2.6c	1.2b		0.129c	80b	148c	40.9c
30 kg N ha^{-1}	7.7c	2.8	2.9bc	0.8b	11.3cb	4.7cd	3.6c	1.1cd	13.9d	6.4cd	5.1bc	1.5ab	19.8c	0.152c	89b	178bc	50.4c
60 kg N ha^{-1}	8.9bc	3.7	3.5abc	1.1ab	13.9bc	6.1bc	4.8b	1.3bc	20.8c	7.8cb	7.1ab	1.6ab	26.9c	0.220b	115ab	190ab	80.6b
90 kg N ha^{-1}	10.5b	4.4	4.0ab	1.3a	16.8b	7.0b	5.5b	1.5ab	23.5b	9.2ab	8.0ab	1.8a	37.3b	0.265ab	130a	200ab	87.9ab
15 kg N ha^{-1} plus FC	13.6c	4.7	4.9a	1.5a	20.7a	8.6a	6.9a	1.7a	27.1a	10.1a	9.8a	2.0a	42.5a	0.295a	140a	215a	95.4a
LSD 0.05	2.5	5.0	1.7	0.45	3.5	1.6	0.9	0.34	2.0	2.1	3.1	0.5	b	0.06	36.6	36.3	11.5
CV (%)	13.5	ns	25.5	21.5	12.7	13.3	10.2	13.3	5.3	14.2	23.6	17.1	49.0a	7.0	16.8	9.9	8.2
		27.3											7.2				
													10.5				

- Data followed by the same letter within a column are statistically not different (P>0.05)
- .

5.3.2 Quality parameters: pol, brix, purity, % sucrose and tons of sugar per hectare (TSH)

The results on the effect of different levels of urea and urea plus FC on quality parameters are summarised in Tables 5.4 and 5.5.

During the 2000/01 and 2001/02 growing season results related to pol, purity and brix parameters on the non-saline soil showed an increase with increasing levels of N up to 60 kg N ha^{-1} and a decrease with 90 kg N ha^{-1}. However, differences were not significant in both years. The same observation was true for the saline soil with the exception of the purity parameter in the year 2001/02, for which differences between treatments were significant ($p > 0.05$).

On the non-saline soil, % sucrose and TSH showed significant differences with regard to N application in both years. The 60 kg N ha^{-1} treatment had the highest TSH, which produced 13.2 t ha^{-1} in year one and 13.9 t ha^{-1} in year two. This did not differ significantly from the 15 kg N ha^{-1} plus FC, which produced 11.0 t ha^{-1} in year one and 11.6 t ha^{-1} in year two. On the saline soil, % sucrose did not show significant differences in the year 2000/01, whereby in year 2001/02 the differences were significant. TSH showed significant differences in both years. The 15 kg ha^{-1} plus FC treatment had the highest TSH (8.7 t ha^{-1} in year one and 9.3 t ha^{-1} in year two), which differed significantly from the other treatments in both seasons. Yields in TSH were relatively higher on the the non-saline than on the saline soil.

Table 5.4 The effect of different levels of urea fertilizer and urea plus FC on quality parameters (pol, purity, brix, sucrose and TSH) of sugarcane grown on a non-saline soil during the 2000/01 and 2001/02 growing seasons

Treatment	2000/01 season					2001/02 season				
	% Pol	% Purity	% Brix	% Sucrose	TSH (t ha^{-1})	% Pol	% Purity	% Brix	% Sucrose	TSH (t ha^{-1})
0 kg N ha^{-1}	14.5	88.2	16.5	7.2b	5.4d	14.9	89.3	16.7	7.1b	5.5d
30 kg N ha^{-1}	15.2	90.7	16.8	7.5b	6.6cd	15.5	90.8	17.1	7.5b	6.8cd
60 kg N ha^{-1}	16.2	92.9	17.5	10.9a	13.2a	17.1	93.5	18.8	10.8a	13.9a
90 kg N ha^{-1}	16.0	88.9	18.1	8.1b	9.4bc	16.9	92.6	18.3	8.0ab	9.7bc
15 kg N ha^{-1} plus FC	16.2	91.6	17.7	9.8ab	11.0ab	17.2	92.9	18.5	9.7ab	11.6ab
LSD 0.05	ns	ns	ns	2.8	2.9	ns	ns	ns	2.9	3.1
CV (%)	9.3	3.5	9.4	16.2	16.3	9.3	4.3	8.2	17.1	16.6

* Data followed by the same letter within a column are statistically not different (P>0.05).

Table 5.5 The effect of different levels of urea fertilizer and urea plus FC on quality parameters (pol, purity, brix, sucrose and TSH) of sugarcane grown on a saline soil during the 2000/01 and 2001/02 growing seasons

Treatment	2000/01 season					2001/02 season				
	% Pol	% Purity	% Brix	% Sucrose	TSH (t ha^{-1})	% Pol	% Purity	% Brix	% Sucrose	TSH (t ha^{-1})
0 kg N ha^{-1}	13.9	77.6	17.9	7.2	2.7c	13.7	78.0c	17.5	7.3b	3.0c
30 kg N ha^{-1}	13.4	80.1	16.7	7.2	3.2c	13.4	81.2bc	16.5	7.4b	3.7c
60 kg N ha^{-1}	14.1	85.6	16.5	7.4	5.5b	14.3	85.7ab	16.7	7.5ab	6.0b
90 kg N ha^{-1}	13.9	85.0	16.4	7.5	6.2b	14.4	86.0ab	16.8	7.5ab	6.6b
15 kg N ha^{-1} plus FC	16.3	90.5	18.0	9.6	8.7a	16.5	90.8a	18.2	9.8a	9.3a
LSD 0.05	ns	ns	ns	ns	1.9	ns	7.2	ns	2.3	2.2
CV (%)	11.6	7.7	10.9	18.1	18.9	10.7	4.3	9.6	15.1	19.8

* Data followed by the same letter within a column are statistically not different (P>0.05).

5.4 Discussion

The performance of the 15 kg N ha^{-1} plus FC treatment on growth parameters studied on the non-saline soil was the same as with the application of either 60 kg N ha^{-1} or 90 kg N ha^{-1}. Moberly and Meyer (1978) have observed that when FC is used as a source of N, 50 % will be available to the plant, hence making the total treatment equivalent to the application of 65 kg ha^{-1}. This application supported the same sugarcane growth as the 60 and 90 kg N ha^{-1}. It is known that nutrients contained in mineral fertilizers are rapidly used by crop plants and seldom leave a residual effect, while those supplied through organic manure like FC are used more slowly and stored for a longer time in the soil (Moberly and Meyer, 1978; Sharma and Mitter, 1991; Yadav and Prasad, 1992). Our experiment shows that the 90 kg N ha^{-1} had the highest total DM at harvest, but lower values of TCH, % sucrose and TSH. The % sucrose and TSH are among the quality parameters, which get to be depressed at high dosages of mineral N. The same observations with sugarcane have also been reported by Ng Kee Kwong et al. (1987) and Robertson et al. (1996b). It appears that like in any other crop, N application to sugarcane has a limit, especially on quality parameters. Smith et al. (1995), with sugar beet, and Carreck and Christian (1993) with barley have also reported similar results.

On the saline soil, canes were severely damaged or scorched resulting in restricted growth, reduction on stalk count and cane yield. Probably this was due to the effect of salinity. Salts reduce the rate and quantity of water absorbed by plant roots as a result of increase in osmotic pressure (Plaut et al., 2000), brings about soil deterioration that impends the movement of water and air, hence reducing the amount of nutrients to be taken by the plant. Also in saline soil, high losses of mineral N occur due to the

volatilization of ammonia gas (Byrnes and Freney, 1995). It appears that although different levels of N were applied in this experiment, under saline conditions, probably most of it was lost and not taken up by the plant. In contrast, the performance of the 15 kg N ha^{-1} plus FC treatment has been found to be significantly better than the other treatments. This was observed with TDM, TCH, % sucrose as well as TSH. As it has been indicated, the application of organic matter on the soil supplies mineral N for a longer time as compared to inorganic fertilizers. It appears that, the 15 kg N ha^{-1} plus FC treatment was able to supply mineral N slowly for quite a long time (Moberly and Meyer, 1978). Furthermore, FC contains a lot of Ca^{++}, which helps to displace Na^{+} on the exchange sites of the saline soil, which might have been drained out and therefore increased the permeability for water and reduced the salt effect of the growing sugarcane plant (Maro, 2001a). In addition, FC on saline soils improves the juice quality. Similar findings have been reported by Lingle and Wiegand (1997), Lingle et al. (2000) and Yaduvanshi et al. (1989). It has been observed that the effect of FC in saline soils is similar as any other organic manure or waste (Moberly and Meyer, 1978). It also improves soil structure, movement of air and water, availability of beneficial microorganism in the soil and water holding capacity of the soil (Yadav Prasad, 1992), and increasing the content of micronutrients such as Zn, Fe and Cu (Kapur and Kanwar, 1989). In addition, it has a nematicidal action against nematodes attacking sugarcane roots such as *Meloidogyne incognita* race1 and *M. javanica* (Albuquerque et al., 2001). The moisture content of the FC is an important factor in stimulating germination and subsequent tillering (Moberly and Meyer, 1978), and therefore FC plays an important role as soil amendment (Rodella et al., 1990).

Normally, ammonium sulphate is recommended on saline soils, because losses are always lower than after urea application. Another advantage of using AS on saline soils is its capacity to lower soil pH (Follet and Hatfield, 2001).

5.5 Conclusion

It is clear that the application of FC at both sites i.e. on the non-saline and saline soils, probably improved N availability of the soil. On the non-saline soil, in accordance to the performance of the treatments tested, the 15 kg N ha^{-1} plus FC treatment is recommended for use at a rate equal to the one tested in this experiment i.e. FC equivalent to 50 t N ha^{-1}, leading to a yield of 11.6 TSH. However, it must be used with extra care since too much FC might enhance mineralization and thus provide more N for uptake by the plant. This can lower the quality by suppressing the sucrose content. But, if urea will continue to be used, the 60 kg N ha^{-1} treatment is still recommended because the 90 kg N ha^{-1} treatment has been found to suppress sucrose content.

The use of the 15 kg N ha^{-1} plus FC is highly recommended for use on the saline soil. Its performance has been significantly better when compared to the highest level, the 90 kg N ha^{-1}. The advantages of using FC or organic manure on saline soils are well known and have been found to influence plant growth and to produce cane of high quality.

Since urea is regarded as a cheap source of N, the use of ammonium sulphate might not be beneficial to the estate. However, for sustainable production of sugarcane, the use of ammonium sulphate is scientifically the best alternative. It might help lowering

soil pH since sugarcane is able to grow well at pH levels ranging from slightly acidic to slightly alkaline.

CHAPTER 6

EFFECT OF DIFFERENT LEVELS OF UREA AND UREA PLUS FILTER CAKE ON CHLOROPHYLL CONTENT, STOMATAL CONDUCTANCE AND NET PHOTOSYNTHESIS OF SUGARCANE

EFFECT OF DIFFERENT LEVELS OF UREA AND UREA PLUS FILTER CAKE ON CHLOROPHYLL CONTENT, STOMATAL CONDUCTANCE AND NET PHOTOSYNTHESIS OF SUGARCANE

Abstract

A field experiment was conducted at the Tanganyika Planting Company (TPC) sugar estate, Tanzania, during the 2000/01 and 2001/02 growing season, with the objective of evaluating the effect of different levels of urea and urea plus filter cake (FC) on the chlorophyll content (chl %), the stomatal conductance (g) and net photosynthesis (A) of sugarcane grown on a non-saline and saline soil. A randomized complete block design (RCBD) was used with four replications and plots made up of five rows of 8 m long. Treatments consisted of four levels of N (0, 30, 60 and 90 kg N ha^{-1}) and a mixture of 15 kg N ha^{-1} plus FC applied at 50 t ha^{-1}. Increased N levels increased the chl %, g and A at both sites and years. These increases were higher in the non-saline soil than in the saline soil. Losses of mineral N and the effect of salt injury in the saline soil could be the possible reasons for these differences in the two contrasting soil types. The performance of the 15 kg N ha^{-1} plus FC was much better in the saline soil than the non- saline soil. These results suggest that salt injury and losses of mineral N in these plots were minimal. This led to higher rates of chl %, g and A compared to the other treatments in the saline soil. The use of ammonium sulphate instead of urea in saline soils might be a

better alternative, followed by a mixture of inorganic fertilizer and FC. However, when FC is used, yield and quality of the crop at harvest must be controlled.

KEY WORDS: urea, nitrogen, salinity, filter cake, photosynthesis, chlorophyll, stomata, conductance, salt, stress

6.1 Introduction

Nitrogen together with C, H and O are the major constituents of plant organic matter. Nitrogen constitutes 2 to 4% of dry matter, and C about 40% (Mengel and Kirkby, 1978). Nitrogen is an obligatory element of numerous organic compounds of general importance for plants (Lanaras et al., 1993), such as proteins, amino acids and peptides. It occurs in the chlorophyll molecule and its presence in leaves increases the photosynthetic capacity of a plant (Bishnoi et al., 1993). It has also been established that photosynthesis, growth and yield of a crop are strongly linked to the concentration of chlorophyll molecules (Subasinghe and Frederick, 1997).

Nitrogen is the most limiting nutrient in tropical soils. Inorganic and organic fertilizers are usually applied to supplement the N requirement of a crop (Yaduvaninshi et al., 1989). However, uptake and efficient utilization of mineral N depends on several factors such as soil type, type of fertilizer, placement, rate of application, soil moisture, variety and photosynthetic efficiency.

Application of mineral N in saline soils is rather complicated when urea is used. In this case losses of mineral N, as a result of NH_3 volatilization, are very high, thus affecting the uptake and efficient utilization of applied N (Fleisher and Hagin, 1981). While soil

salinity itself decreases the photosynthetic efficiency of a plant (Frederick et al., 1994), it is apparently important to understand how the basic physiological process in a leaf affects the efficiency of N use in crop production.

The most pressing aspect of soil chemistry at the TPC sugar estate in Tanzania are the salt affected soils, which cover 37% of the total area under sugarcane cultivation. Poor stand canes, bare field spots, uneven growth, stunted growth and poor yield have been observed. Results of soil analysis conducted in these areas have shown levels of salt of more than 0.4 dS m^{-1} (Maro, 2001a). A survey of different categories of salt-affected soils at TPC is summarized in Table 6.1.

The fertilization policy at the TPC estate has been the application of urea as blanket recommendation at 60 kg N ha^{-1}, regardless of the different existing soil types, ranging from a non-saline soil to a saline soil, mainly because of the cheap cost of the mineral N. However, very high losses are likely to occur when urea is applied to a saline soil. Sometimes filter cake (FC), a factory byproduct of sugarcane fermentation, is used as a source of mineral N in areas in the vicinity of the factory.

The currently available cultivars at TPC sugar estate have been developed outside the TPC estate and are not well adapted to several factors, including salinity. Furthermore, information on the behavior of the commercial varieties grown on saline and non-saline soils with respect to chlorophyll content, stomatal conductance and photosynthetic capacity and their interaction with urea and FC is not known, although it is known that photosynthetic capacity of a plant determines the final yield of a crop.

The present study evaluates net photosynthesis, stomatal conductance and chlorophyll content of sugarcane grown at different levels of urea and urea plus FC on a saline and

non-saline soil. Better understanding of the relative contribution of internal and external controls on physiological processes in sugarcane have the most to offer not only to the grower but also to plant physiologists and breeders in their breeding programme.

Table 6.1 Categories of salt affected soils at the TPC estate

Soil description	pH (1:1)	EC (1:5) dS m^{-1}	**Area covered** ha	% of total arable land
Moderately saline, non-sodic soils	< 8.4	0.4 – 0.8	56.0	0.85
Saline soil	< 8.4	> 0.8	110.3	1.7
Non-saline soil, moderately sodic soils	8.4 – 9.0	< 0.4	981.8	14.9
Sodic soils	> 9.0	< 0.4	28.9	0.4
Moderately saline soil sodic soils	8.4 – 9.0	0.4 – 0.8	723.4	11.0
Highly saline sodic soil	> 9.0	> 0.8	539.3	8.2
Other soil (normal)	< 8.4	< 0.4	4160.5	63.0

6.2 Materials and methods

A field experiment was conducted at two sites chosen for their contrasting soil characteristics (non-saline and saline soil) for two consecutive growing seasons, 2000/01 to 2001/02, involving one plant cane and the first ratoon crop. The popular commercial variety EA 70-97 was used.

The experiment was laid out in a randomized complete block design (RCBD) with four replications. Plots were made up of five rows of 8 m long and a spacing of 1.45 m between the rows. The treatments consisted of four levels of N (0, 30, 60 and 90 kg N ha^{-1}) applied as urea and one level of urea at 15 kg N ha^{-1} plus filter cake (FC) at 50 t ha^{-1} which is equivalent to 65 kg N ha^{-1}.

When determining the amount of N to add in the mixture it was assumed that 50% of the total N in the decomposed FC would be available to the plants (Moberly and Meyer, 1978). The treatment containing FC was broadcasted and disced into the soil at planting. The age of the FC used in the experiment was four weeks.

Prior to fertilizer application, soil samples were collected to a depth of 120 cm to characterize the physico-chemical properties of the experimental site. A detailed analysis of the chemical characteristics of the filter cake was also done separately, to calculate the 50 t ha^{-1} to be mixed with 15 kg N ha^{-1} from urea.

