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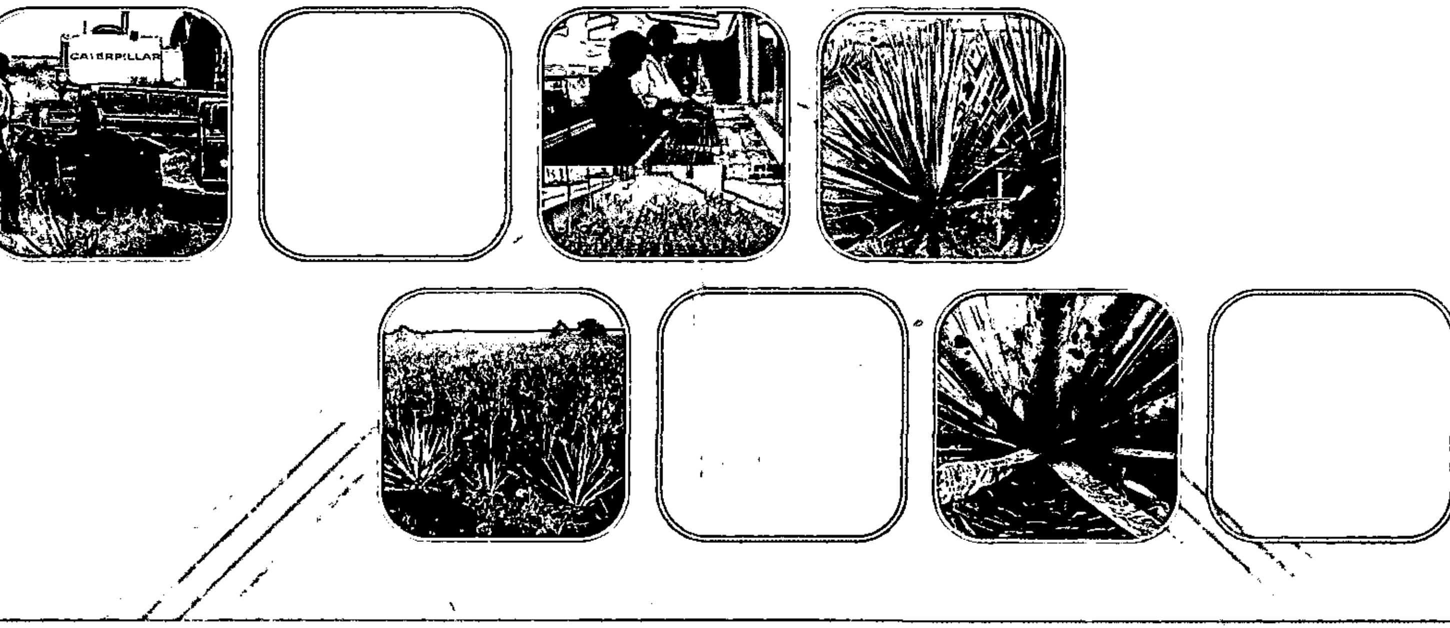
Common Fund for Commodities
Project CFC/FIGHF/07

Product and market development of sisal and henequen



Variety Trials in Estates

Project completion report/Addendum A.3
Part Two: Tanzania

Tanzania, January 1997–December 2004

COMMON FUND FOR COMMODITIES

Product and market development of sisal and henequen

Project completion report, Addendum A.3 – Part Two: Tanzania

Variety Trials in Estates

Tanzania
January 1997–December 2004

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
Vienna, 2006

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Project Completion Report

Sub-component A.3 – Part Two: Tanzania
"Variety Trials in Estates"

CONTENTS

Abbreviations and acronyms

A.	Agave
ADMT	Air Dried Metric Ton
ARI	Agricultural Research Institution
CAN	Calcium Ammonium Nitrate
CEPS	COAID Enhanced Production System for Sisal
CFC	Common Fund for Commodities
COAID	Canada-Overseas Agro-Industrial Development
CV	Coefficient of Variation
D6	Caterpillar D6 Rome
DAP	Di-ammonium Phosphate
DMRT	Duncan Multiple Range Test
ECF	Elemental Chlorine Free
ENT	Enhance nursery trial
FEX	Fibre extraction
H/Hyb	Hybrid
Ha/ha	Hectare
KLS	Korogwe leave spot
Lsd	Least significant difference
ML	Mlola
MOP	Muriate of Potash
MT	Metric Tonne
MTC	Meristematic Tissue Culture
PCC	Project Coordinating Committee
R&D	Research and Development
RCBD	Randomized complete block design
spp	Species
TOR	Terms of Reference
TSA	Tanzania Sisal Authority
TSB	Tanzania Sisal Board
TSP	Triple Super Phosphate
TZS	Tanzanian Shilling
UHD	Ultra high density
UNIDO	United Nations Industrial Development Organization

I. Project sub-component summary

1. Title: Variety Trials in Estates

2. Location: Tanzania: Hale Estate, Gomba Estate and ARI Mlingano

3. Starting Date: January 1997

4. Completion Date: June 2004

5. Sub-component external financing – excluding counterpart contribution:

Total subcomponent cost:	US$ 271,185
Of which:	
CFC Financing:	US$ 80,570
Belgium Government:	US$ 98,144
UNIDO:	US$ 92,471

II. Background and context in which the sub-component was conceived

Over the last 25 years, little research and development was undertaken in sisal production. Most research efforts were directed at developing sisal varieties suitable for line fibre. In trying to provide new market opportunities for sisal, the Project emphasizes the development and confirmation of technologies geared towards producing sisal fibre for traditional use and for the pulp and paper industry. The project stakeholders recognized the fact that the major reduction in costs of production of sisal, through improved varieties and field and crop management practices, are essential, not only for a pulp production industry, but also for the traditional line fibre production industry.

The R&D activities of sub-component A.3 aimed at responding to the producers' needs, in particular to: improve efficiency of cultivation, harvesting, and processing with a view to increasing productivity and greatly reducing costs. Cost reduction and productivity enhancement are the key strategic objectives of the project.

Towards these objectives, the project Appraisal Report called for the performance of some variety and fertilizer trials to be conducted in several locations in Tanzania and Kenya, and indeed in early 1998, three sisal bulbil nurseries were planted to provide a source of planting materials to the various trials.

The project had initially no plans to consider CEPS, which was designed for producing sisal in a project integrating a pulp mill operation. COAID (Canada-Overseas Agro-Industrial Development) is a consulting company that worked on the Canadian-funded feasibility study for the Tanzania Integrated Sisal and Sisal Pulp project in 1992-1993. Nevertheless, subsequent to the workshop conducted for the review of past research in April 1998, the confirmation and demonstration of this CEPS production system became the central issue for A.3 in Tanzania.

The R&D program was based on a number of recommendations resulting from the complete review of the literature on sisal in East Africa, and the April 1998 workshop. An international expert in sisal fibre production systems for the pulp and paper industry designed the program with contributions from national specialists in sisal cultivation and research institutions in Tanzania and Kenya.

The expected output of sub-component A.3 consisted mainly of a comprehensive program of R & D to be delivered within the life of the project establishing, beyond doubt, the potential for using sisal as a competitive raw material in the manufacture of pulp and as reinforcing fibre for the paper industry.

Apart from improving yield and quality through improved nursery and cultivation practices, the Sub-component research activities included also soil fertility management trials. The fertilizer trials were established at Gomba estate to address the problem of low fibre production (fibre yield declined from an average of 1 to 0.6 tons/Ha), coupled with low leaf unfurling. The project contracted ARI, Mlingano to analyze the soil composition searching for alternative causes of low fibre yield The report indicated that the soil fertility status at the estate was low.

Based on fertility observations, it was advised that a fertilizer demonstration trial be established with the main objective of testing different fertilizer combinations to improve the soil fertility and contribute to increased sisal production in the estate.

III. Implementation and results achieved

III.1 General description of CEPS R&D program and confirmation trials

'CEPS' is a term used in this project to distinguish the cultivation practices applied by it from traditional systems of cultivating sisal. It stands for COAID Enhanced Production System for Sisal.

CEPS is based on a combination of sisal literature from Tanzania, field observations collected and generated by the consultant, and on scientifically sound but unconfirmed agronomic principles. The primary concern of the system was to significantly reduce the cost of production of sisal fibre raw material, compared to the traditional system of production, in order to allow the use of sisal fibre as a competitive material in the production of pulp for the paper market.

The outstanding two components of CEPS that needed field confirmation were the high density of planting, together with an enhanced field and crop management system, and the use of whole-plant fibre in a system of total plant harvesting to be completed between 3 - 4 years after field establishment.

As this was the first time anyone had attempted to implement sisal production under these conditions, and since there was a desire to measure the performance of several commercial varieties of sisal prevalent in East Africa, the demonstration trials included the four prevalent varieties of sisal.

Several field demonstration trials were designed and implanted between 1999 and 2000 as part of the CEPS program. Two of the trials were to demonstrate enhanced nursery production methods (ENT-1, and ENT-2); one trial was to confirm the fibre production performance of four varieties under two regimes of density planting, 6,400, and 8,000 at various stages of growth (CEPS-1); one trial was to demonstrate the production capability of the Hybrid sisal 11648 at a density of 6,666 plants per hectare (CEPS-2), and three trials were to evaluate the effect of ultra high density planting on sisal performance (UHDT).

Additionally, and because CEPS included the use of appropriate mechanization of some field operations to help reduce the cost of producing sisal fibre, the International Consultant assisted the project in the design and procurement of three pieces of equipment especially for use in sisal planting and cultivation: a nursery planter; a furrowing field marker, and a cultivating fertilizer side-dresser.

The nature and size of the CEPS trials was considered sufficient to confirm and demonstrate the new sisal production system. However, to ensure the validity of the information a scientifically managed trial was designed with the most important factors under consideration: planting density; variety, and date of total defoliation. As such a 3-factor variety trial was designed for implementation at the ARI atMlingano. The results achieved in this trial would help explain the observations obtained in the CEPS trials. This trial was established in March 2000 and laid out using a Randomized Complete Block Design (RCBD) with three replications. The treatments included three plant populations (4,444, 6,400 and 8,000 plants/Ha), four varieties (Hybrid 11648, Hybrid Mlola 487, Agave Sisalana and Agave Hildana) and three harvesting periods (36, 42 and 48 months after field planting).

Provided with intermittent advice and supervision from the International Consultant, a specialized team of local staff from ARI, Mlingano and from Katani Ltd. undertook the implementation and supervision of this R&D program and confirmation trials on a day-to-day basis until its completion.

III.2.1 CEPS Trials

The CEPS trials were conducted at Hale sisal estate, which belongs to Katani Ltd., the privatized Tanzania Sisal Authority. Segera, the location selected within the estate to conduct most of the trials, is adjacent to the national road linking Dar-es-Salaam to Tanga and Moshi in Tanzania. The 3-factor variety trial was conducted at ARI, Mlingano, halfway between Hale and Tanga, and the fertilization trial, designed by ARI-Mlingano, was implemented at Gomba sisal estate, some 40 km North from Hale.