Total nitrogen was analyzed using the Macro-Kjeldahl method, organic carbon by the Walkley-Black method, available P by the Olsen method, Na^{+} and K^{+} by flame photometry, Ca^{2+} and Mg^{2+} by the EDTA titrimetry method and anions were first extracted from soil by water followed by titration using the procedure outlined in the

National Soil Laboratory Centre (1989). Texture was determined by the Bouyoucos hydrometer method using the USDA triangle classification model.

Application of P at 25 kg ha^{-1} and K also at 25 kg ha^{-1} was done at planting in accordance to the estate's recommendations.

Data collection was made on the three middle rows of each treatment and plot. A portable gas exchange system model LCA-4 ADC was used to measure net photosynthesis (A) and stomatal conductance (g). A total of ten youngest fully expanded leaves per plot were used for this measurement between 10am and 2pm. Stability in measurements was reached after 1 to 2 minutes. Both experimental fields (saline and non-saline fields) were watered a day before as needed and no drought stress was experienced prior to or during measurements (A and g). Measurements were made in May 2001 and 2002 at a crop age of six months, three months after fertilizer application.

Plant samples for determination of chlorophyll content were taken on the same day also from the youngest fully expanded leaf blade, which was excised at its ligule, divided longitudinally and one half of the leaf was taken after removing its midrib. It was immediately put in a deep freezer at -20^0 C to avoid drying out. Chlorophyll content was determined in accordance to the procedure outlined by Stewart (1989). Means of data collected were subjected to statistical analysis using the Mstat C programme, version 2.00.

Regression analysis was also done on the means for chlorophyll content and net photosynthesis as outlined by Mead et al. (1993).

6.3 Results

Physico-chemical characteristics of the experimental sites as well as of the filter cake are given in Table 6.2. The non-saline soil is a soil with a sandy gravel texture. The pH through the depth range from 7.8 to 8.3, the electrical conductivity (EC, 1:5) range from 0.07 to 0.10 dS m^{-1} and the sodium adsorption ratio (SAR) < 1. The soil is therefore considered as 'normal' (non-saline, non-sodic) (Singer and Munns, 1999). In the saline soil, the pH through the depth was between 8.8 and 9.2. The EC of the surface horizon was 1.08 dS m^{-1} (highly saline) (Singer and Munns, 1999), while the sub-soil showed to stabilize at about the threshold of 0.4 dS m^{-1}. High levels of K^{+}, Mg^{++} and Na^{+} were experienced, while the Ca^{++} levels were relatively lower than in the non-saline soil. At both sites, P and K were at acceptable levels for sugarcane cultivation, although N was deficient (Maro, 2001b).

Table 6.2 Physico-chemical characteristics of the experimental sites as well as of the filter cake (FC).

Site	Soil Depth (cm)	pH (1:1)	EC (1:5) dS m^{-1}	P (mg kg^{-1}	K^+	Ca^{++}	Mg^{++}	Na^+ mg kg^{-1})	OC %	Total N %	C/N	SAR
Non saline soil												
Ap	0-25	7.8	0.07	15.1	3077	2640	384	200	1.31	0.19	7.1	0.3
A2	25-55	7.9	0.07	20.6	2976	2240	384	251	0.76	0.14	5.4	0.4
E	55-85	8.3	0.07	17.5	1127	2240	372	400	0.54	0.029	18.6	0.7
Bt	85-120	8.2	0.10	19.3	1743	3280	360	550	0.32	0.013	24.6	0.8
Saline soil												
Ap	0-30	8.8	1.08	17.5	4001	2480	888	1700	0.75	0.06	11.6	2.4
B1	30-50	9.2	0.46	16.5	6568	1960	720	1999	0.16	0.01	14.5	3.1
B2	50-65	9.2	0.30	13.6	4310	1520	576	1296	0.09	0.008	11.3	2.3
B3k	65-120	9.2	0.45	11.2	5132	1760	792	1699	0.05	0.003	16.7	2.8
Filter cake		5.7	0.5.4	16.2	14781	9940	1344	644	4.2	0.20	21.0	0.29

Results for the chlorophyll content (chl %), stomatal conductance (g) and net photosynthesis (A) are summarized in the Tables 6.3 and 6.4.

Data for chlorophyll content show a strong relationship to N application at both sites and seasons. During the 2000/01 growing season, the 90 kg N ha^{-1} treatment on the non-saline soil had the highest chlorophyll content (0.213%), which differed significantly ($p>0.05$) from the other treatments. The 0 kg N ha^{-1} treatment had the lowest chlorophyll content (0.141%) which also differed significantly ($P>0.05$) from the other treatments. Similar observations were recorded during the 2001/02 growing season.

During the 2000/01 growing season, the 15 kg N ha^{-1} plus FC treatment and the 90 kg N ha^{-1} treatment for the saline soil, had the highest and same chlorophyll content, 0.117%, which was statistically the same as for the 60 kg N ha^{-1} treatment (0.103%). The 0 kg N ha^{-1} treatment had the lowest chlorophyll content which differed statistically ($P>0.05$) from the other treatments. This observation was consistent with the data obtained during the 2001/02 growing season.

Data for stomatal conductance and net photosynthesis showed a similar trend as the data obtained on chlorophyll content. During the 2000/01 growing season, on the non-saline soil, the 90 kg N ha^{-1} treatment showed the highest stomatal conductance (0.67 mol $m^{-2}s^{-1}$) and net photosynthesis (25.2 μmol $m^{-2}s^{-1}$), which differed significantly ($P>0.05$) from the other treatments. The 0 kg N ha^{-1} treatment had the lowest value of stomatal conductance (0.28 mol $m^{-2}s^{-1}$) differing statistically from the other treatments. The same treatment had the lowest value of net photosynthesis (7.7 μmol $m^{-2}s^{-1}$), which was statistically different from the 30 kg N ha^{-1} treatment. During the 2001/02 growing

season, the 90 kg N ha^{-1} also had the highest value in stomatal conductance (0.60 mol $m^{-2}s^{-1}$), differing significantly (P>0.05) from the other treatments. The 90 kg N ha^{-1} treatment, however, also gave, the highest value in net photosynthesis, but this value was not statistically different from the 60 kg N ha^{-1}. The 0 kg N ha^{-1} had the lowest value in stomatal conductance and net photosynthesis. During the 2000/01 growing season, the 15 kg N ha^{-1} plus FC treatment for the saline soil had the highest value in stomatal conductance (0.45 mol $m^{-2}s^{-1}$), statistically the same as in the 90 kg N ha^{-1} treatment. Similarly, the 15 kg N ha^{-1} plus FC treatment had the highest value in net photosynthesis, statistically the same as in the 90 kg N ha^{-1} treatment. The 0 kg N ha^{-1} treatment had the lowest value for both parameters. During the 2001/02 growing season, the 15 kg N ha^{-1} plus FC had the highest value in stomatal conductance (0.52 mol $m^{-2}s^{-1}$) and net photosynthesis (17.2 μmol $m^{-2}s^{-1}$), differing significantly (P>0.05) from the other treatments. The 0 kg N ha^{-1} treatment had the lowest value in both parameters. The general observation is that the non-saline soil had higher values of all parameters than the saline soil.

Table 6.3 The effect of different levels of urea and urea plus FC on chlorophyll % (chl%), net photosynthesis (A) and stomatal conductance (g) of sugarcane grown on a non-saline soil during the 2000/01 and 2001/02 growing seasons

Treatment	Chl%	A (μmol $m^{-2}s^{-1}$)	g (mol $m^{-2}s^{-1}$)	Chl%	A (μmol $m^{-2}s^{-1}$)	g (mol $m^{-2}s^{-1}$)
	2000/01 growing season			2001/02 growing season		
0 kg N ha^{-1}	0.141d	7.7c	0.28d	0.138d	8.1c	0.34c
30 kg N ha^{-1}	0.167bc	13.4bc	0.40c	0.174bc	14.3b	0.44bc
60 kg N ha^{-1}	0.172b	18.5b	0.51b	0.185b	19.6a	0.49b
90 kg N ha^{-1}	0.213a	25.2a	0.67a	0.229a	23.2a	0.60a
15 kg N ha^{-1} plus FC	0.153cd	16.2b	0.45bc	0.165c	15.4b	0.50b
$LSD_{0.05}$	0.015	6.2	0.097	0.015	4.1	0.096
CV (%)	7.6	25.0	14.3	5.7	16.4	12.5

- Data followed by the same letter within a column are statistically not different (P>0.05).

Table 6.4 The effect of different levels of urea and urea plus FC on chlorophyll % (chl%), net photosynthesis (A) and stomatal conductance (g) of sugarcane grown on a saline soil during the 2000/01 and 2001/02 growing seasons

Treatment	Chl%	A (μmol $m^{-2}s^{-1}$)	g (mol $m^{-2}s^{-1}$)	Chl%	A (μmol $m^{-2}s^{-1}$)	g (mol $m^{-2}s^{-1}$)
	2000/01 growing season			2001/02 growing season		
0 kg N ha^{-1}	0.070c	4.5c	0.21c	0.080d	6.1c	0.29b
30 kg N ha^{-1}	0.091b	6.1c	0.26c	0.100c	6.9c	0.33b
60 kg N ha^{-1}	0.103ab	10.8b	0.37b	0.114bc	11.2b	0.36b
90 kg N ha^{-1}	0.117a	15.1a	0.39ab	0.130a	13.1b	0.37b
15 kg N ha^{-1} plus FC	0.117a	16.1a	0.45a	0.127ab	17.2a	0.52a
$LSD_{0.05}$	0.015	3.5	0.07	0.015	3.8	0.10
CV (%)	7.8	21.7	14.0	7.4	22.8	15.8

* Data followed by the same letter within a column are statistically not different (P>0.05).

Results on regression analysis between chlorophyll content and net photosynthesis are summarized in Figure 6.1.

There was a statistically significant ($P>0.05$) relationship (R^2) between chlorophyll content and the photosynthesis on the non-saline soil in both seasons. A similar observation was also recorded on the saline soil in the first season. It was not significant in the second season.

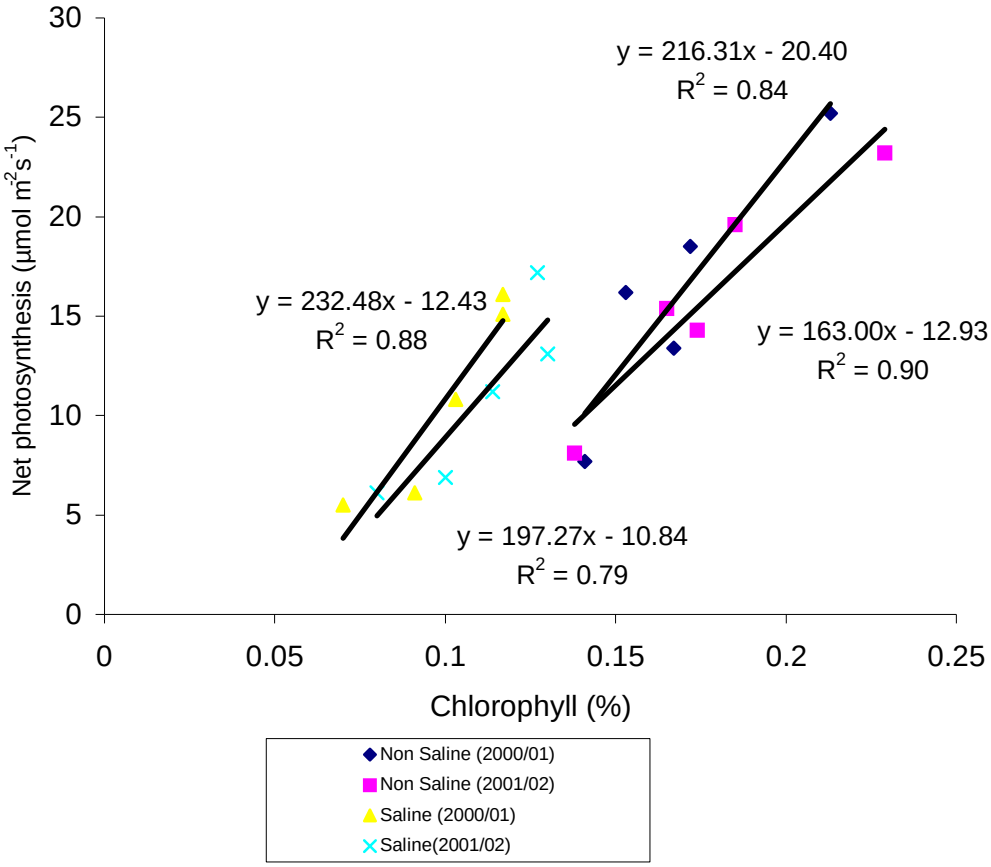


Figure 6.1 Relationship between chlorophyll content and net photosynthesis of sugarcane grown on a saline and non-saline soil during the 2000/01 and 2001/02 growing seasons

6.4 Discussion

Nitrogen is a major constituent of plants and is found in numerous organic compounds of general importance including chlorophyll (Hussein et al., 1992). Like in any other crop, greater N use in sugarcane is strongly associated with on increasing relative partitioning of leaf N to chlorophyll and Rubisco (Subasinghe and Frederick, 1997). Riedell and Kieckhefer (1993) have reported that a high amount of mineral N in the leaf increases the concentration of chlorophyll molecules and photosynthetic capacity of a leaf. Similar observations were also made in this study, whereby increases in N application increase the concentration of chlorophyll content in the leaf, stomatal conductance and net photosynthesis at both sites and years. These parameters, however, were higher on the non-saline soil than on the saline soil. A possible reason could be the losses of urea-N from the saline soil (Freney, 1992). Furthermore, this study was conducted in a tropical area where soil temperature and biological activity at the soil surface are high, conditions which are favourable for rapid hydrolysis of urea to ammonia (Byrnes and Freney, 1995). As a result, a lot of urea applied to the saline soil might have been lost and very little N was used to form the chlorophyll molecules, resulting in reduced stomatal conductance and net photosynthesis as compared to the non-saline soil. Another possible explanation of the differences in performance at the two different sites could be the excessive presence of Na^{+} and Cl^{-} ions. These ions are always in high concentration in saline soils, exceeding by far the demand, and leading to toxicity in non-tolerant plants (Plaut et al., 2000). Under those conditions, the rate and quantity of water that can be absorbed by the plant roots is reduced because of drought stress (Sen and Maji, 1994). This also brings about the nutrient inbalance in Ca^{++} uptake.

Stunted growth and reduced yield as a result of water stress and nutrient inbalance in Ca^{++} are typical characteristics of plants grown in saline soils (Zidan et al., 1992). This is also the case for sugarcane plants grown on saline soils, not being able to absorb nutrients including N. Consequently very small amounts of N were partitioned to the formation of the chlorophyll molecule, resulting in a reduced stomatal conductance and net photosynthesis as compared to the non-saline soil. Frederick et al. (1994) reported similar results with C_4 grasses, whereby increases in soil salinity led to reduced rates of net photosynthesis, stomatal conductance and shoot growth rate. It was also found that salinity increases bundle sheath leakiness to CO_2 and hence decreasing the C_3 cycle capacity relative to C_4 cycle capacity. Small changes in bundle sheath leakiness to CO_2 apparently have a large effect on photosynthetic rates and growth in sugarcane. Similar results were obtained with salt and water stress in *Zea mays* and *Andropogon glomeratus* (Bowman et al., 1989).

The performance of the 15 kg N ha^{-1} plus FC treatment was better in the saline soil than in the non-saline soil. It is known that when organic matter is added to the soil, the mineral N is gradually supplied following the decomposition of the organic matter added. In this study, it appears that most of the urea fertilizer applied to the saline soil was lost (Isa and Van Cleemput, 2003 submitted). In contrast, the 15 kg N ha^{-1} plus FC treatment was able to supply N slowly for quite a long time (Moberly and Meyer, 1978). FC has a lot of Ca^{++}, which helps to displace Na^{+} slowly on the exchange sites of the saline soil reducing salt injury and losses of mineral N. This has also been reported by Yadav and Prasad (1992). It leads to higher rates of photosynthesis and stomatal conductance as compared to the other treatment in the saline soil.

Photosynthesis, growth and yield are strongly linked to N availability, particularly in C_4 plants (Subasinghe and Frederick, 1997). However, the response of yield to N has limitations (Greenwood et al., 1980) and if not properly applied it affects the quality of the crop (Ng Kee Kwong et al., 1999). Likewise the use of 15 kg N ha^{-1} plus FC treatment has to be done with extra care. In soils with a very high mineralisation potential, addition of FC would enhance mineralisation, which may lead to too much uptake of mineral N, affecting the quality of the sugarcane juice at the end of the season (Lingle and Wiegand, 1997).

Since urea fertilizer has a very high potential for N loss due to volatilisation when used on saline soils, the use of ammonium sulphate could scientifically be a better alternative. It is known that when ammonium sulphate and urea are applied to the soil, N losses from ammonium sulphate are smaller, less related to meteorological conditions, rates of application and method of incorporation into the soil (Ellington, 1986). In addition, the use of improved management practices such as mixing of organic matter with inorganic fertilizers could decrease the losses (Yadav and Prasad, 1992).

6.5 Conclusion

In this study a strong relationship was found between N application and chlorophyll content in the leaf, stomatal conductance and net photosynthesis. Increases in N application increased concentration of chlorophyll in the leaf, stomatal conductance and net photosynthesis. Soil salinity decreased chlorophyll concentration in the leaf, stomatal conductance and net photosynthesis. Since photosynthesis is a biological

process controlled by many factors ranging from internal factors such as sink demand for carbohydrate and leaf conductance to external factors such as light, temperature and agronomic practices, the use of FC as a soil amendment agent in saline soils is recommended. It has been found that it increases chlorophyll content, stomatal conductance and net photosynthesis. However, it has to be used with caution in order to avoid quality deterioration of the crop. Furthermore, the use of ammonium sulphate in saline soil is highly recommended

CHAPTER 7

NITROGEN MINERALIZATION POTENTIAL OF SOILS UNDER SUGARCANE CULTIVATION

NITROGEN MINERALIZATION POTENTIAL OF SOILS UNDER SUGARCANE CULTIVATION

Abstract

A laboratory study was conducted, whereby 250 g air-dried soil samples of varying properties were incubated at room temperature (25±1 ^{0}C), and 60% water holding capacity for 90 days. The objective of this study was to evaluate the mineralization potential of soils collected from sugarcane fields in 2002 and 2003. The experimental treatments included: (1) native non-saline soil, (2) native saline soil, (3) native non-saline soil plus filter cake (FC), and (4) native saline soil plus FC, incubated in duplicate and arranged in a randomized complete block design (RCBD). Nitrification curves for treatment (1) and (2) and total mineral N curves for treatment (1) exhibited a lag phase, an exponential phase and a retarded phase. Total mineral N curve for the saline soil was gradually declining throughout of the experimentation period. Only the native non-saline soil showed some mineralization for a short period of time. Similar results were observed in both 2002 and 2003. The nitrification curves for treatment (3) and (4) showed a lag phase and an exponential phase, which was rising very slowly. The exponential phase was more rapid in treatment (1) and (2) than in treatment (3) and (4). Addition of FC also led to some decline in total mineral N produced during the first 20 to 30 days in both soil types, followed by a gradual rising. Maximum amount was not reached after 90 days of incubation.

KEY WORDS: nitrogen, filter cake, immobilization, mineralization, ammonification, nitrification.

7.1 Introduction

To maintain soil fertility in the Tanzanian sugarcane estates, the common practice is the application of chemical N fertilizers, soil amendment agents such as filter cake (FC), a factory by-product, or a combination of chemical N fertilizers plus FC. That means that in the case of application of chemical N fertilizers together with FC, the source of N in the sugarcane plant is native soil N, fertilizer N as well as N from mineralized FC. Therefore, the required amount of fertilizer N in sugarcane depends on the accurate assessment of the native soil N availability (De Neve et al., 1996) and the net mineralization of FC. Ideally, N fertilization should supply sufficient N to make up the difference between available N from the soil and from FC and N required for optimal yield, taking into account that no loss processes occur. The amount of plant N derived from the soil depends on the initial residual N present in the soil at planting and the mineralization potential of organic soil N (De Neve and Hofman, 1996) and that of FC (Lingle et al., 2000). The potential of soil N mineralization is more difficult to estimate, as it is influenced by several factors such as temperature, moisture, micro-organisms, soil type, and in the case of soil amendments, the C/N ratio of the amendment (Abril et al., 2001). The use of organic matter and chemical fertilizers to enhance the mineralization process has been reported by several scientists including Azam et al. (1992) and Evdokimov et al. (1993). In the case of sugarcane, the commonly used fertilizers include

NH_4^+-N and NO_3^--N and organic manure such as FC. Several disadvantages have been reported associated with the use of NH_4^+-N fertilizer types. They include a higher susceptibility to immobilization by soil micro-organism (Singh and Singh, 1993), a susceptibility to volatilization in high pH soils (Byrnes and Freney, 1995), a potential to acidify soils and a potential for chemical or clay mineral fixation in certain soils (Jarquin et al., 2003). Urease inhibitors should be used if urea is to be used to decrease the chances for volatilization upon hydrolysis. When NO_3^--N forms of fertilizers are used, they are very mobile and will be carried readily to plant roots by mass flow. But, under wet conditions they are subject to loss due to leaching and denitrification (Singer and Munns, 1999). Sometimes, it may be necessary to add a nitrification inhibitor to the NH_4^+-N fertilizer to ensure that the fertilizer remains positionally available to young cane.

In sugarcane cultivation, the importance of keeping as accurately as possible the N needs cannot be overemphasized. Excess N is not only wasteful but also depresses sugarcane sucrose content (Ng Kee Kwong et al., 1987). It implies that the use of chemical fertilizer or a soil amendment in sugarcane must be done with extra care. There is evidence that addition of a chemical fertilizer or soil amendment enhances the capacity to mineralize relatively large amounts of N. An increased rate of mineralization might, however, result in luxurious N uptake by the plant and consequently a reduction in sucrose content (Lingle and Wiegand, 1997).

At the moment, very little information is available about the mineralization potential of native soils in sugarcane plantations of Tanzania. The objective of this study therefore was to evaluate the mineralization potential of two types of soils, a saline and a non-

saline one, under laboratory conditions, either alone or when filter cake is used as amendment.

7.2 Materials and methods

Soil samples were collected from the top 10 cm in areas where sugarcane has been cropped continuously, in both a non-saline and a saline zone. It was done at the end of the growing season one week after the preharvest burning of sugarcane. This time corresponds with the start of the sampling campaign by the estates' agronomist to monitor the nutrient status of their fields. Samples collected were air-dried and slightly crushed to pass a 4 mm sieve. A portion of the soil sample was taken for analysis on selected physico-chemical characteristics. The treatments tested were:

1) native non-saline soil;

2) native saline soil;

3) native non-saline soil plus filter cake (equivalent to 50 t ha $^{-1}$); and

4) native saline soil plus filter cake (equivalent to 50 t ha $^{-1}$).

About 250 g of air-dried soil was thoroughly mixed and brought to 60% water holding capacity, placed in plastic bags and incubated at room temperature (25±1 ^{0}C). This temperature was considered as a good mean field temperature. Each treatment was incubated in duplicate arranged in a randomized complete block design (RCBD). The moisture content of the incubated samples was maintained by weighing each bag weekly and when necessary, distilled water was added, distributed uniformly on the surface of the soil and allowed to equilibrate with the soil mass by capillary movement. Destructive

sampling was done at 10 days interval. Since sampling was done on a 10 days interval, no preincubation was used. At each sampling, the content of the bag was thoroughly mixed, sampled and analyzed for NH_4^+-N and NO_3^--N using the procedure outlined in the manual prepared by the National Soil Laboratory Service Center, Tanzania (1989). Means of the data collected were subjected to statistical analysis. The LSD 0.05 was further used to compare means if they appear to differ significantly.

7.3 Results

The physico-chemical characteristics of the experimental soil are given in Table 7.1. In the non-saline soil, soil pH was 7.6, electrical conductivity (EC) was around 0.07 dS m^{-1} and sodium adsorption ratio (SAR) was less than 1. Therefore, the soil was considered as a normal clay loamy soil. In the saline soil, the pH was 8.9 with a value of EC around 1.07 dS m^{-1}. Therefore, this soil was considered as a highly saline silt loamy soil. FC chemical characteristics FC are shown in Table 7.2. FC contains high levels of Ca^{++}, K^+ and Mg^{++} when compared to their level in the native non-saline and saline soil. Also important to note is its C/N ratio of 21, which predicts net mineralization to occur during the initial stages of incubation. The results for mineralization (ammonification and nitrification) and total mineral N (NO_3^--N + NH_4^+-N) of the native soils are shown in Figure 7.1 and 7.2. The results of the soil amended with FC are shown in Figure 7.3 and 7.4.

The nitrification curve for the native non-saline (Figure 7.1) was clearly sigmoidal, while the nitrification curve of the native saline (Figure 7.2) soil had a slightly sigmoidal shape.

Generally, they exhibit a lag phase, an exponential phase and an immobilization phase, in which the amount of nitrate gradually declined. In the non-saline soil the lag phase was between 10 to 20 days of incubation, followed by the exponential phase during 20 to 30 days and reaching a maximum NO_3^--N content around 40 days of incubation. Thereafter, a gradual decline in NO_3^--N was observed up to the 90 days of incubation. Similar results were observed with the soil samples taken at both seasons, in 2002 and 2003. The highest amount of NO_3^--N produced was 35.8 mg kg^{-1} and 40.1 mg kg^{-1} in 2002 and 2003, respectively.

Nitrification curves obtained from the saline soil were different from those of the non-saline soil. In the saline soil, the lag phase showed a small NO_3^--N decline during the first ten days, followed by an increasing phase, which was rather slow in comparison with the non-saline soil during the 30 to 60 days of incubation, and reaching a maximum at 70 to 80 days, followed by some decline. The highest value of the NO_3^--N content was 30.4 mg kg^{-1} and 34.5 mg kg^{-1} in 2002 and 2003, respectively.

Table 7.1 Physico-chemical characteristics of the experimental soils

Depth	pH	P	K^+	Ca^{++}	Mg^{++}	Na^+	SAR*	EC (1:5)	Total	Texture
cm	(1:1)	{	———	mg kg^{-1}	———	}		dS m^{-1}	N %	
Non-saline soil										
0-10	7.6	15.4	3035	2624	364	211	0.3	0.07	0.19	Clay loam
Saline soil										
0-10	8.9	17.4	4000	2483	880	1712	2.4	1.07	0.06	Silt loam

SAR* = Sodium adsorption ratio

Table 7.2 Chemical characteristics of the filter cake

pH	EC (1:5)	P	K^+	Ca^{++}	Mg^{++}	Na^+	OC%	Total	C/N	SAR
(1:1)	dS m^{-1}	{		mg kg^{-1}		}		N %		
5.7	0.05	16.2	147781	9940	1344	644	4.2	0.20	21	21

SAR* = Sodium adsorption ratio

Nitrification curves for the non-saline soil amended with FC (Figure 7.3) and the native saline soil plus FC (Figure 7.4) were not sigmoidal. Two phases were experienced, a lag phase with some immobilization followed by a more or less constant nitrification rate. In these treatments, the lag phase was characterized by a decline in NO_3^--N during the first 10 days. The total lag phase in the saline soil was much longer (30 days) than in the non-saline soil (20 days). The nitrification process in the non-saline soil plus FC was much faster than in the saline soil plus FC. After 90 days of incubation the nitrification process was still going on showing that the substrate was not yet exhausted. The results of 2002 and 2003 did not differ importantly.

The evolution of the NH_4^+-N content was almost constant during the first 10 to 20 days of incubation in all treatments, followed by a gradual decline throughout the incubation period, in both years.

The total mineral N curves (NH_4^+-N+NO_3^--N) for the non-saline soil showed a rather constant level up to 50–60 days (except for some immobilization between day 10 and 20), there after the values gradually decreased till 90 days of incubation. Similar results were observed in both seasons 2002 and 2003. The maximum amount of total mineral N was 79.4 mg kg^{-1} and 84.9 mg kg^{-1} in year 2002 and 2003, respectively. This is 11.2 mg kg^{-1} and 8.3 mg kg^{-1} more than the total mineral N when the experiment was initiated.

When calculated on a field scale for a soil layer of 30 cm using the procedure outlined by Myres (1984), the maximum amount of mineral N that was produced for this soil was 41 kg N ha^{-1} and 30 kg N ha^{-1} in season 2002 and 2003, respectively. The total mineral N curves for the saline soil was quite different from the non-saline soil. In the saline one, values of total mineral N were almost constant during the first 20 days followed by a gradual decline throughout the entire incubation period. The decline of total mineral N in the non-amended non-saline or saline soil is difficult to explain. Leaching is excluded in our type of incubation. The other possibility is denitrification, which might occur to some extent (hot-spots) or immobilization. Ammonia volatilization can also not be excluded. A total balance with labelled N could bring more information.

The total mineral N curves for the non-saline and saline soils amended with FC were almost similar to one another. They started with some immobilization during the first 20 days for the non-saline soil and 30 to 50 days for the saline soil. The values started to rise gradually thereafter. They were still rising by the time the experiment was terminated. The values of total mineral N were higher on the non-saline plus FC then the ones obtained from the saline soil plus FC.

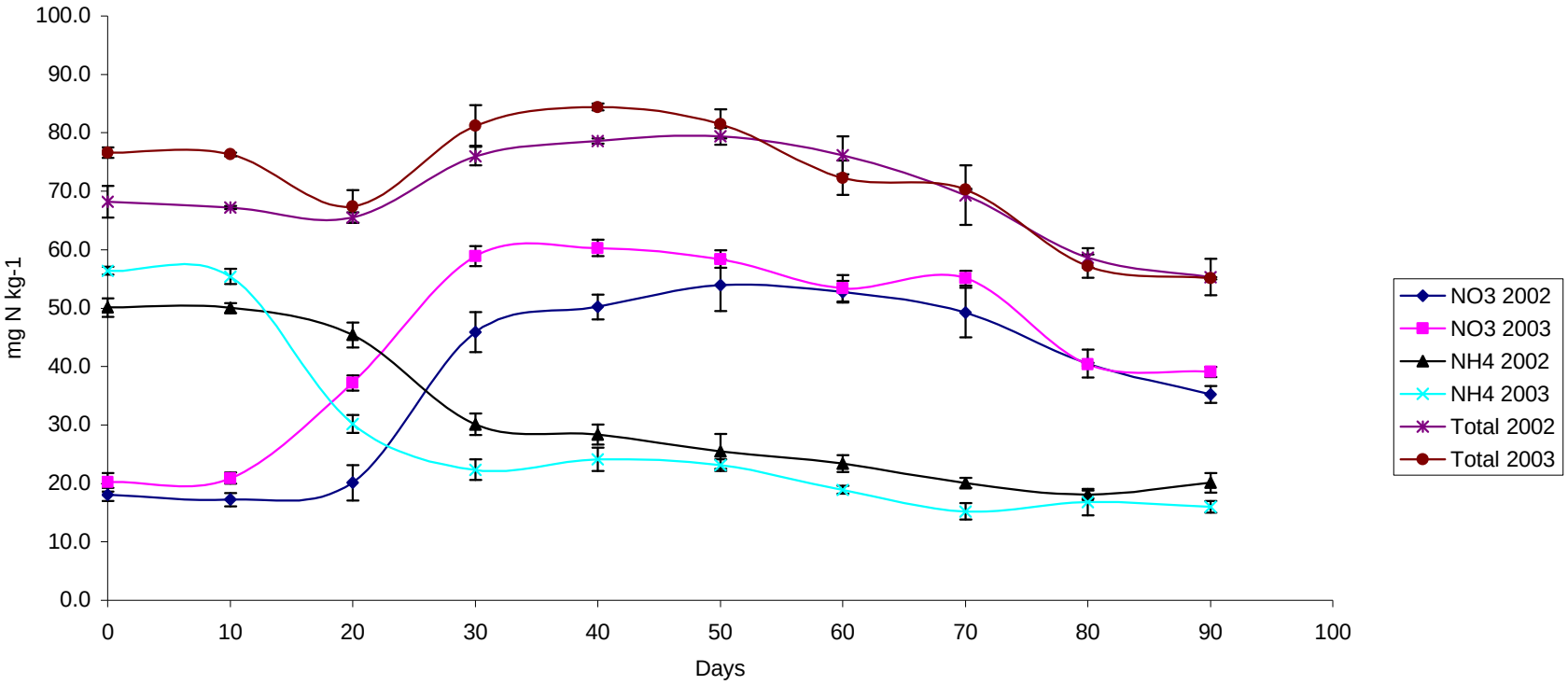


Figure 7.1 Mineralization and nitrification potential of the native non-saline soil