Hale sisal estate is in the heart of what is known as the Tanga Line in sisal. When the sisal industry was in its prime days in the 1960's, this region had more than 200,000 ha of sisal plantations. This region receives an average of over 1000 mm of rainfall distributed over two distinct seasons, with the majority of the rains falling between April and June (long rains) and to a lesser extent during September to December (short rains). Although sisal is tolerant of drought, it performs best when it receives between 800 and 1200 mm of rain throughout the year.

Table 1 shows the rainfall data recorded at Hale estate throughout the life of the various trials from 1999 to 2004. The Table is helpful in explaining the performance of the trials from one season to another.

Table 1. Rainfall distribution between 1999 and 2003 at Hale.

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Total	No. Rain Days
1999	28.9	0.0	182.4	305.0	148.7	77.5	89.9	87.0	42.9	49.0	161.3	5.0	1174.6	106
2000	0.0	0.0	37.6	222.9	121.8	128.4	31.7	44.0	31.7	20.5	108.8	59.3	806.7	72
2001	21.0	18.0	133.0	254.0	183.9	78.0	46.7	29.0	4.0	29.0	4.0	18.2	818.8	72
2002	86.5	16.3	97.0	309.9	78.0	14.0	39.6	132.0	75.5	200.	54.0	151.0	1253.8	80
2003	0.0	5.0	33.0	117.3	109.1	30.0	9.5	12.8	38.0	62.2	9.5	14.0	440.4	34
Mean	**27.3**	**7.9**	**96.6**	**241.8**	**128.3**	**65.6**	**43.5**	**61.0**	**38.4**	**66.3**	**67.5**	**49.5**	**898.9**	**73**

Ambient temperatures year-round vary from 25°C to 33°C, and relative humidity is in the nineties during the rainy seasons, but it is lower during the drier months. Other than sisal, the most important crops in the region are: maize, citrus, bananas, coconuts, cashews, mangoes, and cassava. But these are not plantation crops and at present the majority of traditional sisal plantations have been abandoned and reverted to natural bush.

The soils of the selected sites are typical of the whole region. Soil analysis from various points in the targeted fields indicated that the soils were highly weathered, ferralitic, and very acidic (pH from 4.5 to 5.5). They were low in organic Carbon content, and very low or lacking in major nutritional elements like Nitrogen, Potassium, Phosphorus, Calcium, and Magnesium. This was expected since over the last 90 years, traditional sisal plantations have rarely used fertilizers and agricultural lime in the production of line fibre. Hence any crop grown on these soils was expected to respond well to the application of lime and inorganic fertilizer. Of major importance was the use of agricultural lime to bring up the level of exchangeable calcium and magnesium of the soils and to raise its pH level, so other nutrients become available. The soil analysis, conducted at Mlingano Research Institute, indicated lime requirements ranging from 0.5 to 80 MT/Ha in order to improve the soil fertility for sisal.

III.2.2 Three-factor trial

The 3-factor trial was located at the ARI Mlingano experimental site along Kibaranga road just 100 m from the Tanga – Muheza main road. The soils of the trial site are classified as Rhodic Ferrasols (AHT, 1976). Soil laboratory results indicated that the fertility status of the trial site before planting was low. The soils lacked most of the essential nutrients and therefore fertilizer application was required for improved sisal production.

III.2.3 Fertilizer management trial

The fertilizer management trial was conducted at Gomba sisal estate, about 4 km south of Mombo in Korogwe District along the main road connecting Segera to Moshi. The soils of the trial site are chromic luvisol with low soil pH, organic Carbon, Calcium, and total Nitrogen.

III.3 The research and development program

As required by the CEPS program, most trials were designed with an emphasis on using the total biomass from the whole plant to produce pulping fibre. The Gomba fertilizer trial however, was designed and implemented with emphasis on using the sisal for producing traditional line fibre. One of the CEPS trials at Hale was also used to obtain information about the potential of using CEPS for the production of line fibre for the traditional industry.

Most information generated from all the trials can be useful for both production systems (pulping and traditional line fibre), particularly the enhanced nursery production techniques.

III.3.1 The enhanced nursery trials (ENT I and ENT II)

Traditional practice in producing sisal propagation materials uses two systems: the use of suckers from mature sisal fields for planting directly in the permanent field, or the use of nursery plants produced from bulbils. Bulbils are small plantlets produced on the top part of the inflorescence (pole), produced by plants at the end of their life, in general when they are 10-13 years old. Bulbils are planted at the rate of 75-80 thousand per hectare usually in a site close to the intended permanent fields for a period of 12-18 months before they are manually uplifted and used to establish new production fields.

Previous studies have established that the rate of success and productivity of sisal planted from bulbil nurseries is superior to that planted from suckers. Unfortunately plants from bulbil nurseries are twice as costly as suckers collected from old fields. Traditional bulbil nursery techniques have been quite successful, but can further be improved and this is one of the components of the CEPS program. In particular, because CEPS uses high-density planting, there is an increased demand for planting material.

It is thus important to establish a specialized and permanent nursery operation with a greater management input to produce healthy and uniform planting material in 1/3 of the time used by traditional nurseries. The size of the plants produced will be smaller, and this introduces some savings in the cost of transportation and field establishment without losses in productivity.

A typical CEPS sisal nursery is established on a well-managed ***permanent*** site supplied with a sprinkler irrigation system. The site should be large enough to accommodate one or two rotational crops between sisal nursery crops to reduce the possibility of damage from diseases and insects, usually observed in situations of continuous cropping. The soils shall be kept fertile and fully managed to facilitate smooth seedbed preparation and non-destructive nursery lifting, using appropriate mechanical inputs, including a mechanical planter and a mechanical nursery lifter.

The project had not given any earlier consideration to such a proposal in the funding provided, which made it impossible to demonstrate a complete enhanced nursery system. However, it was possible to demonstrate the potential of growing healthier nursery plants by using the required agricultural inputs, and the project approved the modification and supply of a mechanical nursery planter.

Hence two adjacent nursery trials were established at Hale. A one-hectare ENT-1 was manually established in March-April 1999 from bulbils, over which an improved package of cultural practices was superimposed, including seedbed preparation, pre-planting application of fertilizers indicated by soil fertility analysis, and post planting chemical and hand weed control, and insect control. Another one-hectare ENT-2 nursery was established six months later in September 1999 using a specially adapted mechanical transplanter, and the same cultural package as ENT-1. Only hybrid 11648 was used to demonstrate enhanced nursery techniques.

The two nurseries were manually and selectively lifted in March 2000 to establish the second CEPS trial and to continue to be used as a basis for high-density trials.

III.3.2 The CEPS demonstration trials: CEPS-1 and CEPS-2

These trials were designed to field-test and confirm the effectiveness of CEPS. The planting materials for CEPS -1 came from traditional bulbil nurseries established by the project in early 1998 at Mwelya and Kwaraguru sisal estates. These nurseries contained the 4 sisal varieties used in the demonstration trials. While CEPS-1 was established from traditional bulbil nursery using 1-year old plants, CEPS-2 trial was established from the enhanced nurseries.

The main objective of these trials was to establish a fibre production curve for each variety and at each density of planting, to be used as a guideline for producing reliable information on expected pulping fibre productivity and equivalent pulp characteristics. This information is required in establishing costs of production for use in any feasibility study for the production of sisal for pulping purposes.

The simple design and relatively large size of these trials (5 Ha each) was effectively used to simulate as closely as possible large-scale sisal farming, and in order to give the project the opportunity to establish mechanical and manual production norms and costs. It also allowed the possibility of testing the appropriateness and benefits of using some of the especially adapted equipment prescribed by CEPS, which is designed to enhance the productivity of the crop and reduce the costs of some field management operations such as fertilization and weed control.

Furthermore the large size of the trials was used to demonstrate the system for any farmers or estate operators who are usually quite critical of research results obtained from much smaller trials. It also made it possible to provide the project with adequate amounts of CEPS representative raw material required to confirm the fibre extraction technology identified by the project, and to produce adequate amounts of fibre and pulp to be used in the market study sub-component of the project.

Traditional sisal for production of line fibre is planted at 3,300 - 4,000 plants/Ha in single row or double row configuration. CEPS recommends increasing the density to between 6,000 and 8,000 plants/Ha. CEPS demonstration trials included 6,400, 6,666, and 8,000 plants/Ha with a maximum of 1.5 meters between rows. CEPS recommended whole-plant harvesting at 42 months of plant age after transplanting, and the trials could demonstrate the differences between various treatments on a large scale.

III.3.3 The three-factor trial at ARI, Mlingano

Three major factors: variety, density, and months to total harvesting might have an influence on fibre production. CEPS trials were not scientifically controlled experiments whose results could be statistically tested, and as such could not be used to measure the effect of any interaction between these three major factors.

To provide very reliable back-up information which could help to interpret the differences in performance according to the different combinations of the three factors, it was necessary to conduct a scientifically designed replicated trial encompassing the full range of possible combinations of these factors. This is referred to as the 3-factor trial.

The 3-factor trial was designed for implementation by the sisal research institution at ARI, Mlingano, where it would potentially receive the most attention, and be implemented under exacting conditions.

The 3-factor trial included:

- four varieties: the two commercial varieties in Tanzania Hybrid 11648 and Agave Sisalana, Agave Hildana, which is commercially grown in Kenya, and hybrid Mlola 487;
- three planting densities: 4,444 (1.5m x 1.5m), 6,400 (1.25m x 1.25m), and 8,000 (1.25m x 1m) plants/Ha, and
- three dates of whole-plant harvesting: 36, 42, and 48 months after transplanting.

The trial included 36 treatments and it was replicated 3 times in a randomized complete block design. Therefore the trial had in total 108 treatments (i.e. 3 spacing X 4 varieties X 3 harvesting periods X 3 replications) planted in 108 plots. The plot size adopted was 12.5m x 12.5m which in total gave an area of 1.69 Ha.

Planting material for this trial was obtained from a project nursery established at Kwaraguru sisal estate and at Mwelya sisal estate, because the original nursery intended to be used for the trial and which was established at Mlingano had been condemned as inadequate due to a severe infestation by Korogwe leaf spots (KLS) and inadequate growth. Nursery plants were uplifted manually using hand hoes. After lifting, they were left under the sun for three weeks to "cure" before planting. The lifted plants were transported to ARI, Mlingano from Kwaraguru/Mwelya using transport trucks. Leaf pruning and root trimming of the plants was also manually done before planting.

The trial site was manually cleared/brush-cut, and stumps uprooted, collected and burned. Ploughing and cross ploughing was carried out using a Caterpillar D6 crawler from Ngombezi Central Workshop of Katani limited. Disc harrowing was undertaken using a tractor from ARI Mlingano.

Agro-inputs included fertilizers like Calcium Ammonium nitrate (CAN), Triple Super Phosphate (TSP) with 46% P_2O_5 and Muriate of Potash (MOP), and Benlate fungicide for bole rot, and Decis insecticide for weevil control. Agricultural lime was also purchased at Kiomoni and applied after planting; disc harrowing was planned but not performed. Marking the trial layout was carried out using a chain link pre-marked at the required spacing. TSP was later applied in the planting holes at 134 kg/Ha. The trial was manually planted using hand hoes and was supervised by ARI Mlingano staff. The soil main chemical characteristics before the establishment of the trial and in 2003 are presented in Annex 8.