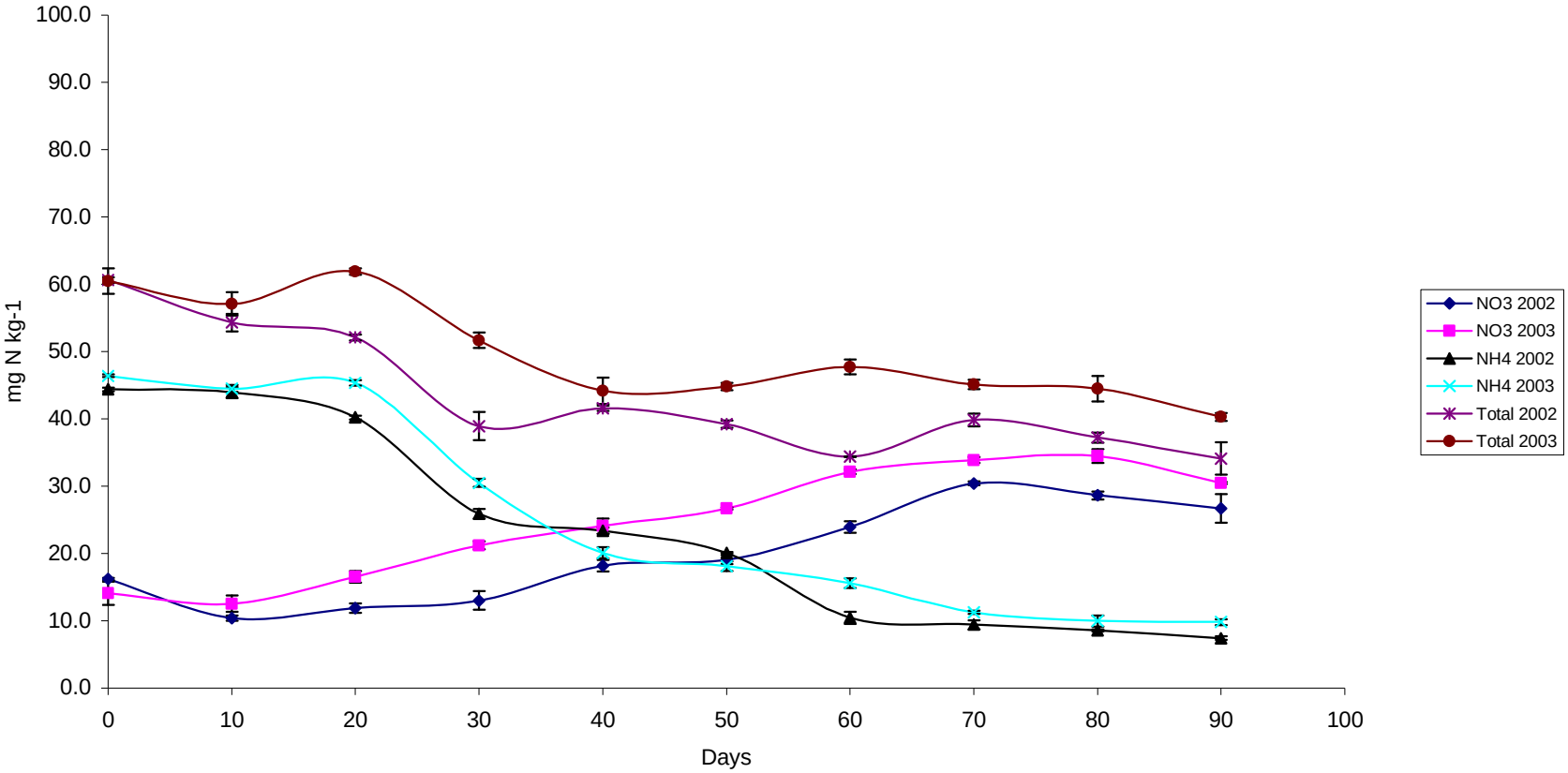


Figure 7.2 Mineralization and nitrification potential of the native saline soil

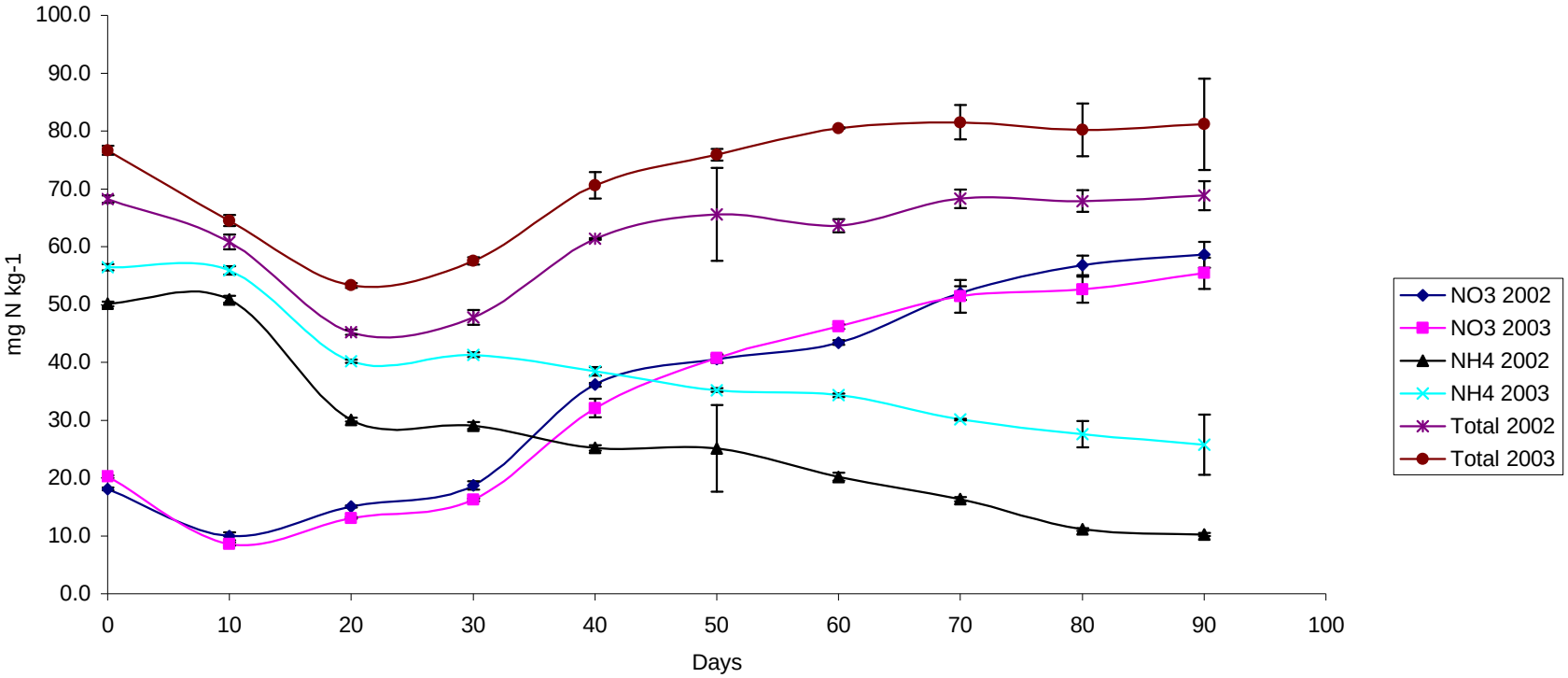


Figure 7.3 Mineralization and nitrification of the native non-saline soil plus FC

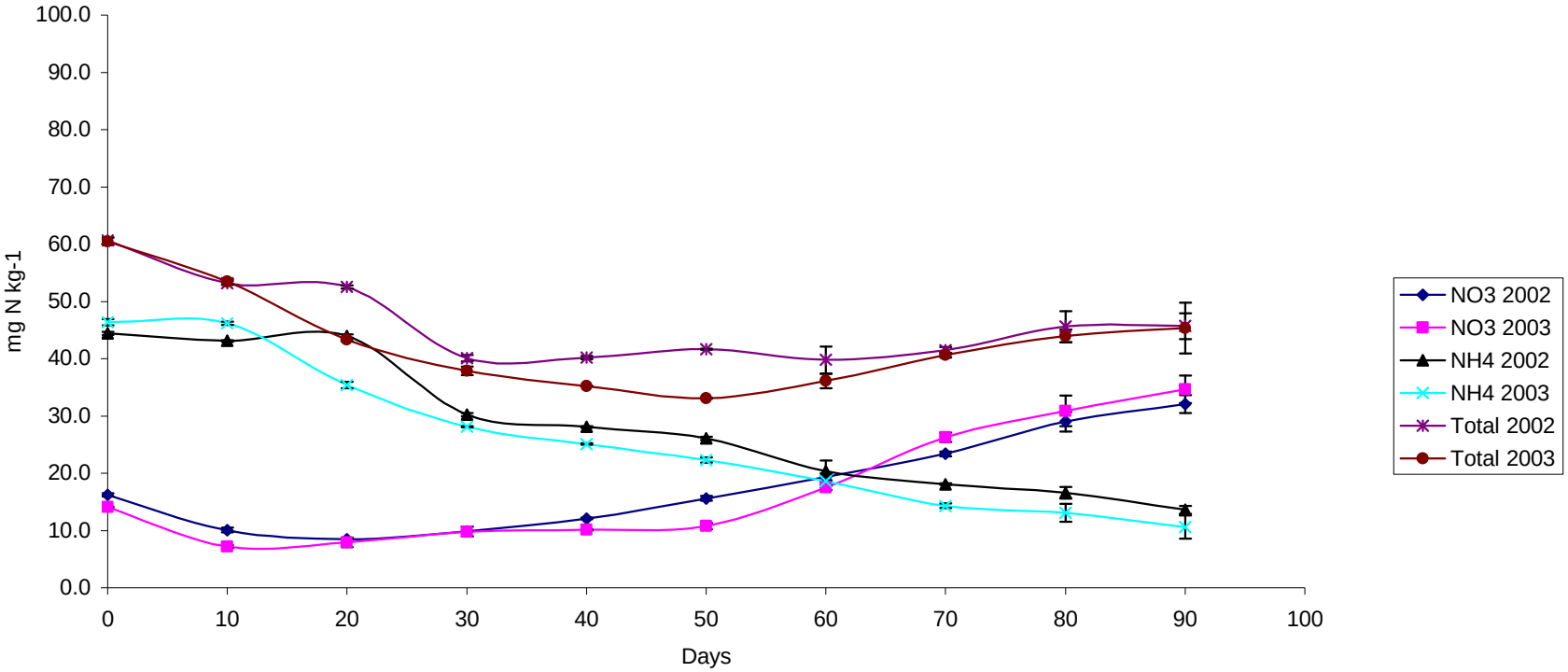


Figure 7.4 Mineralization and nitrification potential of the native saline soil plus FC

A summary of the statistical analysis of the NO_3^--N content at 10, 50 and 90 days of incubation in 2002 and 2003 is given in Table 7.3.

At 10 days of incubation in 2002, the native non-saline treatment showed the highest values of NO_3^--N that was statistically different from the other treatments (LSD 0.05). In 2003, the native non-saline soil also had the highest NO_3^--N content, which was statistically different from the other treatments. The native saline soil plus FC had the lowest NO_3^--N content, which differed statistically from the other treatments. Significant differences at early stages of incubation can also be due to differences in NO_3^--N at the start of the incubation period. At 50 days of incubation in 2002, the native non-saline treatment also had the highest NO_3^--N content, which did not statistically differ from the native saline soil and the native non-saline soil plus FC treatment, but they differed statistically from the native saline soil plus FC treatment (LSD 0.05). In 2003, the native non-saline soil had the highest NO_3^--N content, which was statistically different from the other treatments, followed by the native non-saline soil, which was also statistically different from the other treatments. The native saline soil plus FC treatment had the lowest NO_3^--N content, statistically different from the other treatments. The contribution of FC to the total NO_3^--N content at 10 and 50 days of incubation was rather negative. At 90 days, the native non-saline soil added with FC had the highest NO_3^--N content, which differed statistically from the rest of the treatments (LSD 0.05), followed by the native non-saline soil, which was statistically the same as the native saline soil plus FC and the saline soil treatments. In 2003, there was a statistical difference between the native non-saline and native saline soil. The contribution of FC to the total NO_3^--N content at 90 days of incubation was positive.

A summary of net changes of mineral N over a period of 90 days of incubation is given in Table 7.4. In 2002, the native non-saline soil plus FC provided the highest

NO_3^--N amount, followed by the native non-saline soil, the native saline soil plus FC and the native saline soil. There was not much difference between the native non-saline soil and the native saline soil plus FC. In 2003, the native non-saline soil plus FC provided the highest NO_3^--N amount, followed by the native saline soil plus FC, the native non-saline soil and the native saline soil. The net changes of NH_4^+-N were negative in all treatments and both years ranging from -30 mg N kg^{-1} to -40 mg N kg^{-1}. The net changes of the total mineral N were negative in all treatments, except with the native non-saline soil plus FC, which showed an increase of 0.6 mg N kg^{-1} and 5.0 mg N kg^{-1}, in 2002 and 2003 respectively. The contribution of FC to the total mineral N in the non-saline soil after 90 days was 50% and 98%, in 2002 and 2003 respectively (Table 7.5). In the saline soil, the contribution of FC to the total mineral N at 90 days was 43% and 18%, in 2002 and 2003 respectively.

Table 7.3 Mean gross NO_3^--N (mg kg^{-1}) values at 10, 50 and 90 days of incubation in 2002 and 2003

	2002			2003		
Treatment	10 days	50 days	90 days	10 days	50 days	90 days
Native non-saline	17.2a	53.9a	35.2b	20.9a	58.4a	35.6b
Native saline soil	10.4b	39.7a	26.7b	12.5b	26.7c	23.4c
Native non-saline soil + filter cake	9.9b	40.5a	56.1a	8.6c	40.7b	52.9a
Native saline soil + filter cake	10.1b	15.6b	30.6b	7.2d	10.8d	33.2bc
CV (%)	26.8	16.6	18.8	24.9	8.7	10.0
LSD0.05	5.1	19.8	18.6	3.5	9.5	11.6

Means followed by the same letter per column are statistically not different ($p<0.05$).

Table 7.4 Net changes of mineral N (mg N kg^{-1}) over a period of 90 days (difference with data at 0 days)

Treatment	NO_3^--N		NH_4^+-N		Total mineral N	
	2002	2003	2002	2003	2002	2003
Native non-saline soil	17.1	18.9	-30.2	-40.4	-12.9	-21.5
Native saline soil	10.5	16.4	-37.0	-36.6	-26.5	-20.2
Native non-saline soil + FC	40.5	35.2	-39.9	-30.6	0.6	5.0
Native saline soil + FC	15.9	20.6	-30.8	-35.8	-14.9	-15.2

Table 7.5 Effect of FC on the formation of mineral N (mg N kg $^{-1}$) at 90 days in the non-saline and saline soil

Treatments	Mineral N		% of added N*	
	2002	2003	2002	2003
Native non-saline soil	13.5	26.5	50	98
Native saline soil	11.6	5.0	43	18

*added N with FC=27.1 mg kg $^{-1}$

7.4 Discussion

Mineralization depends on a number of factors. According to Brady and Weil (1999), those factors include soil moisture, pH level, temperature, microbial biomass, C/N ratio of the incorporated organic material and the amount of other nutrients. There is a very close relationship between N mineralization and the C/N-ratio of applied organic material as reported by Buamsha et al. (1998), Neale et al. (1997) and many others. A narrow C/N ratio of less than 15 enhances mineralization (Barakah et al., 1995). Compton and Boone (2000) reported a substantial net mineralization in soils with a C/N ratio between 16 and 18. Under normal soil conditions, in a moist and biologically non-amended active soil, there will be a net production of NO_3^--N and a net decrease of the NH_4^+-N pool (Nelida et al., 1993). After drying and rewetting, the nitrification process shows in most cases a characteristic sigmoidal curve showing a lag period of 3 to 10 days (Fleisher and Hagin, 1981). It is thought that this is the period when the population of nitrifying bacteria is growing and also adapting to the new environmental conditions to which they have been introduced after drying (Singer and Munns, 1999). Both soils, the native non-saline soil and the native saline

soil exhibited a lag phase, though the lag period for the saline soil was much longer than the one observed for the non-saline soil. The possible explanation of the length of the lag phase in the saline soil can come from the effect of Na^+ and Cl^-. The presence of these ions leads to variable effects on C and N mineralization in both soils. Depending on the amount present in the soil, nitrification can be retarded, suppressed or completely inhibited by these ions. It appears that both the population and the microbial metabolic activity of autotrophic organisms responsible for nitrification are affected by these ions, either by one of them or by a combination of them (Rubinigg et al., 2003). Jarquin et al. (2003) reported that under saline conditions NH_4^+-N is temporarily immobilized. In both soils, non-saline and saline, the lag phase in the nitrification process was followed by an exponential phase, which was more rapid in the non-saline soil than in the saline soil. However, it started to decline again after reaching a maximum value. These observations are similar to the ones from Fleisher and Hagin (1981).

The evolution of total mineral N, with the lag phase, the exponential phase and the declining phase, was observed in the native non-saline soil only. The maximum net (with zero time as reference) total amount of mineral N produced in the non-saline soil, under the experimental conditions, was 41 kg N ha^{-1} and 30 kg N ha^{-1} for both seasons, in 2002 and 2003. The period of net mineralization was 40 days (Figure 7.1). The net changes of total mineral over a period of 90 days were negative in both years. It appears that the native non-saline soil hardly showed any mineralization. These results are common in tropical soils when almost all organic N has been mineralized. A general characteristic of tropical soils is that the organic matter content of native soils is very low. The turnover of this remaining organic matter (resistant) into mineral N through mineralization is consequently also low (Smithson and Giller,

2002; Snapp, 1998). In sugarcane production, however, an additional reason for low organic matter could be the preharvest burning of sugarcane fields. As a result, plant residues and cane trashes are destroyed which otherwise might contribute to the building up of soil organic matter and supply of N for the subsequent crop (Albrecht et al., 1995). Burning of fields also produces other several undesired effects on the environment. Soils exposed by burning are very susceptible to both wind and water erosion. Nutrients are lost when the soils are eroded (Albrecht et al., 1995). Repeated burning can alter both physical and chemical properties of the soil. The loss of organic matter, coupled with excessive tillage as in case of sugarcane fields, increases soil compaction and reduces water infiltration and retention (Pimentel et al., 1995). Many mineral nutrients (e.g. calcium, magnesium, potassium, zinc, copper and manganese) remain on the soil in the ash following burning. However, the major elements required for plant growth i.e. N and S, are appreciably vaporized during burning (Ball, et al., 1993; Boerner, 1982). After carbon, N is the element most affected by fire; a temperature of only 200^0C can induce volatilization (Raison, 1979), and therefore the total mineral N content decreases after a fire. In the long-term it might increase the fertilizer requirement of a crop. Information about burning of sugarcane, as it affects organic matter, is scarce (Albrecht et al., 1995). Repeated burning can cause gradual loss of organic matter and a decreased microbial activity (Rasmussen et al., 1980). The possible reason for the reduced microbial activity is the loss of soil microorganisms during the fire. Soil microorganisms are re-established from the underlying soil, wet and dry deposition, or from small islands of unburned residue. Microbial activity in the soil can be lost or reduced by removal of the food supply by fire (Ojima et al., 1994). Fire also reduces the most labile organic fractions, leaving only the resistant ones. These observations could be the possible reason for

the very low potential of N mineralization in the native non-saline soil under study. Furthermore, it is very unlikely that the sugarcane plant can benefit from the N mineralized. In the Tanzanian estates, the common practice is to apply N at three months after planting. At that time, the root system is in an advanced stage of development and is able to absorb N quite efficiently. If the mineralization of the native soil is very low, a sugarcane crop is unlikely to importantly benefit from mineralization at its initial stage of growth. At the beginning, very little N will be taken up by the plant as the root system is not at an advanced stage of development and most of the N remaining will either be leached or undergo other N transformations which could lead to losses. This observation emphasizes the need for the use of either chemical fertilizers or soil amendments like FC to improve the N status in the native non-saline soil.