Fertilizer application was carried out during the rain periods in the first two years. CAN and MOP were banded along the sisal rows at 100 kg/Ha/year and 500 kg/Ha/cycle respectively. Fertilizer losses should have been minimized by covering the fertilizer with soils just after application, but this was not done.

Weeding and slashing was done when necessary. About six instances of weeding were required per year. Firebreaks were prepared twice per annum to control fire outbreaks. Other management practices like sisal weevil control were carried out during the first two years. Decis was applied at 7 ml/litres of water using knapsack sprayer in four applications per year.

Fungal diseases like bole rots and zebra diseases were controlled through uprooting followed by destruction of diseased plants. Fungicide applications in the first two years were done using benlate at 1kg/Ha/year. Upon replacement of new plants, benlate was placed in the planting holes to avoid further infection of bole rots to the plants. Both monkeys and baboons were controlled through scaring.

III.3.4 The ultra high density (UHD) trials: *UHD-1, UHD-2, UHD-3*

Although previously considered planting densities in excess of 8,000 plants/Ha were not included in the original CEPS program. The project mid-term evaluation held in early 2000, recommended to investigate higher densities of planting as well. The international consultant responsible of the activity designed and supervised the implementation of the trials in March 2000.

Implementation of UHD-1 and UHD-2 was done on the existing ENT-1 and ENT-2 nurseries, since their design and plant density made it easy to do so by selective uplifting of nursery plants. Thus, UHD-1and UHD-2 were superimposed on ENT-1 and ENT-2 and each had 5 densities, varying from 6,666 to 33,333; while UHD-3 was freshly planted from bulbils directly in the field and had densities from 6,666 to 26,666 bulbils/Ha.

III.3.5 The selective leaf defoliation trials

Plants in CEPS-1 trial grew at a very fast rate, given the good rainfall conditions and new soil fertility. Therefore, 18 months after the plants/trial's establishment in August 2001, access to the inside of the plantation to undertake further fertilizer application and to provide manual weed control became difficult. This meant that this would be the last chance any fertilizer could be applied and manual weed control undertaken. At the age of 24 months, access was rendered impossible. It was then decided to advance the first observation on potential staple fibre production from 30 months to 24 months. This was done by measuring plant biomass and determining fibre yields. Fibre was obtained from the sisal leaves and chopped bole material using a roller crusher. Fibre samples harvested indicated potential fibre yields of 10-18 MT/Ha. When the fibre was pulped, pulp yields varied from 60 to 70%.

Additionally, when leaves resulting from total plant defoliation were decorticated using a traditional corona, the resulting line fibre was of good quality UG grade, and the potential yields varied from 2-5 MT of line fibre per ha.

Such fibre yield was quite impressive. These results led the International Consultant to propose the possibility of using CEPS also for the production of traditional line fibre. However, as there was no previous experience on the response of plants and their tolerance to aggressive plant defoliation under high density, it was decided to *superimpose a trial to measure the effect of intensity of plant defoliation on leaf fibre* production potential and persistence of the plantation. The trial was easily accommodated in the CEPS-1 field and the first observation was taken at the age of 24 months.

Furthermore, since the quality of pulp from whole-plant fibre from older plants was not assured, it also looked likely that selective leaf harvesting may have to be used for the production of pulping fibre in a program that maintains the plantation beyond four years of age.

Traditional leaf harvesting in sisal is conducted once every 6 - 8 months. The oldest 30 - 35 leaves are removed starting from the ground up, after sand leaves are removed. At each harvest, some 60-70 leaves remain on the plant. This allows the sisal to survive up to 12 years.

It was proposed by the international consultant that, under a more intensive field and crop management program, such as the case in CEPS, it might be possible to harvest a much higher number of leaves from the plant periodically without gravely affecting the performance of the plant.

On that basis a trial was superimposed on CEPS-1, which had 5 levels of leaf removal intensity for every density-variety combination, starting by total defoliation and changing by leaving on the plant increments of 5 unfurled leaves up to 20 leaves. Because 4 varieties and two planting densities were under consideration, 40 treatments were considered superimposed. Thus, the first observation was made when the plants were 24 months, the second 9 months after, and the third 10 months after that.

The results obtained were very interesting and will be detailed in subsequent sections.

III.3.6 The Gomba fertilizer trials

The fertilizer trials were established in April 2000: traditional planting material from a bulbil nursery of Hybrid 11648 was planted at the trial site using a double row system of planting with plant population of 4,000 plants/Ha. The trial, which covered one hectare of land, was laid out using 25 fertilizer treatment combinations. The treatments included: agricultural lime, well-decomposed sisal waste, and inorganic *fertilizers (mainly CAN, and MOP). A control treatment (no fertilizer application)* was also included. The plot size for each treatment was 20m by 20m.

Land preparation for the trial site was carried out in February 2000. Major activities implemented included brush cutting of the old sisal using D6, manual collection and burning of boles and trash, ploughing and cross ploughing with ordinary tractor.

Well-decomposed sisal waste was manually excavated and transported to the trial site with tractor and trailer. Both agricultural lime and sisal waste were dispensed manually and incorporated in the soil using a tractor harrow before field planting. MOP and CAN were also banded along the sisal rows six months after field planting.

Most of the field activities like: weeding, vermin control, slashing, application of lime, sisal waste, pesticides (Decis) for weevil control and fertilizers (MOP and CAN) were carried out by the estate management. The project financed the costs of agro-input procurement, fuel for transport of research staff and their costs to supervise various field operations. Staff from ARI Mlingano carried out the supervision of the field activities.

Lime was applied in three splits (2.5 tons/Ha/year) for plots receiving 7.5 and 10 tons of lime/Ha. All plots received full amount of fertilizers (CAN and MOP) in 2000. Other activities like firebreak preparations were carried out once per year. Manual weeding and harrowing using a tractor was carried out on routine basis for the first two years.

Traditional harvesting method (selective cutting of mature leaves) using manual labour was applied. A stationary decorticator was used for fibre extraction.

III.4 CEPS data collection methods and factors affecting implementation of the various trials

To ensure that the trials correspond closely to the recommendations required by CEPS, several principles were adhered to:

- The overall site of the trials was designed as a commercial size CEPS plantation, including field size, as well as field and main plantation roads.
- Whenever possible, recommended primary and secondary tillage and land preparation were attempted within available capabilities,
- Methodology of field marking and planting was uniform in most trials.
- A soil analysis was conducted and quantities of lime and fertilizers were applied as per indication of soil analysis, and known requirements by the crop.
- Planting materials always consisted of bulbil seedlings grown from project nurseries .
- For each trial, a set of follow-up management practices was prepared for implementation throughout the life of the project, and was updated annually during the field visits of the international expert.

In all cases each trial went through a planning phase, during which detailed execution plans were given, and corresponding budgets drawn. This was then followed by trial execution and management, and by data collection and analysis.

In almost all cases, the trial execution schedule could not be followed as planned due to many reasons, prominent among which were shortages in equipment and materials, but also lack of funds when required. Hence timetables for application of the field husbandry program including weed control and fertilizer application, whether manual or through the use of the especially supplied equipment, were not adhered to. In most cases this might have resulted in reduced performance of the trials.

In order to measure the potential productivity of CEPS, two critical pieces of data were needed: the fresh whole-plant biomass yield, and the fibre content of the biomass. The biomass yield was collected from an undisturbed sample of one 100-meter row of sisal plants, containing a potential number of plants ranging from 81 to 101 plants, depending on density, while the fibre content was collected from a representative sample of only one plant. This was true for the first 2-3 harvests, before more productive fibre extraction equipment became available, at which time larger samples were used.

To measure the biomass yield, sample plants were totally defoliated leaving only the unfurled leaves in the centre of the plant, using traditional sisal cutters. The harvested leaves were bundled as usual, stacked in separate piles and identified using labels. The leaf stacks were weighed within hours in the field using a tripod, a sling, and a spring balance, and the fresh weight recorded.

To measure the bole contribution to biomass, a random sample of 10 boles was cut using manual labour and a machete, and weighed including the centre leaves remaining on the plant after defoliation.

To measure staple fibre content in the whole plant, several methods of fibre extraction were employed. The ratio of the dry weight of the fibre to the fresh weight of the plant represents the fibre percentage in the whole plant. The extraction methods used were the following:

1- Roller crushing. Leaves and bole from one plant were chopped in 2-4 inch sections and were passed several times between rollers to extract the fibre free from parenchyma. This was followed by several cycles of washing. Although this method allowed the extraction of bole fibre, it was however noted that fibre losses in the washing cycles could not be avoided. The more passes were made, the more parenchyma was extracted, but this was causing the fibre to grind between the two rollers, which also caused fibre losses. In any case, the recuperated fibre was sun-dried and weighed.

2- Hand-fed decorticating: In the absence of a working roller crusher, sample leaves were decorticated in a locally designed and built hand-fed motor driven small decorticator, but in this case, the bole was not decorticated, and hence bole fibre content had to be estimated.

3- Hammer milling: Hammer milling was introduced towards the end of the trials when the technology became available. The mill was fed with 2-4 inch plant sections produced by the sisal chippers. Trials in the Hammer mill indicated that to obtain adequate parenchyma removal sisal chips have to be passed once and the resulting fibre passed again in the hammer mill before the fibre is washed and dried. This system achieved fibre with only 4-5% parenchyma content. However, because of its size the system requires biomass material in excess of one metric ton as a sample, and even then it was difficult to recuperate all the resulting fibre from the system to make accurate assessment of fibre content. It should also be noted that, because of the timing at which the system became available, it was only possible to use it for the last observation on CEPS-2 trial. The hammer mill can measure very accurately the amount of recoverable fibre from the whole plant, or any of its parts.

Each one of these systems had its shortfalls and could not be very reliable for measuring the amount of fibre in the biomass being sampled. And in fact if the data resulting from any of the methods of fibre extraction is used without questioning its validity, this could lead to unrealistic conclusions regarding the potential of fibre production from sisal for pulping purposes. For comparative purposes, it was decided to rely more on the data obtained from biomass rather than fibre.

Potential staple fibre production capacity was determined by multiplying the potential fresh weight of the green biomass produced by the percentage of fibre found in the biomass. Fresh biomass production potential was measured from a large number of plants usually 50-100 per treatment in CEPS-1 trial and the first two observations in CEPS-2, and no less than 10 plants in the 3-factor trials.

For the first 2-3 observations, since the hammer mill was not available, the percentage of fibre in green biomass was based on a one-plant representative sample per treatment. After the installation of the high-capacity hammer milling system, much larger samples from CEPS-2 were taken to measure the extractable percentage of fibre in the biomass. These second figures are more representative of what would be expected on large scale.

III.5 Trials performance

III.5.1 The enhanced nursery trials

Immediately after planting, at the beginning of 1999, the ENT-1 nursery benefited from an above-average well-distributed long-rains season between April and July 1999 (Table 1). Thus, varieties developed extremely well and after six months, an excellent nursery was obtained. Nursery plants attained a height of 30 cm and were at least 500 grams in weight. The season simulated a well-grown nursery under irrigation, despite the fact that no irrigation was made. Compared to traditional nurseries of the same age, the nursery plants were bigger and healthier, and could be transplanted at this age with high degree of establishment.

The large size and health of the plants compared to a traditional nursery clearly indicated the benefits of the lime and the DAP fertilizer applied before planting. The nursery plants had a remarkable uniformity and did not require any grading before field planting. The root system was well developed. No diseases were noted, and losses due to sisal weevil attack were negligible.

The short rainy season (August - November) arrived with below-average rainfall and rains were not very effective, except in the months of October and November. The urea fertilizer applied in late September was also useful for further vigorous growth in height and mass, so that by February 2000, at 11 months of age, each nursery plant attained more than 35 cm in height, and more than 1.4 kg in weight. The ENT-1 nursery plants had a unique deep green-blue color and looked very healthy. Field losses were negligible. A survival rate of more than 97,000 plants/Ha was observed.

It would have been ideal to transplant the nursery in September, when the plants were half the size, and much easier to uproot, transport, and transplant in the permanent fields as ENT-2 demonstrated. This would have also saved on the second application of Nitrogen and the hand weeding which was required after 6 months.

The second nursery, ENT-2, was planted in September 1999, using the mechanical transplanter. It did not develop as vigorously as ENT-1 because of a shortage of rainfall during the critical period after planting. Subsequent rains falling in late October and November, helped get the bulbils growing, but by February 2000, the bulbils had only grown to no more than 4 times their original size. January and February did not bring much rainfall, and the plants were practically dormant until March 2000, when some 20 mm of rain fell on the nursery. This caused the dormant plants to initiate a flurry of new roots in preparation for new growth.

However, it was time to use the nursery plants to establish the second CEPS trial, and plant lifting was simply done by hand pulling. Larger plants were selected for planting, but even those were less than 1/3 the size of ENT-1 seedlings. This, together with the death of the newly initiated roots due to drying out after transplanting, slightly reduced the rate of development of sisal in CEPS-II block (A) compared to that in block (B) that used larger ENT-1 seedlings.

The experience gained clearly indicates that, if it is important to produce bulbils nurseries within a period of 6 months, the ability to irrigate the nursery, if rainfall is inadequate, is a requirement.

In both nurseries, plant development within a period of six months did not result in complete land coverage. This indicates that in an intensively managed nursery operation it is possible to reduce the between-row and within row spacing to produce more than 100,000 plants/Ha. For example, if between-row spacing is reduced from 50 cm to 25 cm and within row spacing is kept at 20 cm the density possible is doubled to 200,000. This is possible in an intensively managed site receiving a balanced package of soil-fertility, moisture, and herbicidal control of weeds.

III.5.2 The CEPS-1 demonstration trial

The CEPS-1 trial included four varieties: Hybrid 11648, Agave Sisalana, Agave Hildana, and the hybrid Mlola 487. The first three varieties are commercially planted in both Tanzania and Kenya, while Mlola 487 is a hybrid developed at Mlingano, and it is not used in commercial cultivation. Hybrid 11648 is by far the most widely used variety for line fibre production in East Africa.

Depending on availability of planting material, a variable number of rows from each variety was planted in March 1999 in two densities: 6,400 and 8,000 plants/Ha. The between-row distance was kept at 1.25 m, regardless of density. The higher population density of 8,000 was obtained by reducing the distance between plants in the same row from 1.25 m to 1 meter.

The profile of the trial, together with the actual field and crop management interventions made and directly related costs is outlined in Section IV.

Five months after field establishment, the sisal plants had at least tripled in size. An average of more than 20 new leaves was produced per plant, and leaves had increased in length by 50%. The mean height of the tallest standing spike was 75 cm, and the free-from-leaf tillable area between rows was reduced to between 75 and 90 cm.

It was therefore possible to perform mechanical cultivation and fertilizer application using the cultivator-cum side-dressing implement adapted specifically for CEPS sisal, together with a high-chassis tractor.

However, within the same density, the four varieties differed in their performance. Hybrid 11648 grew larger and more vigorously than the other three, while Agave Sisalana was the weakest performer. All four varieties responded positively to improved soil fertility and adequate rainfall, and were certainly superior in growth to traditionally grown sisal.

All four varieties were free from any symptoms of nutritional deficiencies, and none was expected. During the wet season, right after planting, sisal weevil activity increased, but was adequately managed using traps and Decis insecticide.

However, an unexpectedly high level of bole rot incidence in the plot on all varieties made it necessary to replace many of the diseased and dead plants. In some areas of the plot, the losses were more than 10%. It is difficult to explain such high incidence of bole rot, as this disease is normally attributed to sisal growing in highly acidic soils with low fertility, and with some water logging, conditions which were not prevalent in the trial plot.

During the following season, between September 1999 and March 2000, and despite a shortage of rainfall, all varieties in CEPS-1 continued to grow at a fast rate. The plant leaf canopy attained an average diameter of 1 meter and plants increased 30% in height. The inter-row leaf-free distance was now less than 30 cm. Entering the plantation to conduct cultural operations mechanically became impossible and only manual operations were possible, and even these with difficulty.

The Hybrid 11648 appeared again to have surpassed the other varieties in its development. In the 8,000 plants/Ha field, leaves of plants within the row became intertwined. Some weed growth, which occurred, was manually controlled during this period. This stage, just one year after planting, presented the last chance to apply any fertilizers in the plot, as the plantation would certainly close-up within the next 6 months of additional growth. Hence, the importance of using slow-release fertilizers, which would continue to provide adequate nutrition over the following 12-18 months of development, the anticipated harvesting time, became evident. Unfortunately there are no commercial fertilizers which can last that long. Therefore the period of access to the field should be lengthened by increasing the distance between rows to 1.5 meters, with 1 m spacing within plants in the same row, to give a density of 6,666 plants/Ha.

As this was a significant issue in the management of the plantation, this spacing was adopted for CEPS-2 demonstration trials.

At 24 months after planting, in March 2001, CEPS-1 plants continued to develop and grow. Within-field access had become impossible. The only way to enter into the field was through leaf cutting. Faced with such impressive growth rate, it was necessary to advance the date of the first scheduled harvest from 30 months to 24 months.

Performance of the varieties continued to be variable. Hybrid 11648 continued to outperform the others, with Agave Hildana showing more improvement than Agave Sisalana and Mlola 487. At this stage quite a bit of weed growth within the plantation had occurred in addition to growth from live stumps of various brushes that were in the fields before brush cutting and ploughing.

The plantation continued to manifest some mild losses due to bole rot disease, and sisal weevils, however, the KLS disease started to manifest itself on the older leaves of the plants of the two hybrids. The other two varieties were resistant to the disease and did not show any such manifestation. At this stage, the incidence of banding disease, which is due to potassium deficiency in the soil and a general lack of soil moisture, also appeared on many plants. No Potassium had been added at the planting stage as the soil analysis indicated sufficient levels before planting, but the soil fertility recommendations were based on Potassium requirements in traditional plantations. In CEPS however, with an increase of 50% in planting density, the uptake of potassium increased and hence it must be added to avoid losses to banding disease.

During a period of three years between the first cut at 24 months and January 2004, the plantation was undisturbed except in areas where sampling was conducted to measure biomass yield and fibre production potential. Three more harvests from undisturbed CEPS-1 sisal stands were made at 34, 44, and 54 months, instead of at the planned 30, 36, and 42 months.

III.5.3 The CEPS-2 demonstration trial

The trial started in March 2000, one year after CEPS-1 and contained two blocks (block A and block B), each with an approximate area of 2.5 Ha. Only Hybrid 11648 was used as planting material, and the density was 6,666 plants/Ha., with a 1.5 meter spacing between rows and 1 meter within the row. In block B, 1-year old plants from ENT-1 were planted while block A received small nursery plants from ENT-2. The difference in development between the two blocks continued throughout the 4 years of observation after establishment of the experiment.

Like in CEPS-1 the development of the CEPS-2 plantation was quite impressive, despite some stiff competition from weeds during the first 6-8 months after establishment. Weeds could not be controlled as recommended, due to breakdown of the tractor designated for use with the between-row cultivator built specially for the purpose. Any hand weeding applied was done very late, and this drastically affected the development of the CEPS-2 plants.

Another aspect, which negatively affected the development of the plantation, was the early manifestation of banding disease symptoms due to lack of Potassium. Although the problem was diagnosed at an early stage, the application of corrective fertilizer was done at least 16 months later because of reasons not related to technical matters. This significantly retarded the development of the plantation compared to CEPS-1.
In CEPS-2 the fields remained accessible to mechanical intervention during the first 18 months after establishment, but only in the direction between the sisal rows. Leaves of plants within the row began to intertwine at the age of 16 months. Beginning at the age of 24 months all cultural operations had to be performed using hand labour.

In addition to banding disease, the plantation had also suffered from attack of sisal weevil throughout the first three years after establishment, and despite use of traditional traps and control measures, up to 3% of plant losses were recorded.

From 24 months, CEPS-2 plants were attacked, although mildly, by the KLS disease, and this disease incidence persisted throughout the life of the plantation, its intensity increasing with age. The KLS disease affects the quality of the line fibre, but its effect on short fibre produced by the hammer mill has not been determined.

III.5.4 The three-factor trials at ARI, Mlingano

Data collected included leaf length, plant height, leaf number, data from the soils and plant analysis, pest and disease incidences. Other variables, which were recorded after harvesting, included leaf weight and bole weight including total biomass. Climatic information on rainfall amounts and distribution was also recorded.

Harvesting was carried out at 36, 42 and 48 months after planting. Leaf defoliation of the data plants including bole harvesting was carried out to simulate whole plant harvesting. Fibre extraction (FEX) of representative plants/plot at 36 months after field planting was carried out using a roller crusher at Hale estate. Boles and leaves were chopped in pieces of 3cm before fibre extraction work. During the third harvest, a hammer mill was used to extract fibre from leaves of ten plants/plot in the first replication (12 plots). Fibre from leaves of guard plants was extracted using stationary decorticators at Kumburu and Muheza Mkumbi sisal estate.

The data collected was analyzed using MSTATC program for Analysis of Variance.

Unfortunately no more information was provided by ARI, Mlingano on the results achieved, therefore no final conclusions are available.

III.5.5 The 'Ultra High Density' (UHD) trials

UHD-1 was obtained in March 2000 through selective plant uplifting of ENT-1 (planted in March 1999 together with CEPS-1). Like CEPS-1 plant development in all densities was quite vigorous during the first year of growth from nursery and after thinning. After one year plants were 50-60 cm tall and 50-60 cm in leaf canopy diameter. In all planting densities above 6,666 plants/Ha it had become difficult to gain access inside the plantation. However it was possible to apply urea fertilizers by hand by moving between rows. Weed growth, although not significant, could not be controlled effectively.