In the saline soil, the curve for the total mineral N declined gradually throughout the entire period of experimentation. The net changes (zero time as reference) of total mineral N over a period of 90 days were negative in both years. This can be explained by the presence of Na^+ and Cl^-, retarding the mineralization process. Of course, the length of incubation is another factor of influence. First, the nitrification process was inhibited due to the presence of these ions and secondly the N loss by volatilization of ammonia can be substantial compared to the rate of nitrification (Byrnes and Freney, 1995). However, another possible explanation could also be the immobilization of both NO_3^--N and NH_4^+-N (Jarquin et al., 2003). A decrease of ammonification and nitrification led to the decrease of total mineral N produced. The potential of this soil to mineralize was very poor compared to the non-saline soil. Therefore, it requires chemical fertilizers to supplement mineral N for a growing plant and also addition of organic matter to improve its mineralization potential.

In the treatments to which FC was added, the lag phase also showed a decline in NO_3^--N and total mineral N during the first 10 to 20 days for the non-saline soil and up to 40 days for the saline soil. These results are similar to the ones of Abbasi et al. (2001). Addition of fresh organic matter or inorganic N to a soil may either stimulate (positive priming effect) or retard (negative priming effect) the decomposition of organic matter already present in the soil (Cookson et al., 2002), depending on the C/N as reported by many authors (Buamsha et al., 1998; Compton and Boone, 2000; and Barakah et al., 1995). This is also known as 'priming action' of the soil amendments. A negative priming effect occurs if the decomposing organic material has a small amount of N in relation to the C present. A positive priming effect occurs if the added material contains much N in proportion to the C present; hence there will normally be no decrease in the level of mineral N in the soil (Compton and Boone, 2000). It appears that the decline of NO_3^--N during the first 10 to 20 days in the treatments containing FC was due to immobilization of soil N already available (Jarquin et al., 2003). The FC used had a C/N ratio of 21 (Table 7.2), which supports the possibility of net mineralization rather than immobilization at the initial stage of incubation (Singer and Munns, 1999). Therefore, a possible reason of the immobilization observed could be the rewetting of the soil resulting in an exponential re-growth and consumption of the mineral N. However, the decline of NO_3^--N was much longer in the saline soil than in the non-saline soil. This is due to the retardation of the nitrification process caused by the presence of Na^+ and Cl^- ions as reported by Hynes and Knowles (1993) and Ward (2000). Probably it could also be due to N losses through volatilization (Byrnes and Freney, 1995). The occurrence of denitrification is unlikely because the 250 g were loosely packed with a relatively large surface area and sufficiently aerated.

However, in the soils treated with FC, total mineral N and NO_3^--N evolution curves started to rise slowly during the last days of the incubation period, although the rise was slightly more pronounced in the non-saline soil plus FC, and curves were still on the rising side at 90 days when the experiment was terminated. The native non-saline soil added with FC was the only treatment in which the net changes of total mineral over a period of 90 days were positive in both years. Of the native saline soil added with FC, the net changes of the total mineral were higher than those of the native saline soil in both years. And therefore, the addition of FC improved the N amount in both soils. In the native non-saline soil, after 90 days, the FC was able to provide 50% to 98% of the added FC-N. In the native saline soil it was able to provide 18% to 43% of the added FC-N. The mineralization of the FC was faster with the native non-saline soil as compared with the native saline soil. Therefore, the use of FC in the native non-saline soil should be done with some care. Heavy application of FC in soils might result in more uptake of N by the plant and consequently reduce sucrose content. On the saline soil, the release of mineral N from FC is slow and it will probably continue for a longer period of time. These results are similar to those reported by Lingle et al. (2000) and Yaduvanishi et al. (1989). The inhibition of the nitrification process in the saline soil is due to the presence of Na^+ and Cl^- as reported in the previous paragraphs. But with application of FC over several years, Ca^{++} from the FC will displace Na^+ and the nitrification rate can improve.

The pattern of ammonification has been generally repetitive in all treatments tested. Also there is a fairly general and direct relationship with the nitrification process. Even though ammonification was generally constant during the initial stage (0 to 20 days) of incubation; it was declining, while the nitrification process was rising. The net changes of NH_4^+-N over a period of 90 days were negative in both years. These

findings are similar to those reported by Beauchamp et al. (1986). However, results similar to this depend on the technique used to handle soil samples collected prior to the start of the incubation experiment. It happens when soils collected for the study are dried and re-wetted to initiate the experiment.

On the other side, results of this experiment are somehow difficult to explain with regard to the levels of NH_4^+-N and NO_3^--N prior to the start of the experiment. They appear to be on the high side. Probably mineralization process continued in the samples collected when they were dried in the laboratory. It could also be due to the pre harvest burning of the sugarcane field one week before sampling. This observation is in agreement with Yang et al. (2003) who reported an increase in mineralization of nutrients associated with increased microbe number, enzyme activities and elevated soil respiration five days after burning. In addition, Wan et al. (2001) also observed similar effects of burning in the terrestrial ecosystem, where there was an increase of NH_4^+-N and NO_3^--N of approximately two folds and 24% respectively. However, in both studies it was established that this increase was temporarily.

7.5 Conclusion

According to the results shown by the total mineral N curves, it appears that only the native non-saline soil had a small potential to mineralize soil N up to about 40 days. Net mineralization started at 20 days, the maximum point was reached at 40 days and it started to decline at 50 days of incubation. With regard to the total growing period of the sugarcane, the mineralization potential of the native non-saline soil was short-lived and unable to support sugarcane growth for a relatively longer period. Hence, chemical fertilizers must be applied to supplement mineral N as well as application of organic matter to improve the mineralization potential of the soil. With regard to the native saline soil, the curves for the total mineral N were declining gradually up to 40 to 50 days of incubation and they started to rise slowly and gradually afterwards. Its mineralization is very slow. This can be due to the presence of Na^+ and Cl^- in high concentration. The nitrification process was retarded and also the mineral N was probably lost as a result of volatilization of ammonia. However, signs of net mineralization started to appear by the time the experiment was terminated. It is recommended to apply chemical fertilizers and organic matter to supplement mineral N and to increase the general fertility status.

On the other hand, when FC was added to both the native non-saline and native saline soil, the nitrification process was slow. A decline in total mineral N was observed in both soils, although it was more pronounced in the non-saline soil. Nitrification and total mineral N curves were still rising when the experiment was terminated. The net changes of the total mineral N over a period of 90 days were higher when FC was added as compared to the native non-saline and the saline soil treatments without FC.

It shows how FC has the potential to release mineral N even in the saline soil. It also shows how FC can reduce the effect of salt on nitrification. It appears that addition of FC as an amendment was beneficial and could improve the supply of the mineral N in both soil types. In view of the rising energy cost and limited input availability, the use of FC, a factory byproduct, as an agent of the integrated nutrient management package has proven to be potentially useful for sustained sugarcane production. Consequently, the use of FC as a soil amendment is recommended in both soil types, although care must be taken to ensure that the enhanced mineralization potential does not affect the cane quality by suppressed sucrose content.

CHAPTER 8

A MATHEMATICAL MODEL FOR ESTIMATING NITROGEN FERTILIZER REQUIREMENT OF A SUGARCANE CROP

A MATHEMATICAL MODEL FOR ESTIMATING NITROGEN FERTILIZER REQUIREMENT OF A SUGARCANE CROP

Abstract

Results of fertilizer N studies conducted at a sugarcane estate Tanganyika Planting Company (TPC) were integrated into a model in order to predict the 'optimum and economical' level of fertilizer N application in sugarcane. The model involves the major components of nutrition in crops i.e. the confrontation between demand and efficiency of uptake. To be able to calculate the demand of the crop, the crop response to various rates of fertilizer application was used, based on mathematical functions using a quadratic equation. Nitrogen loss and fertilizer efficiencies were computed from the results of field experiments conducted during the 2000/01 and 2001/02 growing seasons. Data on crop response to N levels conducted at the same site, but in previous years, together with those conducted during the 2000/01 and 2001/02 seasons were used to calculate the average value of the optimum N required. The estimated level of mineral N was obtained by adding the optimum N required with the % loss expected. This was approximately 85 kg N ha^{-1}. Thereafter a field experiment was conducted during the 2002/03 growing season, on the same site, to verify the predicted level of fertilizer N required for optimal and economical yield. The experiment was laid out in a randomized complete block design (RCBD) with six treatments of N (0, 30, 60, 70, 85, 120 kg N ha^{-1}). Treatment 60 kg N ha^{-1} is the current recommended rate while treatment 85 kg ha^{-1} is the rate estimated by the model. There was a significant difference in tons of cane ha^{-1} (TCH) produced.

Treatment 70 kg N ha^{-1} produced the highest TCH, but it was statistically not different from the 85 kg N ha^{-1} (estimated level). However, there was a significant difference (LSD 0.05) with the 60 kg N ha^{-1} treatment (currently recommended rate). Also, treatment 70 kg N ha^{-1} had the highest net returns followed by the estimated level. It appears that the current recommended rate underestimates the N requirement of the variety tested in that particular site.

KEY WORDS: Nitrogen, model, sugarcane, N efficiency

8.1 Introduction

Mineral N is the most limiting nutrient for sugarcane production in sugarcane states of Tanzania. A number of experiments are carried out to determine the optimum level of fertilizer N using the traditional method or the indirect method, which measures the efficiency of N uptake indirectly by measuring yield response. The results have always either underestimated or overestimated the optimum level of the required N.

Due to the upward trend of fertilizer prices caused by the energy crisis, efforts to enhance the effectiveness of fertilizer N and to reduce N loss in the fertilization process have become vital to the estate and the world in general (Van Cleemput et al., 1981). Scientists are studying fertilizer use efficiency (Greenwood, 1981) with the isotopic dilution method (direct method), which is more accurate than the traditional method. Furthermore the approach to fertilizer recommendation is now based on addition of scientific input related to crop demand, losses, economic yield, soil moisture and ability of the soil to

supply mineral N during the growing period (Rao & Dao, 1996). As it has been observed, losses of mineral N are high if the fertilizer applied does not match the demand of the crop. Furthermore, crop mineral N requirement will vary depending on N supplied the soil. Likewise, in a situation where the rate of mineralization is high, application of fertilizer N might cause a luxurious uptake of mineral N, which may reduce both % sucrose and sucrose production in crops like sugar beet (Werker, 1998) and sugarcane (Ingawale et al., 1992). On the other hand, the quantity of nutrients absorbed will depend not only on root development but also on soil moisture (Abreu et al., 1993). Murugappan et al. (1989) reported that essential parameters needed for determining the amount of fertilizer required for specified yield targets are soil nutrient efficiency, fertilizer nutrient efficiency and crop requirement. That becomes possible if results from field experiments are integrated into models, which allow the input of scientific parameters. That is why during the last few decades there is a shift from an overriding importance of field experiments to a balanced approach including theory development and modeling (Van Noordwijk, 1999). This approach is widely accepted as a useful tool for research purposes in agriculture, such as in sugar industries (Inman-Bamber et al., 2001). The grower also needs such a prediction or model in order to improve planning and management of important matters (Robertson et al., 1999a; Singles & Bezuidenhout, 2002) in crop production and crop forecast (McGlinchey, 1999).

The present paper summarizes the fertilizer N studies conducted at the TPC sugar estate. Results are integrated into a model to predict the 'the optimum and economical' level of fertilizer N in sugarcane. Data on crop response to various N levels were used to derive the optimum amount of fertilizer N needed for maximum financial yield on the basis of

mathematical functions. These calculations are known to be simple, rapid and the calculated optimum of fertilizer N is reliable (Armstrong, 1986). The proposed model also utilizes information on the fate of fertilizer N applied, obtained from experiments conducted using labeled fertilizers. Information on the fate of fertilizer N is necessary not only to determine the complete economic benefits of fertilization N, but also to determine how the fertilizer can be best utilized to reduce or eliminate potential pollution hazards (MacKnown & Sutton, 1997).

8.2 Module formulation

The concept of the model described is a combination of ideas from Myers (1984), Gomez and Gomez (1984), Sahota & Muktar (1984), Neeteson & Wadman (1987), Murugappan et al. (1989), Keating et al. (1999) and Salassi et al. (2002) among others. The proposed model involves the three major components of N nutrition of crops: the demand for N by the particular crop, soil mineral N supply, the efficiency of uptake of fertilizer N by the crop or variety and the losses.

The optimum amount of fertilizer N needed for maximum yield, also described as the 'optimum' of fertilizer N can be obtained from results of field trials in which crop response curves to various rates of fertilizer application are determined on the basis of mathematical functions such the quadratic regression equation (Gomez & Gomez, 1984). The response curve provides the relationship between the amounts of fertilizer applied and crop yield. From this curve the optimum application rate of fertilizer can be derived (Gunst & Mason, 1980).

However, in sugarcane production, the price the farmer obtains for his sugarcane does not only depend on the tons of cane produced but also on the sucrose content which is expressed in the form of the percentage recoverable sugar, also known as rendement (R) (Kaswanu, personal communication). Prices given to farmers are based on cane with a standard R-value of 10 %; the lower the sugar content, the lower the price and vice versa. This means that the relationship between tons of cane produced and price may not be linear (Neeteson and Wadman, 1987). But this is the condition required to calculate the 'optimum and economical' level of fertilizer N. Linearity between cane yield and prices can be introduced by adjusting data on measured cane yield in such a way that they all pertain to cane yield with 10 % R, being the estate's standard value. Therefore measured cane yield is to be converted to adjusted cane yield. Yield adjusted to a sugar content of 10 %, decreases when too much fertilizer N is applied due to the negative relationship between amount of fertilizer N and sugar content (Robertson et al., 1999b).

8.2.1 The tons of cane per hectare (TCH) and tons of sugar per hectare (TSH) prediction models

A successful model application strongly depends on accurate predictions of stalk yield, sucrose yield and sucrose content (Singles and Bezuidenhout, 2002).

The amount of raw sugar in a field is a function of several variables including TCH and TSH.

TCH = NMS * AWS……..……(01)

TSH = R * TCH = R * NMS * AWS……..…(02)

Where,

TSH = Tons of sugar per hectare;

TCH = Tons of cane per hectare;

NMS = Number of millable stalks;

R = Rendement = percentage recovable sugar per tons of cane;

AWS = Average weight per stalk (kg).

NMS cane be assumed to be constant throughout the season, but R and AWS increase as the harvest season progresses; therefore, estimates from these factors for each variety of sugarcane produced must be obtained on a daily basis during the harvest season.

8.2.2 Rendement prediction model

For farmers, to obtain a measurable rendement, the efficiency of the factory itself must be considered i.e. Factory rendement

FR = [{(Tons of Pol in mixed juice * SJM * BHE) / Pol % sugar * 10^{-2}}] / tons of cane crushed……(03)

Where,

FR = Factory Rendement = Factory percentage recoverable sugar;

BHE = Boiling house efficiency;

SJM = Percentage recoverable sucrose;

Pol = Apparent sucrose content of a sugar product.

Thereafter follows the determination of Brix and Pol values of cane samples collected from a farmer, which is done in the laboratory.

Brix - Pol = N.S……...……(04)

Where,

Brix = is the percentage of soluble solutes in cane juice;

N.S = Non sugars.

Corrected N.S= N.S * molasses factor. ……. (05)

Where,

Molasses factor = Final molasses purity / 100 - Final molasses purity. ……(06)

Corrected Pol = Pol - Correction N.S..……(07)

Farmers measurable rendement (FMR) = Corrected Pol * Juice factor. ……(08)

Where,

Juice factor = FR / Corrected Pol of 24 hrs factory juice……....(09)

8.2.3 Yield adjustment model

As it has already been indicated, linearity between yield (tons of cane per hectare -TCH) and price can only be ensured if measured yields are adjusted on the basis of the 10% R, being the estates' standard value. Yield adjustments can be done using a procedure outlined by Neeteson & Wadman (1987).

MTCH = TCH = NMS*AWS from equation (01)

ATCH = MTCH + MTCH (FMR - 10) * (FMR - 10 / 100)……...……(10)

Where,

MTCH = Measured yields in tons of cane per hectare;

ATCH = Adjusted yield in tons of cane per hectare;

FMR = Farmers measurable rendement from equation (08).

8.2.4 Y_{max} model using quadratic regression analysis

This involves a defined set of different levels of N applied and yields (ATCH) as a result of field experiments. The quadratic regression equation (second degree polynomial) to be used has the form of:

$$Y = b_0 + b_1N + b_2N^2 \quad \ldots\ldots(11)$$

Where,

Y = expected yield

N = applied fertilizer in kg ha^{-1}

b_o, b_1 and b_2 = coefficients (calculations are shown below).