UHD-2, which was obtained by selective plant uplifting in ENT-2 (planted in September 1999 together with CEPS-2), developed quite rapidly during the first year after thinning. As expected, it developed at the same rate as UHD-1, and when plants were one year old in September 2000, they had also grown to 50-60 cm in height and in leaf canopy diameter.

Only UHD-3 plants, which were produced from direct planting of bulbils in the field, did not attain the same degree of growth, despite doubling in size from one year to the next.

At the age of two years after thinning, sisal plants in all densities in UHD-1 and UHD-2 had become mature enough for harvesting. Plots with densities above 6,666 plants/Ha had become completely intertwined, and no intervention in any form could be exercised. Some weed species, which managed to survive the competition from sisal, had become quite prevalent and could not be controlled. Any attempts to harvest sisal for chipping and fibre extraction would have yielded biomass with much foreign green material. Signs of banding disease due to lack of available potassium, and stunted growth due to shortage of nitrogen, became evident in the plots, and no corrective measures were possible.

III.5.6 The selective leaf defoliation trials

This trial was superimposed on block 1 of CEPS-1 trial, whose performance was described in the previous section III.3.5. Generally speaking however, it was noted that severe leaf defoliation caused a reduction in plant growth. Total defoliation also affected the longevity of the plant, and caused the death of a significant number of plants irrespective of variety.

III.5.7 The Gomba fertilizer trials

Different parameters were collected monthly from the trials including: leaf length, plant height, leaf number, pest and disease incidences. Other parameters like number of "cuttable" leaves, leaf weight and fibre yield in tons/Ha were recorded at each harvesting period. Rainfall data for the trial site was also collected. Description of the data collected and of the results achieved is included in section IV.1.6.

Results of the soil analysis from the experimental site before planting indicated that the soils were acidic in nature, deficient in phosphorus and calcium probably due to continuous cultivation without fertilizer application. Exchangeable Calcium was low (1.1-3.8 Cmols(+)/kg) and total Nitrogen was very low (0.05-0.08%). Other plant nutrients like exchangeable potassium was also very low (0.05-0.08 Cmols(+)/kg) while available Phosphorus was medium (17-21 mg/kg) and organic Carbon was low (0.73-1.12%) (Annex 1, Table 1).

Based on these observations it was recommended that inorganic fertilizers like CAN (100kg/Ha), MOP (100-500kg/Ha/life cycle) and lime (7-10 tons/Ha) be incorporated to improve the soil pH and Calcium level in the soil. Alternatively it was advised to apply organic fertilizers (sisal waste) at 40-50 tons/Ha or plant leguminous plants (as cover crops) to improve soil Nitrogen and organic matter.

Based on these observations, treatments for the different fertilizer types and amounts were selected and applied as presented in Annex 1, Table 2.

In September 2003 the soil was analyzed again and the results indicated that the soil fertility had improved considerably (Annex 1, Table 3). Soil pH for example improved from medium acid to slightly acid (6.1 - 6.6), total Nitrogen percentage also slightly increased from the previous tests (0.1-0.18%), available Phosphorus improved mostly from medium to high (22.09-34.47 mg/kg). Both exchangeable Calcium (5.3-12.6 Cmols (+)/kg) and Potassium (0.33-11.14 Cmols (+)/kg) improved considerably.

The information provided by ARI, Mlingano on the results achieved is included in Annex 8. No other information or comment on the performance of the trials was provided.

III.6 Dissemination of results

The results of this sub-component were disseminated through:

- A Dissemination Workshop held in Tanga in February 2003: At the Workshop a presentation was given on A.3 by the international expert;
- An International Dissemination Workshop held in Tanga in November 2004: at the Workshop presentations were given by the national and the international experts;

The CEPS trials, the 3-factor trials and the Gomba trials are accessible to farmers and stakeholders and the positive results achieved with CEPS are well known by estate owners and small holders.

IV. Lessons Learned

IV.1 Data, results and conclusions

IV.1.1 The enhanced nursery trials

Results from the two enhanced nursery trials ENT-1 and ENT-2 indicate that in the project area, if soil amendments and fertility are managed according to indications based on a soil test, sisal bulbils nurseries planted at the rate of 100,000 bulbils or more per hectare, just before the onset of the long rains, can be expected to produce vigorous and healthy plants ready for transplanting, within a period of six months, at the onset of the short rains.

The cost per nursery seedling, before lifting, will vary with the density of planting, and will range from 4 to 8 TZS (Tanzanian Shilling)/plant.

The single most costly input in the operation is the dolomitic limestone required to amend the acidic soils prevalent in the area (40% of total cost). If the site is used more than once as a permanent nursery location, this cost can be spread over at least 3-4 crops, hence greatly reducing the cost of the resulting seedlings.

Advantages stemming from the vigour, size, and uniformity of the seedling lead to further savings in the establishment of permanent sisal fields. Therefore investing in the ability to provide irrigation water in a sisal nursery when needed, guarantees the capability to produce healthy vigorous plants in a period of 6 months or less, regardless of season.

Unfortunately it was not possible to establish project nurseries with Meristematic Tissue Culture (MTC) material produced by the project (sub-component A.5) because at the time when the nursery was established the MTC laboratory was still under development and not enough material was available.

IV.1.2 The CEPS demonstration trials

The most important attribute of the trials for the purposes of the project was the fibre production potential and cost per unit area, even though other observations such as rate of leaf unfurling, leaf length, number of leaves per plant, plant height, and damage due to diseases and pests were also important and were duly recorded.

In order to establish the staple fibre production potential of the new CEPS production system, biomass and fibre production yields were measured through sampling at incremental ages of plant development starting at 24 months after planting and ending at 54 months. At each harvest a number of undisturbed plants ranging from 50 to 100 were totally defoliated to measure fresh leaf biomass. Bole biomass was obtained, based on the average of a representative sample of 10 boles.

Although the size of the sample from which data was drawn was relatively large, it is not implied that the data obtained accurately depicts the anticipated results from a large commercial size plantation established using the same system of production. The nature of the sampling and the trials does not allow, for making judgements on the statistical significance of the data obtained. Nevertheless the numbers shown in the tables to follow are based on the assumption that the plantation would hold 100 % of the plants planted.

Table 2 below shows the potential total plant biomass production per hectare of plantation for the four commercial varieties at two densities of planting; sampled sections of the plantation were allowed to develop undisturbed from planting to harvesting age.

Table 2. Potential fresh whole-plant biomass production capabilities of four sisal varieties at two high-density planting modes when harvested at four field stages (1999-2004).

Variety and Density		Potential fresh whole-plant biomass yield at various ages (MT/Ha)			
Variety	**Density** (plants/Ha)	**24 Months**	**34 Months**	**44 Months**	**54 Months**
Hybrid 11648	6,400	317	361	580	634
Hybrid 11648	8,000	260	306	295	344
A. Sisalana	6,400	234	254	239	250
A. Sisalana	8,000	202	230	235	351
A. Hildana	6,400	224	247	372	323
A. Hildana	8,000	272	258	224	319
H. Mlola	6,400	224	215	256	374
H. Mlola	8,000	211	229	148	377

The data in Table 2 clearly indicate that under conditions of the trial, irrespective of density of planting, sisal varieties had the potential of increasing their biomass output as time passes by. The degree of increase of potential biomass was highest for the Hybrid 11648, followed by Hybrid Mlola 487: the Hybrid 11648 at 6,400 plants/Ha displayed the ability to double in biomass yield from the age of 24 months to the age of 54 months.

Hybrid 11648 performed significantly better at the lower density of 6,400 plants/Ha, while Hybrid Mlola 487 performed equally at both densities. Agave Sisalana and Agave Hildana were quite similar in their performance and produced significantly less biomass than the two hybrids.

When the biomass data is broken down into its contributing factors: leaves and bole, all varieties at all planting densities had a higher ratio of leaf biomass to bole biomass at a lower age of the plant. In fact after the age of 44 months the contribution of bole biomass to total biomass was in the majority of the cases higher than leaf biomass. This suggests that the potential of the plant to produce leaf biomass is generally constant and it is dependent on soil fertility and moisture. It was noted that the older the unharvested plant gets, the more dried-out lower leaves it will have, while new leaves unfurl and increase the size of the bole. So if the sisal plant is left undisturbed (no selective leaf harvesting is done), the bole mass increases and the leaf mass increases, but because of apical dominance (youngest leaves "unfurled" receive most nutrients and have the highest growth rate), in the presence of limited nutrient and water resources, the oldest leaves die out and their nutrients are used up by the younger leaves. In fact measurements of number of leaves available for harvest at any one stage were around 100 leaves plus/minus 10-15 % per plant.

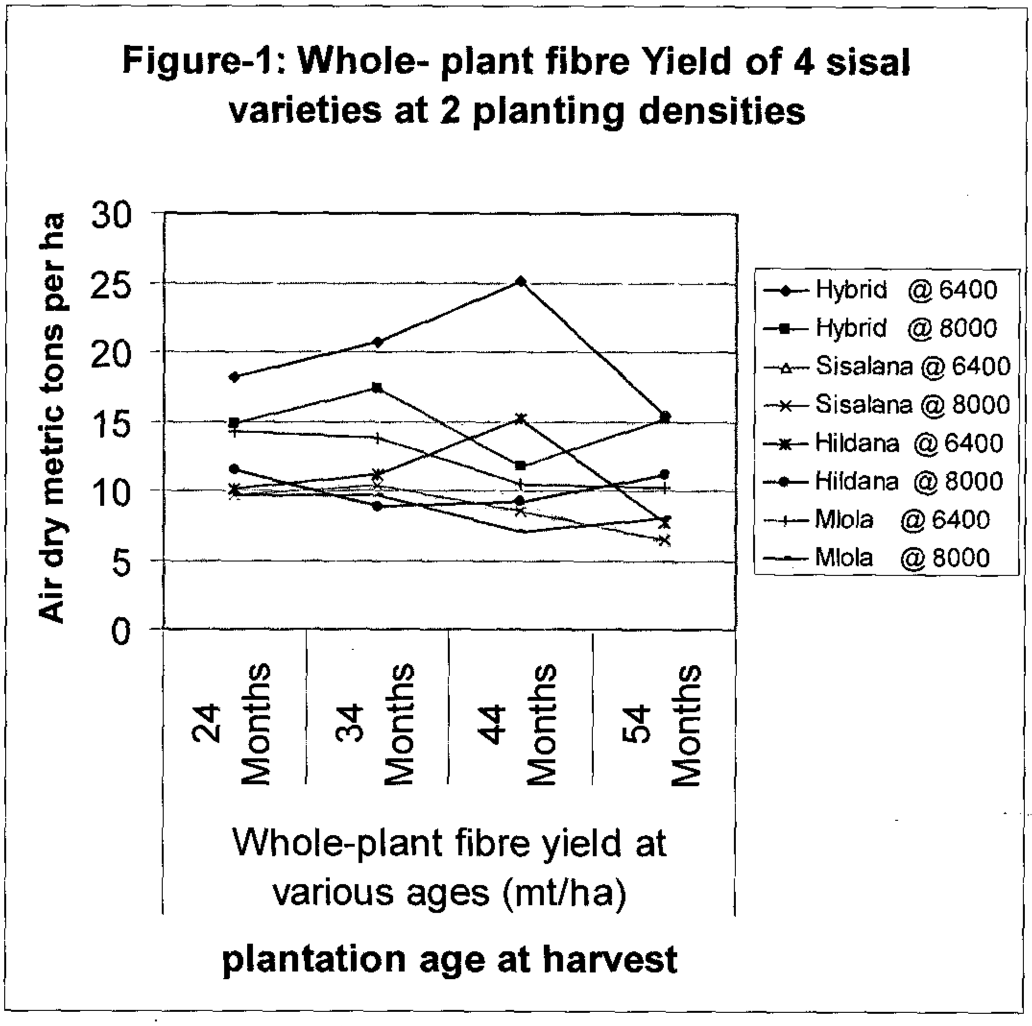
Hence in order to maintain a high growth rate and a higher contribution of leaf biomass, when selective leaf harvesting is done (the oldest leaves are harvested regularly), the soil should be provided with additional nutrients to replace those lost in the harvested leaves.

At each harvesting stage, the fibre content in the biomass was measured using either a roller-crusher, or a decorticator or a hammer mill. As anticipated, the percentage of fibre was obtained by dividing the air-dry weight of the fibre by the fresh weight of the parent biomass. The potential fibre production capacity of the four sisal varieties planted at two planting densities, at various stages of development is presented in Table 3 and a fibre production curve is represented in Figure 1.

Table 3. Potential whole-plant staple fibre production capabilities of four sisal varieties at two high-density planting modes when harvested at 4 field stages (1999-2004).

Variety and density		Whole-plant fibre yield at various ages (MT/Ha)			
Variety	**Density** (plants/Ha)	**24 Months**	**34 Months**	**44 Months**	**54 Months**
Hybrid 11648	6,400	18.2	20.7	25.1	15.4
Hybrid 11648	8,000	14.8	17.4	11.7	15.2
A. Sisalana	6,400	13.5	14.6	9.1	5.8
A. Sisalana	8,000	9.6	10.3	8.5	6.4
A. Hildana	6,400	10.1	11.1	15.2	7.7
A. Hildana	8,000	11.5	8.9	9.2	11.2
H. Mlola	6,400	14.3	13.8	10.5	10.2
H. Mlola	8,000	9.7	9.7	7.0	8.0

Figure 1. Fibre production curve of four sisal varieties (1999-2004).



The data in Table 3 and Figure 1 clearly indicate that Hybrid 11468 is superior to the other varieties for the production of whole-plant staple fibre, irrespective of density of planting. Hybrid 11648 continued to increase fibre production from the age of 24 to 44 months, when the density was 6,400 plants/Ha, but that at 8,000 plant/Ha there was no advantage in leaving the sisal to grow beyond 34 months before total harvesting.

Hybrid Mlola 487 performed well at 24 months and did not significantly increase its fibre production capability after two years, if left uncut (note that all samples were left uncut until their harvest). Its performance actually became negative after the third year in the field.

Agave Sisalana had a performance similar to Mlola's, but Agave Hildana, displayed better potential for increasing fibre production at the 6,400 plants/Ha, but not at the 8,000 plants/Ha density.

The results for potential biomass production do not exactly reflect the results for potential fibre production, as can be inferred comparing Table 1 and Table 3. If the percentage of fibre in the biomass had remained constant, Hybrid 11648 would have demonstrated a fibre production curve that continued to increase, as the plant got older between 44 and 54 months. Instead we see that even though biomass increased at 54 months, fibre decreased. This can be explained by the fact that at growth stage older than 44 months the contribution to the (total) biomass comes heavily from bole material. When extracted, fibre in the bole material tends to be shorter in size and would be lost in the process of fibre extraction and cleaning. Moreover, at 54 months, up to 50% of the older leaves on the plant have become dry and unusable. Some of these leaves may have contributed to the biomass but not to the extracted fibre. Leaf fibre percent in sisal is known to stabilize at around 5.5% - 6% as the plant matures, and in traditional cyclical harvesting systems, which use only mature leaves, this percentage is widely accepted as the norm. This observation is further illustrated in Table 4.

The above data indicates that if one is able to use fibre from the whole plant for pulping purposes, it is possible, under the CEPS system of production to obtain more than 20 air-dry metric tons (ADMT) of fibre per hectare. This can be achieved when the Hybrid 11648 is planted at a density of 6400 plants per hectare and is well managed until whole-plant harvesting at the age of 44 months.

In January 2003 it was found that leaf butt-end fibre coming from boles of plants that are over 30 months of age do not get well-cooked while mixed with leaf fibre from the plants of the same age. This has obviously cast great doubts on the potential of using the whole plant for the production of staple fibre for producing high quality pulp.

Bole fibre can, and may, be cooked separately, to produce a lower quality pulp, if there is a market for it. There is no apparent advantage in producing sisal pulp from the whole plant, as this pulp, even though it is available in larger quantities than pulp from leaves only, shall have a lower commercial value and be less competitive than other fibres available on the market.

If leaf fibre is the fibre that is sought for the production of sisal pulp, then from the same data collected, information can be obtained on the comparative potential of leaf fibre production among the various varieties and densities of planting, when plants are left undisturbed and then harvested between 24 and 54 months after planting.

At each round of harvesting made, leaves from the data plants were harvested and weighed separately, this information is reported in Table 4.

Table 4. Potential leaf fibre production capabilities[1] of four sisal varieties at two high-density planting modes when harvested at 4 field stages (2001-2004).

Variety and density		Leaf fibre production potential at various ages (MT/Ha)							
		24 Months		**34 Months**		**44 Months**		**54 Months**	
Variety	**Density** (plants/Ha)	Biomass[1]	Fibre[2]	Biomass	Fibre	Biomass	Fibre	Biomass	Fibre
Hybrid 11648	6,400	209	12.04	191	11.00	247	14.2	334.9	16.6
Hybrid 11648	8,000	182	10.34	163	9.25	168	9.58	203.4	6.2
A. Sisalana	6,400	146	8.41	106	5.8	91	5.0	94.5	4.1
A. Sisalana	8,000	128	6.04	114	6.27	124	6.8	189.3	2.7
A. Hildana	6,400	145	6.50	142	7.1	222	11.10	183.6	6.2
A. Hildana	8,000	179	7.59	145	7.3	112	5.6	185.0	6.0
H. Mlola	6,400	142	9.08	116	6.6	118	6.7	250.6	7.4
H. Mlola	8,000	140	6.5	136	7.75	92	5.25	185.9	6.0

The data shown in Table 4 indicates that, if the plants are left unharvested, the potential for leaf fibre production does not significantly increase in time. In fact, in most cases except in Hybrid at 6,400 and Hildana at 6,400, there seems to be a regression in leaf fibre productivity regardless of variety or planting density.

It can therefore be concluded that the CEPS system of fibre production should be changed so that during at least the first 4-5 years, only leaf fibre would be used from leaf biomass through recurrent selective leaf harvesting, in a way and at an intensity which does not negatively affect the livelihood and production capability of the plant.

In a CEPS plantation, the above data demonstrate that leaf harvesting should begin when plants are 24 months old, maybe even younger. In traditional sisal cultivation, although practiced under lower planting densities, the standard recommendation is to begin leaf harvesting at the field age of 30-36 months. This is explained by the fact that since the CEPS' plantations receive an enhanced package of agronomic inputs which encourages faster crop establishment and growth, and due to higher densities, plant leaves mature earlier, and can therefore be harvested earlier.

In essence, in well-managed CEPS plantations it can be expected (section IV.1.4) to obtain more than four MT/Ha of leaf fibre per annum. This is almost double of what is achieved under traditional practice.

[1] This refers to fresh weight of all harvestable leaves from the plant excluding the centre leaves known as spike, multiplied by 6400 plants/Ha, and divided by 1000.
[2] This is the result of multiplying the potential leaf biomass yield by the percentage of fibre in the leaf as determined from leaves of one representative plant only.

In CEPS-2, as in UHD-1, only the Hybrid 11648 was planted. Data on the three harvests performed on CEPS-2 and on UHD-1 is included in Table 5. It should be noted that the percentage of fibre was determined separately for leaves and boles, using the experimental roller crusher developed by the project.

At 33 months of age, the potential biomass yield per hectare was highest in CEPS-II-A (317 MT/Ha) with a potential total plant fibre yield of 12.2 MT/Ha. The potential fibre production yield varied between the three trials from 8.4 to 12.2 MT/Ha. Unfortunately the number of plants sampled was relatively low, as the maximum number of plants harvested was only 38, despite the fact that 100 were planned. The percentage of leaf fibre varied from 2.8% for UHD-1 plot to 5% for CEPS-II-A plot. This variability is not easily justified, as the traditionally accepted figure is around 5%, and points to possible errors in weighing and to losses in fibre from the roller crushing.

At 44 months of age, the sample accounted for even less plants. The mean plant biomass ranged from 35 to 62 kg, with a potential biomass yield of 227 to 400 MT/Ha, and a potential whole-plant fibre yield from 4.1 to 16 MT/Ha. Mean potential leaf fibre yield of 2.7 to 12.8 MT/Ha were noted. Again the methodology used to extract the fibre from the leaf and bole biomass appears to have yielded abnormally low fibre content, which cannot be justified. This has resulted in a wide range in expected fibre yield from the plantation, and suggests great care be taken before extrapolating these results to the whole plantation.

At 49 months age, in March 2004, the sample size originally asked for of 100 plants was adhered to, and this time fibre yield was actually determined from all the hundred plants, but only from the resulting leaves, since the fibre was extracted using the hammer mill. Mean bole weight was determined from 15% of the plants harvested, but bole fibre was not determined. The actual leaf fibre yield from the three plots varied from 5.6 to 6.3 MT/Ha. The percentage leaf fibre (as extracted by the hammer mill) varied from 3.1 to 4.1%. This is the most significant representation of what might be expected in a large-scale trial, since the results came from a representative sample. Fibre yield in all other observations was obtained from one plant only since the method of extraction was cumbersome and very time consuming.

It should be noted that the average number of harvestable leaves per plant varied from 77 to 102, and the average weight of leaves/plant was around 25.5 Kg/plant. It appears that there is no clear advantage in leaving the plantation to grow beyond 33 months before any harvesting is done. If a whole-plant harvesting system is employed the expected yield of fibre would be around 12-14 MT/Ha regardless whether the plantation is harvested at 33 months of age or left in the field to an age of 49 months.

It should be mentioned however, that the plantation had been already subjected to some leaf cutting in May-June 2003 in order to allow the labourers to enter between rows of plants to apply potash fertilizers and to do some weed control.

The ultimate observation that determines the actual yield of CEPS-II is when the whole plantation is selectively harvested removing an average of 80 leaves/plant, and extracting the leaf fibre using the hammer mill. It is expected that the plantation would yield an average of 8-10 MT of leaf fibre per hectare. The plantation would regenerate to give a crop yielding no less than four MT of leaf fibre per hectare. This would be expected to continue for 3-5 subsequent harvests before the plantation is renewed.