The exponential function is modified by addition of a linear term to allow for decreasing yields of N in excess to the level for maximum yield. Linearization is done by the creation of a new variable, according to a technique outlined by Gomez & Gomez (1984).

$Y = b_0 + b_1N + b_2N^2$ from equation (11).

It is linearized in the form of

$$Y = b_0 + b_1Z_1 + b_2Z_2 \quad \ldots\ldots(12)$$

Where the two newly created variables Z_1 and Z_2 are defined as $Z_1 = X$ and $Z_2 = X^2$.

X values are different levels of N applied.

Then, values of each newly created variable for all n units of observation are computed as follows:

$$b_1 = (\sum z_2^2)(\sum z_1 y) - (\sum z_1 z_2)(\sum z_2 y) / (\sum z_1^2)(\sum z_2^2) - (\sum z_1 z_2)^2 \quad \ldots\ldots(13)$$

$b_2 = (\sum z_1^2)(\sum z_2 y) - (\sum z_1 z_2)(\sum z_1 y) / (\sum z_1^2)(\sum z_2^2) - (\sum z_1 z_2)^2$……..…….... (14)

$b_o = Y - b_1 Z_1 - b_2 Z_2$……..…….(15)

8.2.5 Optimum and Economical level of N fertilizer

The optimal and economical rate of fertilizer N is calculated using the formula developed by Sahota & Mukhtar (1984) and also Neeteson and Wadman (1987).

$$N_{opt} = \frac{q\backslash p - b_1}{2b_2} \quad \text{…….. (16)}$$

Where N_{opt} is the optimal economical fertilizer N rate in kilograms, b_1 and b_2 the coefficients (see above), p and q represent the price of one ton of sugarcane and cost of one kilogram of N, respectively.

8.2.6 Efficiency of N uptake

The use of the stable N isotope (^{15}N) in investigations of N transformations in the soil has increased importantly during the past 20 years. This is due to the result of the need for more accurate quantitative measurements of N transformations. This information is useful for attempts to maximise the efficiency of N use in agriculture and preserve the quality of the environment.

From the results of field experiments conducted to study the uptake and loss of mineral N using labelled urea and ammonium sulphate, it has been observed that the sugarcane crop

does not utilize all soil mineral N and fertilizer N. Consequently, the uptake efficiency of fertilizer N and loss processes are also included in this model.

The efficiencies can be calculated using the formula of Hauck and Bremner (1976):

% ^{15}N recovery from fertilizer = Nsample(c - b) *100 /R (a- b)……...….(17)

Where,

Nsample: total nitrogen content of the sample

a: ^{15}N abundance of the applied fertilizer

b: ^{15}N abundance of an untreated sample, (background level)

c: ^{15}N abundance of the treated value

R: rate of applied fertilizer

N loss = 100 - ∑%^{15}N recovery from fertilizer……... (18)

From the results of the experiment conducted during two consecutive years to monitor the fate of N using labelled fertilizer, the %N loss or non accounted for N were 5.9 and 8.7 respectively. The average of the two losses equals to approximately 7.0%, the value used in this model. Fertilizer N required was obtained by adding the optimum N level and the expected % loss.

The fertilizer requirement for optimum yield is:

$$N_{fert} = \left[\frac{q/p - b_1}{2b_2} * \frac{\%N\ loss}{100}\right] + \frac{q/p - b_1}{2b_2} \quad \text{……... (19)}$$

8.2.7 The inputs required by the model are:

Efficiency of uptake = ∑% ^{15}N recovery from fertilizer

N loss

Price of 1 kg of N

Price of one ton of sugarcane

Data on cane yield (TCH) versus N levels

The expected output is:

The fertilizer requirement for optimum yield

8.3 Model testing

The model was tested against four sets (Table 8.1) of data for sugarcane yield. The sugarcane response data from field experiments conducted during the growing seasons 1998/99 to 2001/02 were used. The crop response to various rates of fertilizer application was described on the basis of a mathematical function using the quadratic equation (equation 11). Calculation on yield adjustments, linearity, and optimal level of N were done using the equations described in the previous section. Details of that calculation are shown on the last page of this chapter. Response equations and optimum rates with respect to data on yield versus N application are shown in Table 8.2. Fertilizer efficiency and N loss were computed from the results of the field experiments conducted during the

2000/01 and 2001/02 growing season, when the uptake of N by the variety EA 70-97 with labelled urea and AS a source of N was studied.

The average value of fertilizer N required obtained from the four sets of data tested was 79.1 kg N ha^{-1}. The expected N loss was 7 %. Therefore, the estimated N level from the model is 85 kg N ha^{-1} which is the summation of the value of fertilizer N required and the expected loss. In order to verify this fertilization level, a field experiment was conducted during the 2002/03 growing season on the same field as where the data for the construction of the model were obtained. The objective of this experiment was to verify the level of N fertilizer required for optimum and economical yield as predicted by the model. The experiment was laid out in a randomized block design with six treatments of N (0, 30, 60, 70, 85 and 120 kg N ha^{-1}), and four replications. Application of 60 kg N ha^{-1} is the current recommended rate while 85 kg N ha^{-1} is the rate predicted by the model. The same variety EA 70-97 was used. P and K at 25 kg ha^{-1} each were applied at planting in furrows. Nitrogen (as urea) was top dressed on the 90^{th} day after planting. The crop was harvested at the age of ten months. Data collected included TCH, SC, purity, stalks ha^{-1} and stalk height.

Table 8.1 Four sets of data (N levels versus yield in TCH) used for the construction of the model

1998/99		1999/00		2000/01		2001/02	
Rate	Yield (ATCH)	Rate	Yield (ATCH)	Rate	Yield (ATCH)	Rate	Yield (ATCH)
0 kg N ha^{-1}	67.9	0 kg N ha^{-1}	70.3	0 kg N ha^{-1}	76.3	0 kg N ha^{-1}	77.8
30 kg N ha^{-1}	80.2	30 kg N ha^{-1}	82.5	30 kg N ha^{-1}	88.3	30 kg N ha^{-1}	88.2
60 kg N ha^{-1}	117.2	60 kg N ha^{-1}	120.6	60 kg N ha^{-1}	123.2	60 kg N ha^{-1}	130.2
90 kg N ha^{-1}	115.6	90 kg N ha^{-1}	119.3	90 kg N ha^{-1}	116.0	90 kg N ha^{-1}	119.1
120 kg N ha^{-1}	95.9	120 kg N ha^{-1}	100.3	15 kg N ha^{-1} + FC*	118.0	15 kg N ha^{-1} + FC*	118.9

ATCH = Adjusted Tons of cane ha^{-1}
FC = Filter Cake
* = Equivalent to 65 kg N ha^{-1}

Table 8.2 Response equations and optimum rates in respect to data on yield versus N application

Season	Response equation	Optimum rate kg N ha^{-1}
1998/99	$Y = 62.4 + 1.29x - 0.0082x^2$	74.1
1999/00	$Y = 64.7 + 1.3x - 0.0081x^2$	75.6
2000/01	$Y = 72.8 + 1.1x - 0.0058x^2$	88.4
2001/02	$Y = 73.6 + 1.0x - 0.0059x^2$	78.4
		79.1*

*Mean of optimum rate of mineral N obtained from the four response curves

8.4 Results

The effect of different levels of N on selected agronomic data is summarized in Table 8.3.

There was a significant difference in TCH ($p<0.05$) among the different treatments. Treatment 0 kg N ha^{-1} had the lowest TCH, not statistically different from the 30 kg N ha^{-1} treatment ($LSD_{0.05}$). Treatment 70 kg N ha^{-1} produced the highest TCH, statistically the same as treatment 85 kg N ha^{-1} (estimated level), but statistically different from treatment 60 kg N ha^{-1} (currently recommended rate) and treatment 120 kg N ha^{-1}. Treatment 70 kg N ha^{-1} also produced the highest TSH, which was statistically the same as the 85 kg ha^{-1} and the 120 kg N ha^{-1} treatments, but statistically different from the currently the recommended rate (60 kg N ha^{-1}). Furthermore, results on the cost benefit analysis show that the highest net returns were obtained from treatment 70 kg N ha^{-1}, followed by the level estimated from the model 85 kg N ha^{-1} (Table 8.4).

Table 8.3 Results of the fertilizer trial conducted during the 2002/03 growing season to verify N level estimated from the model

Treatment	ATCH	%SC*	TSH	%Purity	Stalks ha^{-1}	Stalk length (cm)
0 kg N ha^{-1}	65.0d	7.4b	10.9b	84.0	146 554	263
30 kg N ha^{-1}	76.0d	9.5a	11.1b	85.6	167 244	274
60 kg N ha^{-1}	119.3b	9.8a	10.4b	86.2	174 715	269
70 kg N ha^{-1}	140.8a	10.8a	14.7a	85.6	178 451	293
85 kg N ha^{-1}	135.9a	10.5a	13.9a	85.6	183 048	292
120 kg N ha^{-1}	100.0c	9.5a	13.5a	86.4	174 715	275
CV (%)	7.3	13.5	9.3			
$LSD_{0.05}$	11.7	1.9	1.7			

Means followed by the same latter per column are statistically not different
* % sucrose content

Table 8.4 Cost benefit analysis

Treatment	ATCH	Gross returns Tsh	Costs Tsh.	Net return Tsh.
0 kg N ha^{-1}	65.0	65 000	-	65 000
30 kg N ha^{-1}	76.0	76 000	25 000	51 000
60 kg N ha^{-1}	119.3	1 193 000	47 500	1 146 000
70 kg N ha^{-1}	140.8	1 408 000	55 000	1 353 000
85 kg N ha^{-1}	135.9	1 359 000	66 250	1 292 750
120 kg N ha^{-1}	100.0	1 000 000	92 500	907 500

ATCH = Adjusted tons of cane ha^{-1}
Tsh. = Tanzanian shilling currency
1000 Tsh. = 1 US $

8.5 Discussion

The direct method, indirect method as well as the prediction model can all estimate the fertilizer N required for optimum yield. The three methods may give estimates, which can be quite different from one another. In the indirect method, which is used by all sugarcane estates in Tanzania, the efficiency of N utilization is calculated indirectly using the formula of Harmsen and Moraghan (1988).

$ARF = (NP - Np_o) / NF$

Where,

ARF= apparent recovery fraction;

Np_o= the amount of N taken up by the unfertilized crop (kg ha^{-1});

NP= the amount of N taken up by the fertilized crop (kg ha^{-1});

NF= Fertilizer N applied (kg ha^{-1}).

Unfortunately, this method often gives misleading results (Broadbent, 1981). Users of this method erroneously assume that immobilization-mineralization and other N transformations during the course of the experiment are the same for both treated and untreated plots. That assumption may not be true. Addition of fertilizer N to the soil can increase the rate of mineralization and the concentration of available N in the soil. Likewise, immobilization of both added N and mineralized N increases, and as a result the concentration of available N decreases (Hauck & Bremner, 1976). Furthermore, there is an increase in plant growth and root development in fertilized plots, which increases the volume of soil to be explored for N. This technique, however, cannot differentiate either the efficient N uptake of a crop from the soil and fertilizer applied or measure the losses, which are likely to occur through leaching, denitrification and ammonia volatilization (Hatch et al., 1990). As a result, it gives higher N recoveries than expected (Jansson and Persson, 1982). Eventually, recommended rates have been either overestimated or underestimated (Broadbent, 1981) with massive variation within varieties, seasons and sites. Attempts to optimize fertilizer N requirement of crops are hampered by large differences between site and years in mineralizable native organic N and nature of the plant response to applied fertilizer N, even on the same site. The direct method is said to produce estimates, which are more accurate than the indirect method. It can measure the losses and the uptake efficiency of both soil N and fertilizer N. The use of models is actually a combination of several scientific inputs including the data from the direct and indirect methods, and is said to be more accurate than the other two methods. The general recommendation of N application at the estate is currently at 60 kg

N ha^{-1}. According to the results obtained from this experiment, application of 85 kg N ha^{-1} (estimated from the model) was significantly higher in terms of TCH produced than the current recommended rate. It appears that the TPC estate has been underestimating the amount of fertilizer N required for optimal economical yield. The reason behind this could be the methodology used to estimate the fertilizer rate. The estate has been using the indirect method, which is said to give results, which are either underestimating or overestimating since this method does not take into account N transformation, occurring in the soil. According to the results of the soil analysis of the experimental site, the pH was above 7.0. At that level, losses of N through ammonia volatilization are likely to be very high. Under such condition the actual uptake by the variety, and losses are very important inputs to be considered during the estimation of N level required. Consequently, the estimated level from the model performed better than the current recommended rate. This model utilizes the information on fertilizer N uptake efficiency and losses during the season. However, in this study, the loss used was determined from a study conducted at a rate of 60 kg N ha^{-1}. Therefore, the estimated level might have slightly overestimated the N level. As a result the 70 kg N ha^{-1} performed better. It is suggested, in future to study in detail the losses at different N levels. Meanwhile, the use of this model is limited to an area where data on uptake of fertilizer N and N loss have been obtained using labelled N fertilizers. Discrepancies between the model estimation and the observed response are likely to occur if the estimated N level is used with another variety having a different capacity to utilize mineral N or if it is used on another site with other physico-chemical characteristics.

8.6 Conclusion

Though the application of 70 kg N ha^{-1} produced the highest TCH, and the difference in performance was statistically the same with the estimated level of 85 kg N ha^{-1}, it differed statistically from the current recommended rate (60 kg N ha^{-1}). The highest net returns were also observed with 70 kg N ha^{-1} followed by the estimated level. It appears that the current recommended rate of 60 kg ha^{-1} underestimates the actual requirement of the variety under study on that particular site. It emphasizes the need for a review of the approach used to determine the fertilizer N level to include other scientific inputs such as N uptake efficiency (using labelled fertilizer or direct techniques) and N losses.

CALCULATIONS: Linearization of yield in TCH to N levels and calculations of the coefficients b0, b1, b2, soil N, and the 'optimal and economical' level of N. Results of 1998/99 growing season

Pair	ATCH	y	y^2	X=Z1	z_1	z_1^2	X2=Z2	z_2	z_2^2	z_1y	z_2y	z_1z_2
1	67.9	27.5	758.5	0	60	3600	0	5400	29160000	1652.4	148716	324000
2	80.2	15.2	232.3	30	30	900	900	4500	20250000	457.2	68580	135000
3	117.2	-22.2	491.1	60	0	0	3600	1800	3240000	0	-39888	0
4	115.6	-20.2	406.4	90	-30	900	8100	-2700	7290000	604.8	54432	81000
5	95.9	-0.5	0.2	120	-60	3600	14400	-9000	81000000	27.6	4140	540000
Total	477.2		1888.4	300		9000	27000		140940000	2742	235980	1080000
Mean	Y=95.4			60		1800	5400		28188000			

a) b_1, b_2 and b_0 are computed as

$b_1 = (\sum z_2^2)(\sum z_1 y) - (\sum z_1 z_2)(\sum z_2 y) / (\sum z_1^2)(\sum z_2^2) - (\sum z_1 z_2)^2$

$b_2 = (\sum z_1^2)(\sum z_2 y) - (\sum z_1 z_2)(\sum z_1 y) / (\sum z_1^2)(\sum z_2^2) - (\sum z_1 z_2)^2$

$b_o = Y - b_1 Z_1 - b_2 Z_2$

Where,

$\sum y^2 = 1888.4$

$\sum z_2^2 = 140940000$

$\sum z_1 y = 2742$

$\sum z_1 z_2 = 1080000$

$\sum z_2 y = 235980$

$\sum z_1^2 = 9000$

Y = 95.4

Z_1 = 60

Z_2 = 5400

n = 5

k = 2

RESULTS: b_0 = 62.4, b_1 = 1.29, b_2 = -0.0082 and Optimum rate of N 74.1 kg N ha^{-1}

b) Optimum level of N (N_{optm})

$N_{0pt} = q/p\text{-}b_1/2b_2$

b_1 = 1.29

b_2 = -0.0082

q = 750 Tshs.

p = 10 000 Tsh.

N_{opt} = [750Tsh./10000Tsh. – 1.29 / 2 (-0.0082) = 74.1 kg N ha^{-1}

The estimated level used for testing the model was taken as a mean of four sets of data from the previous experiment, which was equal to **79.1 kg N ha^{-1}.**

c) N loss taken from the previous experiment = **7.0%**

d) Estimated level from the model = 79.1 * 7% + 79.1 = **85 kg N ha^{-1}**

CHAPTER 9

GENERAL CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

ALGEMENE CONCLUSIES EN AANBEVELINGEN VOOR VERDER ONDERZOEK

GENERAL CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

1. Justification of the study

Sugar production in Tanzania does not meet the domestic demand. This is due to **low production per unit area of the crop**, unfavourable investment/production environment and inadequate utilization of appropriate agronomical technologies especially those stipulated in **chapter 1.4.3** of this thesis. As a result, the unit cost of producing sugar is relatively high, causing protection of the sugar industry against imported sugar originating from the more efficient low cost sugar producing countries and subsidized sugar from the world market. However, protection cannot be sustained in the mid- or long-term especially in the advent of regional and global trade liberalization. Therefore, survival of the sugar industry in Tanzania will depend on making the industry more competitive. This can be achieved by increasing the production capacities in order to lower the production cost and simultaneously by increasing production efficiencies and thereby optimizing the use of available scarce resources such as irrigation water and fertilizers. Among the strategies advocated for improvement of sugarcane yield there are the use of better sugarcane varieties, control of pests and diseases, improvement of sugarcane field fertility in general and in particular the efficient use of N fertilizers. Mineral N is the most limiting nutrient in all estates producing sugar in Tanzania.

2. Methodology used and survey of experiments

The first experiment involved the use of urea and ammonium sulphate labelled with 10 atom % ^{15}N excess in order to monitor the fate of applied N on two contrasting soil types, a saline and a non-saline soil. Two plots of equal size and adjacent to each other were marked on each site. Means of ^{15}N treated plots were compared with those treated with ordinary fertilizer using the t-test and their variances using the two-tailed F test.

The second experiment also involved the use of urea labelled with 10 atom % ^{15}N excess to determine the fertilizer use efficiency by the two standard varieties, EA 70-98 and B 52 313. This was conducted on the non-saline soil. Two plots of equal size were marked adjacent to each other. Means of parameters recorded were compared statistically using the t-test analysis.

In the third experiment where different levels of urea and urea plus FC were tested, a randomized complete block design (RCBD) was used. Means of different parameters tested were then subjected to a statistical analysis using the Mstat C programme, version 2.00. Least significant difference (LSD) at 0.05 was further used to parameters of which mean values of treatments tested appeared to differ statistically ($p<0.05$).

Data collected for the fourth experiment were derived from the third experiment, which was organized in a RCBD. Means of data on chlorophyll content, stomatal conductance and net photosynthesis were subjected to a statistical analysis using the

Mstat C programme, version 2.00. LSD at 0.05 was further used to parameters of which mean values of treatments tested appeared to differ statistically ($p<0.05$). Regression analysis was also done on the means for the chlorophyll content and net photosynthesis.

In the fifth experiment four incubation treatments were set up in the laboratory at 25± 1^0C and 60% water holding capacity for 90 days. The experiment was arranged in a RCBD. Destructive sampling was done at 10 days interval, for the determination of NO_3^--N and NH_4^+-N. Means of data collected were subjected to statistical analysis using the Mstat C programme, version 2.00. LSD at 0.05 was further used to parameters of which mean values of treatments tested appeared to differ statistically ($p<0.05$). Values of NO_3^--N and NH_4^+-N were plotted against time (days). The mineralization potential (total mineral N) was calculated.

A conceptual model of N fertilization prediction was developed from different ideas of various scientists. Part of the results described in the different chapters was integrated into this model, which was designed to predict the level of fertilizer N required on the basis of mathematical functions. The predicted level was tested in the field together with other levels. It was laid out in a RCBD using the same field where data for the module formulation were obtained. Means of data obtained were then subjected to a statistical analysis using the Mstat C programme, version 2.00. LSD at 0.05 was further used to the parameters of which mean values of treatments tested appeared to differ statistically ($p<0.05$).

The results obtained are summarized in the succeeding paragraphs, including suggestions for future research.

Summarizing, the main research activities in this thesis were:

- to determine the fate of N fertilizer applied as urea or ammonium sulphate, on a saline and non-saline soil i.e. uptake, loss, leaching, and balance;
- to determine the fertilizer N utilization between two commercial sugarcane varieties;
- to determine the distribution of mineral N within the sugarcane plant, its effect on growth, yield and quality;
- to determine the influence of mineral N on chlorophyll content, stomatal conductance and photosynthesis;
- to determine the potential of the native saline and non-saline soil in supplying mineral N;
- to determine the potentiality of filter cake (FC), a factory byproduct or waste, in enhancing soil mineralization;
- to determine the potentiality of FC as a soil amendment on a saline soil, and
- to determine a model in estimating fertilizer N requirement.

3. Uptake and loss of mineral N applied to sugarcane

A field experiment was conducted during the 2000/01 and 2001/02 cropping seasons to investigate the uptake, loss, leaching and balance of the mineral N applied as urea and ammonium sulphate on a saline and non-saline soils. On the non-saline soil, with

urea as N source, total plant recovery ranged from 91% to 94%, 0.14% to 0.19% was recovered from the soil and 5.9% to 8.7% could not be accounted for. Using ammonium sulphate as a N source the total plant recovery ranged from 94% to 96%, 0.16% to 0.2% was recovered from the soil and 4.3% to 5.7% could not be accounted for. On the saline soil, on the other hand, when urea was used as N source, the total plant N recovery ranged from 34% to 37%, 0.09% to 0.11% was recovered from the soil and 62.7% to 65.7% could not be accounted for; yet when ammonium sulphate (AS) was used, the total plant recovery ranged from 76% to 79%, 0.13% to 0.14% was recovered from the soil and 21.2% to 23.7% could not be accounted for. Losses of N using urea as N source from the saline soil were higher compared to those when AS was used. The main loss mechanism of N was probably NH_3 volatilization. With regard to AS, N losses reported from the saline soil could be due to also volatilization of ammonia gas, but probably also to biological denitrification and chemodenitrification. Dry matter production (DM) on the non-saline soil with urea as N source ranged from 65 t ha^{-1} to 70 t ha^{-1}, whereas on the saline soils it ranged from 33 t ha^{-1} to 34 t ha^{-1}. Following AS fertilizer application, DM production on the non-saline soil ranged from 58 t ha^{-1} to 60 t ha^{-1} and on the saline soil it ranged from 53 t ha^{-1} to 55 t ha^{-1}. The differences in performance between urea and AS on the non-saline soil was very small though urea was applied at 60 kg N ha^{-1} and AS at 40 kg ha^{-1}. However, the differences were quite substantial on the saline soil. DM production of the plots treated with urea was almost 50% of that of the plots treated with AS. This implies the possibility of substituting urea with AS on saline soils. Since many soils at the estate have a pH value in excess of 8.5, they are very potential

to N losses, so that the use of AS on both soil types is scientifically recommended in order to increase the percentage of fertilizer N utilization. If urea is still to be used because of its economic benefit, then it has to be buried, or broadcast with immediate irrigation. It is also recommended to formulate fertilizer recommendations specific to soil type and source of N.

Suggestions for further research

As the use of AS might be unpopular because it is more expensive than urea, a study should be conducted to determine the cost/benefit ratio between the two sources of N. Another study should be initiated to determine the suitable depth of burying urea to minimize volatilization of ammonia gas. There is also need for a scientific proof that supplying N fertilizer with irrigation water can effectively minimize N losses. Other potential areas of study include quantification of urease levels in the field, and the use of economically and environmentally friendly urease and nitrifying inhibitors.

4. Dry matter production and fertilizer nitrogen utilization of two commercial sugarcane varieties grown in Tanzania

A field experiment was conducted on a non-saline soil to evaluate the % fertilizer N utilization (% FNU) of the two popular commercial varieties, using the ^{15}N-enriched fertilizer technique. The hypothesis was that the current recommended rate of 60 kg N ha^{-1} does not apply to all varieties. Data collected included dry matter production

(DM), N content and % FNU. Mean values of DM, N content and % FNU were higher with the variety EA 70-97 and significantly different ($p<0.05$) from the variety B 52 313 using the t-test analysis. Therefore the two varieties have different requirements of fertilizer N. Also the % N fertilizer derived from the fertilizer was very small with an average value of 12.5. It is suggested that the varieties under study might also benefit from biological nitrogen fixation. It is recommended that in the future N fertilizer recommendations in sugarcane fields should be adjusted to the specific variety.

Suggestions for further research

Since in sugar plantations many different sugarcane varieties are planted in blocks of 10 to 15 ha, it is necessary to initiate separate fertilizer trials for each variety. There is also a need for scientific proof on the level of importance of biological nitrogen fixation by the sugarcane varieties.

5. The effect of different levels of urea and urea plus filter cake on growth, yield and quality of sugarcane

This field experiment was conducted during the 2000/01 and 2001/02 growing seasons. The objective of this study was to evaluate the effect of different levels of urea and filter cake (FC) on growth, yield and quality of sugarcane grown on a saline and a non-saline soil. Tons of cane ha^{-1} (TCH), sucrose (%) and tons of sugar ha^{-1}

(TSH) increased with increasing N levels up to 60 kg N ha^{-1}, but decreased at 90 kg N ha^{-1}. High levels of N affected the quality of sugarcane resulting into reduced TCH, sucrose (%) and TSH. However, the 60 kg N ha^{-1} and 15 kg N ha^{-1} plus FC gave the best and almost similar results in terms of TCH, sucrose (%) and TSH. Therefore, both rates are recommended for use on non-saline soils. On the saline soil, the treatment of 15 kg N ha^{-1} plus FC gave the best results of all treatments with regard to TCH, sucrose (%) and TSH. The negative effect of salinity was reduced in this treatment. It appears that the application of 15 kg N ha^{-1} plus FC was able to supply mineral N slowly for quite a long time and is therefore recommended for use on saline soils.

Suggestions for further research

Though the use of urea plus filter cake is recommended for use on saline and non-saline soils, care must be taken on non-saline soils. A detailed study should be carried out on the most suitable rate of application of urea plus filter cake, because too much FC tends to enhance more nitrogen mineralization and more uptake by the plant, resulting in the suppression of sucrose content of the cane. Also the use of filter cake in the field is an additional cost to the grower, as it requires transportation of the cake from the factory to the field and labour in loading, unloading and spreading the cake on the field. Consequently, the study must incorporate a cost/benefit analysis. Research on the use of ammonium sulphate as an alternative source of N is also recommended.

6. Effect of different levels of urea and urea plus filter cake on chlorophyll content, stomatal conductance and net photosynthesis of sugarcane

Data from this study were collected from the above described experiment, with the objective of evaluating the effect of different levels of urea and urea plus filter cake on chlorophyll content (chl %), the stomatal conductance (g) and net photosynthesis (A) of sugarcane grown on a non-saline and saline soil. The study was carried out in the 2000/01 and 2001/02 growing seasons. Increased N levels increased the values of the three parameters tested in both years and sites. However, the increase was much higher in the non-saline than in the saline soil. These results suggest that the differences observed could be due to the effect of salt injury and losses of mineral N from the saline soil. The performance of 15 kg N ha^{-1} plus FC was much better on the saline soil than on the non-saline soil. Plots treated with this fertilizer led to higher chl % and higher rates of g and A. These results further suggest that a treatment of 15 kg N ha^{-1} plus FC can be recommended for use on saline soils. However, the use of ammonium sulphate instead of urea in saline soils might be a better alternative.

Suggestions for further research

Research on the level of FC to be used is emphasized in order to avoid quality deterioration of the cane juice. An additional study on the cost/benefit ratio of the FC as a soil amendment on both saline and non-saline soils is recommended.

7. Nitrogen mineralization potential of soils under sugarcane cultivation

A laboratory study was conducted in which soils of varying properties were incubated at room temperature (25± 1^0C) and 60% WHC for 90 days. The objective of the study was to evaluate the mineralization potential of soils collected from sugarcane fields. Treatments tested included: native non-saline soil, native saline soil, native non-saline soil plus FC and native saline soil plus FC. The non-saline soil was the only treatment that was able to mineralize soil N to some extent, but only for 40 days. With regard to the duration of crop growth to reach maturity this period of mineralization is very short, and cannot support the sugarcane crop for a long time. Therefore, it is recommended to supplement native non-saline soil with chemical fertilizer N and also addition of FC to improve the mineralization potential of the native soil. The mineralization potential of the native saline soil was very low. This is due to the presence of Na^+ and Cl^- ions that tend to inhibit microbial activity. In this soil, it is also recommended to apply chemical fertilizers and organic matter to increase the general fertility status. On the other hand, when FC was added, it led to the decline in mineralization on both native soils, non-saline and saline, during the initial days of incubation. The decline was more pronounced in the non-saline soil. However, it rises on later days, and it was still rising when the experiment was terminated. The net changes in total mineral N over a period of 90 days were higher when FC was added as compared to the native non-saline and the saline soil treatments without FC. It shows how FC has the potential to release mineral N even in saline soil. It is,

therefore, recommended to apply FC as a soil amendment on both soil types. Care must be taken to avoid excess of FC that might result in luxurious N uptake and decrease of sucrose content.

Suggestions for further research

Though the use of FC is recommended for use as a soil amendment, it requires a detailed study to establish the appropriate rate of application as suggested by the previous results of the experiments conducted in the field.

8. A mathematical model for estimating the nitrogen fertilizer requirement of a sugarcane crop

A mathematical model was developed to estimate the N fertilizer requirement. A level of 85 kg N ha^{-1} was found as a result of the calculation. A field experiment was conducted to verify the predicted level of N fertilizer required for optimum yield. The experiment was laid out in a randomized complete block design (RCBD), with six treatments of N (0, 30, 60, 70, 85 and 120kg N ha^{-1}). Treatment 60 kg N ha^{-1} was the currently recommended rate while 85 kg N ha^{-1} was the rate estimated from the model. There was a significant difference in tons of cane per hectare (TCH) produced for the treatments tested ($p<0.05$). Treatment 70 kg N ha^{-1} produced the highest TCH, which was statistically the same with the 85 kg N ha^{-1}, the rate estimated from the model (LSD 0.05). However, it differed statistically from the 60 kg N ha^{-1} treatment,

the currently recommended rate. Treatment 70 kg N ha^{-1} also had the highest net return followed by the estimated level. It appears that the N requirement of the variety under study has been underestimated. It is recommended to the sugarcane estate management in Tanzania to review their fertilization policy.

Suggestions for further research

The data for the N uptake used in the construction of the model was obtained from experiment one, in which labelled fertilizer was used at the prevailing recommended rate of 60 kg N ha^{-1}. It is therefore recommended to initiate a study on the uptake of mineral N at different rates of application of N containing fertilizers to check the predicted level of performance against different fertilizer input levels. It is also suggested to initiate research, which could provide data on the ability of the native soil to supply mineral N during the season whilst sugarcane is present and eventually modify the model to estimate the N level.

ALGEMENE BESLUITEN EN AANBEVELINGEN VOOR VERDER ONDERZOEK

1. Verantwoording van de studie

De suikerproductie in Tanzania voldoet niet aan de lokale vraag. Dit is te wijten aan de lage productie per eenheid bebouwde oppervlakte, aan een ongunstig investeringsklimaat en onvoldoende gebruik van geschikte landbouwkundige technologieën, vooral deze aangehaald in hoofdstuk 1.4.3. van deze thesis. Daardoor is de eenheidsprijs van geproduceerde suiker relatief hoog, met als gevolg bescherming van de suikerindustrie tegen geïmporteerde suiker uit lage-loon landen en gesubsidieerde suiker vanuit de wereldmarkt. Deze bescherming is niet houdbaar op middellange en lange termijn, zeker niet in het kader van een regionale en globale liberalisering van de wereldhandel. De suikerindustrie in Tanzania zal dus afhangen van een grotere competitiviteit. Dit kan verwezenlijkt worden door verhoging van de productiecapaciteit om zo de productiekosten te verlagen en terzelfdertijd door verhoging van de productie-efficiëntie met optimalisatie van de schaarse beschikbare grondstoffen zoals irrigatiewater en meststoffen. Strategieën ter verbetering van de suikerrietopbrengst zijn o.a. het gebruik van betere suikerrietvariëteiten, controle van ziekten en plagen, en verbetering van de vruchtbaarheid van suikerrietvelden in het algemeen en het efficiënt gebruik van N meststoffen in het bijzonder. Minerale N is het meest limiterende voedingselement in alle suikerriet-producerende plantages in Tanzania.

2. Gebruikte methodologie en overzicht van de experimenten

In het eerste experiment werd ^{15}N gemerkte (10 atoom% excess) ureum en ammonium- sulfaat gebuikt om de bestemming van toegediende N na te gaan in twee contrasterende bodemtypes, een zout- en niet-zoutbodem. Twee percelen van gelijke grootte en gelegen naast elkaar werden afgebakend bij beide bodemtypes. Gemiddelden van ^{15}N behandelde percelen werden vergeleken met gemiddelden van percelen behandeld met niet-gemerkte N via de t-test en hun variaties met behulp van de 'two-tailed' F test.

In het tweede experiment werd eveneens ureum gebruikt, gemerkt met 10 atoom% ^{15}N, om de meststofefficiëntie te bepalen bij twee standaard variëteiten, EA 70-98 en B 52 313. Dit experiment werd uitgevoerd op de niet-zoutbodem. Twee percelen van gelijke grootte werden afgebakend naast elkaar. Gemiddelden van de gemeten parameters werden statistisch behandeld via de t-test.

In het derde experiment werden verschillende gehalten van ureum en ureum met filterkoek (FC) getest in een 'randomised complete block design RCBD)'. Gemiddelden van verschillende gemeten parameters werden statistisch onderzocht met het Mstat C, versie 2.00, programma. 'Least significant difference (LSD) bij 0.05 werd verder gebruikt voor de parameters waarvan de gemiddelde waarden statistisch verschilden ($p<0.05$).

De gegevens van het vierde experiment waren afkomstig van het derde experiment, georganiseerd in een RCBD. Gemiddelden van het chlorophyllgehalte, stomatale geleidbaarheid en netto photosynthese werden statistisch geanalyseerd met het Mstat C, versie 2.00, programma. LSD bij 0.05 werd verder gebruikt voor de parameters die statistisch verschilden ($p<0.05$). Regressie analyse werd gedaan voor de gemiddelden van het chlorophyll gehalte en de netto photosynthese.