The cost of producing the pulpable leaf fibre would be drawn from the average cost of establishing the sisal plantation to first harvest divided by the number of tons of fibre obtained from the first harvest, plus any other costs incurred in the plantation after the first harvest.

Table 5. CEPS-2 and UHD-1 potential fibre production capabilities of Hybrid 11648 planted at 6,666 plants/Ha, when harvested between 33 and 49 months after establishment (2002-2004).

	No. of plants harvested	Total leaf weight (Kg)	Mean leaf Wt./ plant (Kg)	Mean number of leaves/ plant	Mean bole weight (Kg)	Mean plant biomass (Kg)	Potential biomass (MT/Ha)	% Leaf fibre	% Bole fibre	Mean % whole plant fibre	Potential leaf fibre Yield (MT/Ha)	Potential bole fibre (MT/Ha)	Potencial total fibre (MT/Ha)
33 months													
CEPS-2 A	38	937	24.7	77	24.8	49.5	317	5.0	2.38	3.75	8.23	3.9	12.2
CEPS-2 B	27	612	22.7	98	21.3	44.0	281	3.1	2.27	2.70	4.7	3.2	7.9
UHD-1	23	757	32.9	102	18.0	50.9	326	2.8	1.94	2.50	6.1	2.3	8.4
44 months													
CEPS-2 A	18	663	36.8		25.6	62.4	399	3.3	2.2	2.7	8.0	3.8	11.7
CEPS-2 B	32	646	20.2		15.2	35.4	227	2.0	1.43	1.8	2.7	1.4	4.1
UHD-1	13	363	27.9		17	44.9	287	6.9	2.8	4.1	12.8	3.2	16.0
49 months													
CEPS-2 A	100	2,295	23	100	21	44.3	284	4.1	NA	NA	6.3	NA	NA
CEPS-2 B	100	2726	27.3	88	29.5	56.8	364	3.1	NA	NA	5.6	NA	NA
UHD-1	100	2421	24.2	97	24.5	48.7	312	3.7	NA	NA	6.0	NA	NA

IV.1.3 The three-factor trials

ARI Mlingano provided collected data to compare the effect of variety, spacing and harvesting. The ARI Mlingano final report included the information below.in No clear answers were provided by the laboratory management to the clarifications requested by members of the Project Coordinating Committee (PCC). Doubts were raised during PCC meetings on the actual harvesting time of the variety trials.

The effects of varieties on macronutrient uptake indicated that Mlola 487 had a low uptake of macronutrients while Agave Hildana exhibited high uptake of Nitrogen (N), Phosphorus (P), Calcium (Ca) and Magnesium (Mg). The Hybrid 11648 was found to have higher Potassium uptake while Agave Sisalana and Agave Hildana were found to have higher uptake of Phosphorus (Table below). The variations are probably inherent to the varieties concerned for environmental adaptation.

Mean uptake of macronutrient by different sisal varieties

Variety	N	P	K	Ca	Mg
Mlola 487	1.22	0.13	3.82	1.02	0.92
Hybrid 11648	1.24	0.15	4.24	0.92	0.94
Agave Sisalana	1.43	0.21	4.20	0.82	0.87
Agave Hildana	1.79	0.21	4.13	1.07	0.98

Results from plant tissue analysis also indicated that Nitrogen and Phosphorus uptake was high at 4,444 plants/Ha while the lowest uptake was observed at 8,000 plants/Ha probably due to higher plant competition for nutrients uptake than at low density. However plant density of 6,400 plants/Ha has also high uptake in Potassium and Calcium.

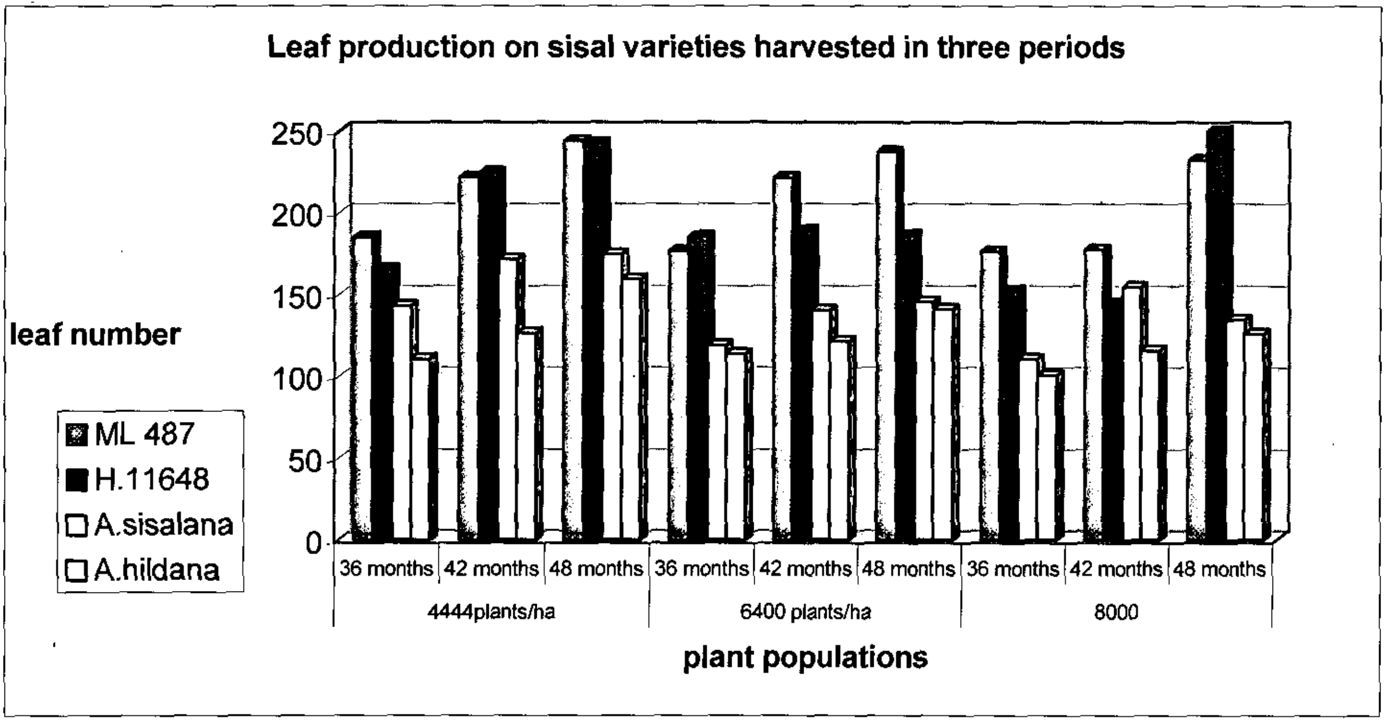
Effects of plant densities on mean uptake of macronutrients of sisal

Plant density	N	P	K	Ca	Mg
4444 plants /Ha	1.55	0.19	3.86	0.95	0.89
6400 plants /Ha	1.41	0.17	4.28	0.98	0.94
8000 plants /Ha	1.30	0.17	4.15	0.93	0.95

The effects of varieties on yields and yield components.

Leaf number is an important yield component due to its major contribution to the fibre yield. Results indicated that at 4,444 plants/Ha ML 487 produced more leaves followed by H.11648. More leaf production at 4,444 plants/Ha was attributed to less competition in terms of moisture, nutrients and light. However, hybrid 11648 produced more leaves at 8,000 plants/Ha than ML 487 particularly at 48 months. Agave hildana produced fewer leaves in all plant densities and harvesting periods followed by A. sisalana. In general treatments harvested at 48 months after planting produced more leaves followed by the second harvesting (42 months from planting). The results imply that the longer the plants remain in the field the more the leaves are produced (Figure2).

Figure 2. Leaf production on sisal varieties harvested in three periods



Leaf number was significantly different with respect to spacing, varieties and harvesting periods (table below). However, leaf number at 4,444 plants/Ha and 8000 plants /Ha was not significantly different. Overall leaf production at 8000 plants/Ha produced fewer leaves probably due to competition for space, nutrients, water and light.

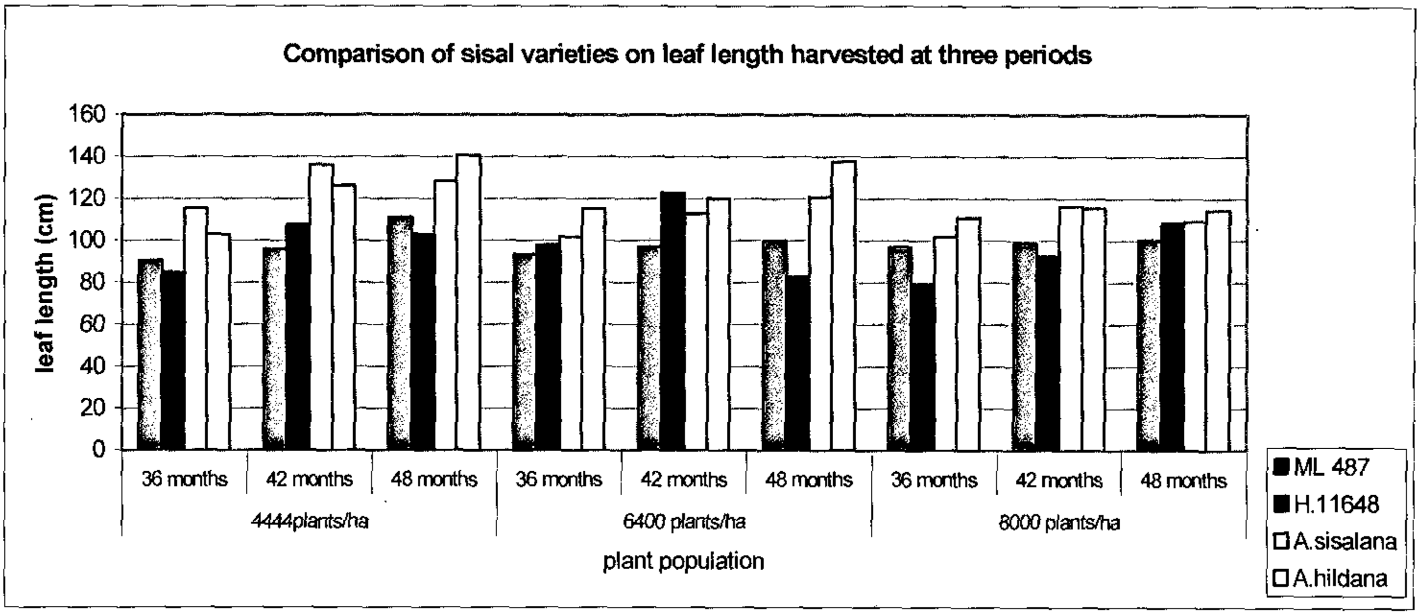
Effects of spacing, varieties and harvesting periods on leaf production

Spacing	Mean leaf number	**Varieties**	**Mean leaf number**	**Harvesting period**	**Mean leaf number**
4444 plants/Ha	180.944 A	ML 487	208.074 A	36 months	145.0 C
6400 plants/Ha	164.917 B	H.11648	188.111 B	42 months	167.6 B
8000 plants/Ha	152.306 B	A,sisalana	144.000 C	48 months	185.6 A
		A.hildana	124.037 D		
CV =16.61					
Lsd(0.05)= 12.92		Lsd(0.05) =14.97		Lsd(0.05) = 12.97	

Leaf extension (leaf length) is an important parameter for field management particularly at high density planting. Results from the trial indicated that at lower plant density (4,444 plants/Ha), Agave Hildana produced longer leaves followed by Agave Sisalana

(Figure 3). Most varieties produced short leaves at 8,000 plants/Ha probably due to competition for space and nutrients.