In het vijfde experiment werden vier incubaties uitgevoerd onder laboratorium condities bij 25±1°C en 60% 'water holding capacity' gedurende 90 dagen. Het experiment werd uitgevoerd met een RCBD. Destructieve bemonstering werd gedaan om de 10 dagen voor de bepaling van NO_3^- -N en NH_4^+-N. De gemiddelden werden statistisch geanalyseerd met het Mstat, versie 2.00, programma. LSD bij 0.05 werd verder gebruikt voor de gemiddelden die statistisch verschilden ($p<0.05$). De waarden van NO_3^- -N en NH_4^+-N werden uitgezet in functie van tijd (dagen). De mineralisatie-potentiaal (totale minerale N) werd berekend.

Een conceptueel model om de N bemesting te voorspellen werd ontwikkeld vanuit verschillende ideeën van verscheidene wetenschappers. Gedeelten van de resultaten uit de verschillende hoofdstukken werden in het model geïntegreerd. Het model beoogde de hoeveelheid N-meststof te bepalen aan de hand van mathematische functies. De voorspelde hoeveelheid werd getest in het veld in vergelijking met andere hoeveelheden. Dit experiment werd uitgevoerd in een RCBD op hetzelfde veld. Gemiddelden werden onderworpen aan een statistische analyse met het Mstat, versie 2.00, programma. LSD bij 0.05 werd verder gebruikt voor de parameters die statistisch verschilden ($p<0.05$).

De resultaten worden geresumeerd in de volgende paragrafen, samen met suggesties voor verder onderzoek.

De belangrijkste onderzoeksactiviteiten kunnen als volgt geresumeerd worden:

- bepaling van de bestemming van toegediende ureum of ammoniumsulfaat, bij een zout- en niet-zoutbodem (bv. opname, verlies, uitloging, en balans);
- bepaling van de N-meststofefficiëntie bij twee commerciële suikerriet variëteiten;

- bepaling van de distributie van minerale N in de suikerrietplant, haar effect op groei, opbrengst en kwaliteit;
- bepaling van de invloed van minerale N op het chlorophyllgehalte, stomatale geleidbaarheid en fotosynthese;
- bepaling van de potentialiteit van natuurlijke zout- en niet-zoutbodems om minerale N te leveren;
- bepaling van de potentialiteit van filterkoek (FC), een bij(afval)product van de suikerindustrie, om mineralisatie te stimuleren ;
- bepaling van mogelijkheden van FC als toevoegsel aan zoutbodems, en
- ontwikkeling van een model ter voorspelling van de meststof N behoefte.

3. Opname en verlies van toegediende minerale N aan suikerriet

Een veldexperiment werd uitgevoerd in 2000/01 en 2001/02 met de bedoeling de opname, verlies, uitloging en balans van minerale N toegediend als ureum en ammoniumsulfaat (AS) na te gaan in een zout- en niet-zoutbodem. In de niet-zoutbodem met ureum als N bron, varieerde de totale recuperatie in de plant tussen de 91% en 94%, 014% tot 0.19% werd teruggevonden in de bodem en 5.9 tot 8.7% werd niet teruggevonden. Met ammoniumsulfaat als N bron was de totale plant recuperatie 94% tot 96%, 0.16% tot 0.2% werd teruggevonden in de bodem en 4.3 tot 5.7% werd niet teruggevonden. In de zoutbodem, daarentegen, met ureum als N bron, was de totale recuperatie door de plant 34% tot 37%, 0.09% tot 0.11% werd teruggevonden in de bodem en 62.7% tot 65.7% werd niet teruggevonden; met ammoniumsulfaat was de totale recuperatie door de plant 76% tot 79%, 0.13% tot 0.14% werd teruggevonden in de bodem en 21.2% tot 23.7% werd niet teruggevonden.

Stikstofverliezen met ureum als N bron in de zoutbodem waren hoger dan met AS. De belangrijkste reden was allicht NH_3 vervluchtiging. Met betrekking tot AS, waren de N verliezen wellicht ook te wijten aan NH_3 vervluchtiging. Maar waarschijnlijk ook aan biologische denitrificatie en chemodenitrificatie. Drogestof productie (DM) op de niet-zoutbodem met ureum als N bron varieerde van 65 t ha^{-1} tot 70 t ha^{-1}, en op de zoutbodem van 33 t ha^{-1} tot 34 t ha^{-1}. Met AS varieerde de drogestof productie (DM) op de niet-zoutbodem van 58 t ha^{-1} tot 60 t ha^{-1} en op de zoutbodem van 53 t ha^{-1} tot 55 t ha^{-1}. De verschillen tussen ureum en AS op de niet-zoutbodem waren gering hoewel ureum was toegediend aan 60 kg N ha^{-1} en AS aan 40 kg ha^{-1}. De verschillen op de zoutbodem waren wel substantieel. De drogestof productie met ureum was ongeveer 50% van de productie met AS. Dit zou suggereren om ureum te vervangen door AS bij zoutbodems. Daar meerdere bodems van de plantage een pH hebben van boven de 8.5, zijn zij zeer gevoelig van N verlies, waardoor het gebruik van AS op beide bodems wetenschappelijk verantwoord is ten einde de meststofefficiëntie te verhogen. Indien ureum verder zou moeten gebruikt worden om economische redenen dan zou het moeten ingewerkt worden of uitgestrooid worden met onmiddellijk daarna irrigatie. Het is dus aanbevolen om het bemestingsadvies specifiek te maken per bodemtype en stikstofbron.

Suggesties voor verder onderzoek

Gezien AS meer kost dan ureum en daardoor niet populair is, zou een studie moeten ondernomen worden naar de kosten/baten verhouding van deze twee N bronnen. Een andere studie zou moeten op gang gebracht worden naar de geschikte diepte om ureum in te werken ten einde ammoniakvervluchtiging te minimaliseren. Er is ook

nood aan wetenschappelijk bewijs dat het toedienen van N-meststoffen met het irrigatiewater de verliezen effectief kan beperken. Andere mogelijke studieonderwerpen zijn de kwantificering van het urease niveau in het veld en het economisch en milieukundig gebruik van urease en nitrificatie inhibitoren.

4. Drogestof productie en stikstofmeststof opname door twee commerciële suikerrietvariëteiten in Tanzania

Een veldexperiment werd uitgevoerd op de niet-zoutbodem om het % meststofstikstof gebruik (% FNU) te evalueren van twee populaire commerciële variëteiten. De ^{15}N aanrijkingstechniek werd hierbij gebruikt. De hypothese was dat de huidige aanbevolen bemestingshoeveelheid van 60 kg N ha^{-1} allicht niet van toepassing is op alle variëteiten. Drogestof productie (DM), N gehalte en % FNU werden bepaald. De gemiddelde DM, N gehalte en % FNU waren hoger met de variëteit EA 70-97 en significant verschillend van de variëteit B 52 313 (t-test analyse). Daardoor blijkt dat beide variëteiten een verschillende N behoefte hebben. Ook het % N afkomstig van de meststof was zeer laag, gemiddeld 12.5%. Er wordt gesuggereerd dat de onderzochte variëteiten ook voordeel hebben van biologische stikstoffixatie. Er wordt aanbevolen om in de toekomst het N bemestingsadies aan te passen per variëteit.

Suggesties voor verder onderzoek

Daar suikerriet in plantages aangeplant wordt in blokken van 10 tot 15 ha, is het belangrijk specifieke bemestingsproeven aan te leggen voor elke variëteit. Er is ook nood aan wetenschappelijk bewijs van het belang van biologische stikstoffixatie door suikerrietvariëteiten.

5. Het effect van verschillende niveaus aan ureum en ureum met filterkoek op groei, opbrengst en kwaliteit van suikerriet

Dit veldexperiment werd uitgevoerd tijdens het groeiseizoen 2000/01 en 2001/02. Het objectief van deze studie was de evaluatie van verschillende dosissen ureum en ureum met filterkoek (FC) op groei, opbrengst en kwaliteit van suikerriet op een zout- en niet-zoutbodem. De hoeveelheid ton riet ha^{-1} (TCH), sucrose (%) en de hoeveelheid ton suiker ha^{-1} nam toe met toenemende N dosissen tot 60 kg N ha^{-1}, maar nam af bij 90 kg N ha^{-1}. Hoge N dosissen hadden een effect op de kwaliteit van het suikerriet, waarbij de TCH daalde, evenals het % sucrose en de TSH. Bemesting met 60 kg N ha^{-1} of 15 kg N ha^{-1} plus FC gaf de beste en omzeggens zelfde resultaten in termen van TCH, sucrose (%) en TSH. Daarom zijn beide dosissen aan te bevelen op niet-zoutbodems. Op de zoutbodem gaf de 15 kg N ha^{-1} plus FC de beste resultaten in termen van TCH, sucrose (%) en TSH. Het negatief effect van het zoutgehalte was hierbij gereduceerd. Het bleek dat de 15 kg N ha^{-1} plus FC in staat was minerale N te leveren gedurende een langere tijd. Het is derhalve aanbevolen op zoutbodems.

Suggesties voor verder onderzoek

Hoewel het gebruik van ureum met filterkoek (FC) aanbevolen wordt voor gebruik op zout- en niet-zoutgronden, moet toch voorzichtigheid aan de dag gelegd worden. Een gedetailleerde studie zou moeten uitgevoerd worden naar de

meest bruikbare dosis aan ureum met filterkoek. Immers FC leidt tot meer N mineralisatie en meer N opname door de plant, waarbij het suikergehalte in de plant kan dalen. Het gebruik van FC in het veld is een bijkomende kost voor de teler, daar ook transportkosten moeten betaald worden voor vervoer van de fabriek naar het veld, evenals de kosten voor laden, lossen en uitspreiden op het veld. De studie moet dus ook een kosten/baten analyse inhouden. Onderzoek naar het gebruik van AS als alternatief wordt ook aanbevolen.

6. Effect van verschillende niveaus aan ureum en ureum plus filterkoek op het chlorophyll gehalte, stomatale geleidbaarheid en netto fotosynthese van suikerriet

Gegevens voor deze studie werden verzameld tijdens de vorige experimenten. Het objectief was de evaluatie van het effect van verschillende dosissen ureum en ureum plus filterkoek op het chlorophylgehalte (chl %), stomatale geleidbaarheid (g) en netto fotosynthese (A) van suikerriet geteeld op een zout- en niet-zoutbodem. De studie werd uitgevoerd tijdens het groeiseizoen 2000/01 en 2001/02. Toenemende N dosissen deden de waarden van de drie parameters toenemen, in beide jaren en op beide lokaties. De toename was echter veel groter op de niet-zoutbodem dan op de zoutbodem. De resultaten suggereren dat de bekomen verschillen te wijten zijn aan het zouteffect en verlies aan minerale N uit de zoutbodem. Het resultaat van 15 kg N met toevoeging van FC was veel beter op de zoutbodem dan op de niet-zoutbodem. Op de percelen behandeld met deze meststof waren het chl %, en de g en A waarden hoger. Deze resultaten suggereren verder dat een behandeling met 15 kg N ha^{-1} plus

FC kan aanbevolen worden op zoutgronden. Het gebruik van ammoniumsulfaat kan evenwel nog een beter alternatief zijn.

Aanbevelingen voor verder onderzoek

Onderzoek is nodig naar de hoeveelheid FC om verlies aan kwaliteit bij het rietsap te vermijden. Er wordt eveneens aanbevolen een kosten/baten analyse uit te voeren naar het gebruik van FC op zowel zout- als niet-zoutbodems.

7. Stikstof mineralisatiepotentiaal van gronden onder suikerriet

Gronden met verschillende eigenschappen werden in het laboratorium geïncubeerd bij kamertemperatuur (25±1°C) en 60% WHC tijdens 90 dagen. Het objectief was de evaluatie van de mineralisatiepotentiaal van gronden bemonsterd uit suikerrietvelden. Volgende behandelingen werden uitgevoerd: een niet-behandelde niet-zoutbodem, een niet-behandelde zoutbodem, een niet-zoutbodem behandeld met FC en een zoutbodem behandeld met FC. Alleen bij de niet-zoutbodem werd enige mineralisatie vastgesteld, en dit enkel tijdens de eerste 40 dagen. Met betrekking tot de groeiperiode van suikerriet is deze mineralisatieperiode zeer beperkt. Het is duidelijk dat hiermee de groei van suikerriet niet kan ondersteund worden. Het zal derhalve nodig zijn chemische N meststoffen toe te voegen naast het gebruik van FC om de mineralisatie van de bodem te verbeteren. De mineralisatiepotentiaal van de niet-behandelde zoutbodems was zeer laag. Dit is te wijten aan het Na^+ en Cl^- gehalte die de microbiële activiteit inhibeerde. Voor deze bodem wordt aanbevolen om

chemische meststoffen naast organisch materiaal aan te wenden en zo de algemene voedingstoestand te verhogen. Er werd echter wel vastgesteld dat na gebruik van FC de mineralisatie van zowel de zout- als niet-zoutbodem afnam bij het begin van de incubatie. Deze afname was duidelijker bij de niet-zoutbodem. Nadien nam die echter weer toe, en was nog niet beëindigd na 90 dagen incubatie. De netto wijzigingen aan totale minerale N over een periode van 90 dagen was hoger na toediening van FC in beide bodems. Het is duidelijk dat voor de zoutbodem hiermee mogelijkheden geboden worden. Te veel FC zou echter ook niet goed zijn omwille van overmatige N opname en daling van het sucrosegehalte.

Suggesties voor verder onderzoek

Alhoewel het gebruik van FC aanbevolen wordt, is het toch noodzakelijk een gedetailleerde studie uit te voeren naar de geschikte dosis onder veldomstandigheden.

8. Een mathematisch model voor de schatting van de stikstofmeststof behoefte van suikerriet

Een mathematisch model werd ontwikkeld om de N meststofbehoefte te schatten. Als resultaat werd een hoeveelheid van 80 kg N ha^{-1} gevonden. Ter verificatie werd een veldexperiment uitgevoerd. Hierbij werd een RCBD gebruikt met zes N dosissen (0, 30, 60, 70, 85 en 120 kg N ha^{-1}). De dosis van 60 kg N ha^{-1} was de huidige gangbare dosis, terwijl 85 kg N ha^{-1} de dosis was

berekend volgens het model. Belangrijke verschillen in tonnen riet ha^{-1} (TCH) werden vastgesteld. Behandeling met 70 kg N ha^{-1} gaf de hoogste TCH, en dit was statistisch niet verschillend van de 85 kg N ha^{-1}. Er was wel een statistisch verschil met de 60 kg N ha^{-1} (de gangbare dosis). Behandeling met 70 kg N ha^{-1} gaf de hoogste netto return gevolgd door de berekende dosis. Het bleek dus dat de N behoefte van de gebruikte variëteit onderschat was. Het is derhalve aanbevolen om de bemestingspolitiek in Tanzania te herzien.

Suggesties voor verder onderzoek

De gegevens voor de N opname gebruikt in het model waren afkomstig van het eerste experiment waarbij gemerkte meststof aan een dosis van 60 kg N ha^{-1} gebruikt was. Het zou derhalve nuttig zijn een veldstudie uit te voeren met verschillende dosissen om de berekende dosis te verifiëren. Er zou ook onderzoek moeten uitgevoerd worden omtrent de stikstoflevering vanuit de bodem tijdens het groeiseizoen om zo ook het model te verbeteren.

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CURRICULUM VITAE

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EDUCATION BACKGROUND

Secondary School

- Kigonsera Sec. School: 1974-1977 ('O'level certificate)
- Moshi High School: 1978-1980 ('A' level certificate)

University/College:

- Uyole Agricultural Training Centre: 1981-1983 – Diploma in Crop Production.
- Sokoine University of Agriculture: 1985-1987 – B.Sc. Agriculture
- Reading University – United Kingdom: 1993-1994 – M.Sc. Crop Physiology

Short Courses**:**

- Applied Plant Breeding, Wageningen, Holland: 1 March – June 21, 1989.

EMPLOYMENT AND WORK EXEPERIENCE

First Appointment : 8/6/1983 – As Agricultural Field Officer

Confirmation : 1/7/1984

Current Position/Title: Senior Agricultural Research Officer II

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Responsibilities:

- Incharge of the day-to-day management of the Agronomy/Physiology Section
- To plan and execute studies in the agronomy section, which will lead to efficient use of limiting resources such as water, land, fertilizers etc.
- Study in weed control strategies in sugarcane fields.

PUBLICATIONS

(i) **Isa D.W. (1987).** Nitrogen requirements in cowpeas. *Thesis submitted to SUA for the BSc degree course.*

(ii) **Isa D.W. (1994).** Carbon exchange rate and water use efficiency of two varieties of *Faba* beans. *Thesis submitted to the University of Reading (U.K) for the MSc degree course*.

(iii) **Isa D.W. (1998).** Determination of optimum levels of P and N at the TPC estate. *Proceedings of the Annual Sugarcane Research Coordinating Committee, May 1998, P.O.Box 30031, Kibaha, Tanzania.*

(iv) **Isa D.W. (2000).** Evaluation of Diurex 80 SC; Velpar 75 DF and Sencor (70 WP an 480 SC) for controlling weeds in sugarcane fields at Kilombero and Mtibwa Estates. *Tropical Pests Management Bulletin, 1(2): 89-96.*

(v) **Isa D.W. and Kalimba H. (2001).** Determination of optimum levels of N and P on sugarcane out growers field. *Proceedings of the Annual Sugarcane Research Coordinating Committee May 2001 P.O.Box 30031, Kibaha, Tanzania.*