Figure 3. Comparison of sisal varieties on leaf length harvested at three periods



Regarding plant height, sisal varieties at wider spacing (4,444 plants/Ha) were taller than at narrow densities (6,400 and 8,000plant/Ha) (Table 6a). In general Agave Sisalana produced the tallest plants followed by Agave Hildana while ML 487 and H.11648 produced the shortest plants. Plant heights of Agave Sisalana and Agave Hildana are not significantly different. The same applied to ML 487 and Hybrid 11648.

The interaction effects between spacing and varieties were also significantly different (see table below). The most suitable combination of plant density and varieties which produced the tallest plants were at 4,444 plants/Ha with Agave Sisalana followed by Agave Hildana at 6,400 plants/Ha

Effects of spacing and varieties on plant height

Spacing	Mean plant height cm	Varieties	Mean plant height (cm)
4,444 plants/Ha	152.6 A	ML 487	136.8 B
6,400 plants/Ha	144.0 B	H.11648	132.0 B
8,000plants/Ha	140.2 B	A. Sisalana	157.9 A
		A. Hildana	155.7 A
CV =11.66			CV =11.66
Lsd (0.05) 7.98			Lsd (0.05) = 9.215

Effects of Interactions between spacing and varieties on plant height

Plant densities	Varieties	Mean Plant height (cm)
4,444 plants/Ha	ML 487	138.444 DE
4,444 plants/Ha	H.11648	135.000 DE
4,444 plants/Ha	A.sisalana	177.889 A
4,444 plants/Ha	A.hildana	159.000 BC
6,400 plants/Ha	ML 487	138.689 DE
6,400 plants/Ha	H.11648	130.667 E
6,400 plants/Ha	A.sisalana	145.111 CDE
6,400 plants/Ha	A.hildana	161.667 B
8,000 plants/Ha	ML 487	133.333 E
8,000 plants/Ha	H.11648	130.478 E
8,000 plants/Ha	A.sisalana	150.778 BCD
8,000 plants/Ha	A.hildana	146.333 BCDE
	Lsd (0.05) = 15.96	

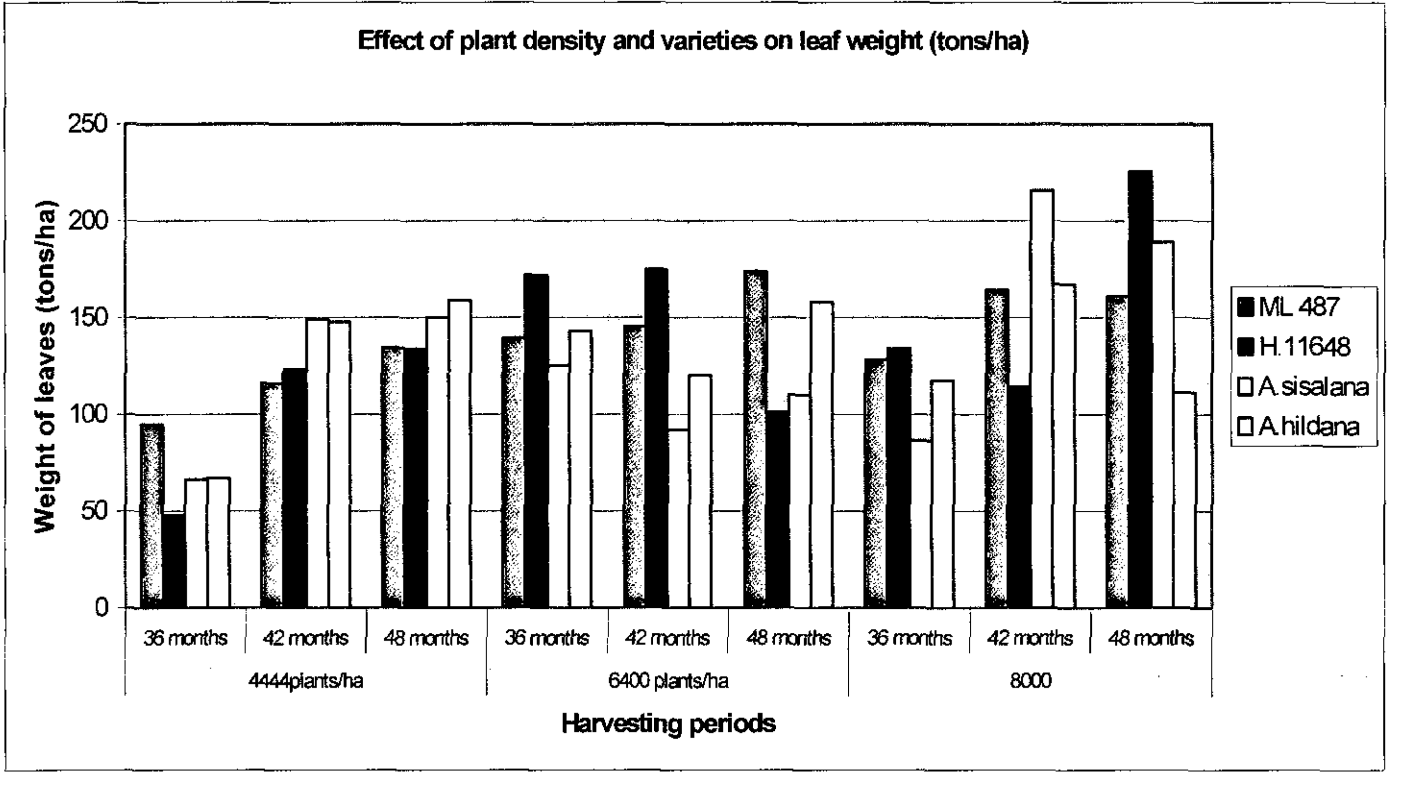
According to Duncan Multiple Range Test (DMRT), means followed by the same letter are not statistically different.

Leaf weight was generally higher at 42 and 48 months after planting probably because the longer the plants stay in the field the more the leaves produced. Hybrid 11648 recorded heavier leaves at 48 months after planting followed by Agave Sisalana (Figure 4). The first harvesting (36 months after planting) differed significantly with the rest (42 and 48 months after planting) in terms of leaf weight. However during the second and third harvesting (42 and 48 months after planting), leaf weight did not result in significant differences between the two harvesting periods (table below).

Effects of harvesting periods on leaf weight

Harvesting time	Leaf weight in (kg)
36 months	424.333B
42 months	584.694A
48 months	562.583A
Lsd (0.05) =110.9	

Figure 4. Effect of plant density and varieties on leaf weight (tons/Ha)



Highly significant differences on bole weight were observed between harvesting times. The third harvesting (48 months after planting) produced heaviest boles followed by the second harvesting (42 months from planting). The results imply that the longer the plants stay in the field, the more boles increase in size and therefore weight more. The most suitable combination between spacing and harvesting time, which produced heavier boles, included 8,000 plants at 48 months followed by 4,444 plants/Ha at 48 months (table below). The choice between the two plant densities depends on economic returns and on how much easier one can carry out field management practices like weeding, slashing and fertilizer applications in the field. In this trial, the lower density (4,444 plants/Ha) made it easier to carry out field management practices than other densities.

The interaction effect of spacing and harvesting time on bole weight

spacing * harvesting time		
Spacing	**Harvesting periods**	**Mean bole weight (kg)**
4,444 plants/Ha	36 months	198.833E
4,444 plants/Ha	42 months	395.417BC
4,444 plants/Ha	48 months	461.000B
6,400 plants/Ha	36 months	346.417CD
6,400 plants/Ha	42 months	364.333BCD
6,400 plants/Ha	48 months	408.333BC
8,000,plants/Ha	36 months	270.250DE
8,000,plants/Ha	42 months	399.500BC
8,000,plants/Ha	48 months	577.750A
Lsd (0.05) =113		

Total biomass (leaf and bole weight) varied significantly at 36 and 48 months after planting (table below). The total biomass at 48 months and at 42 months after planting were however not statistically different.

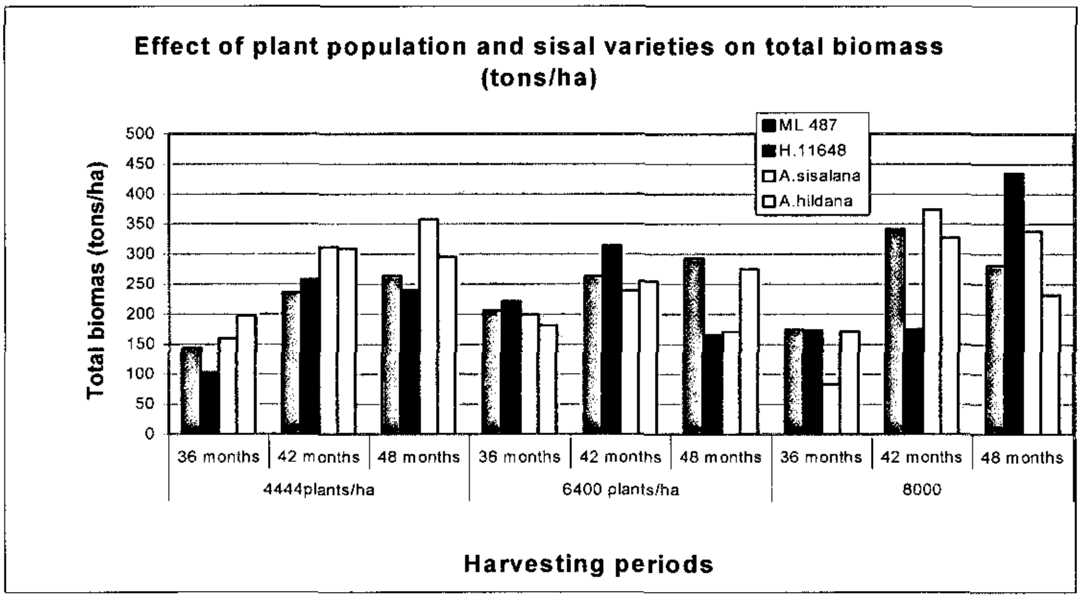
Effects of harvesting time on total biomass

Harvesting time	**Total Biomas (kg)**
36 months	696.1 B
42 months	990.7 A
48 months	1032 A
CV = 37.57	
Lsd (0.05) = 160.1	

According to Duncan Multiple Range Test (DMRT) means followed by the same letters are not statistically different

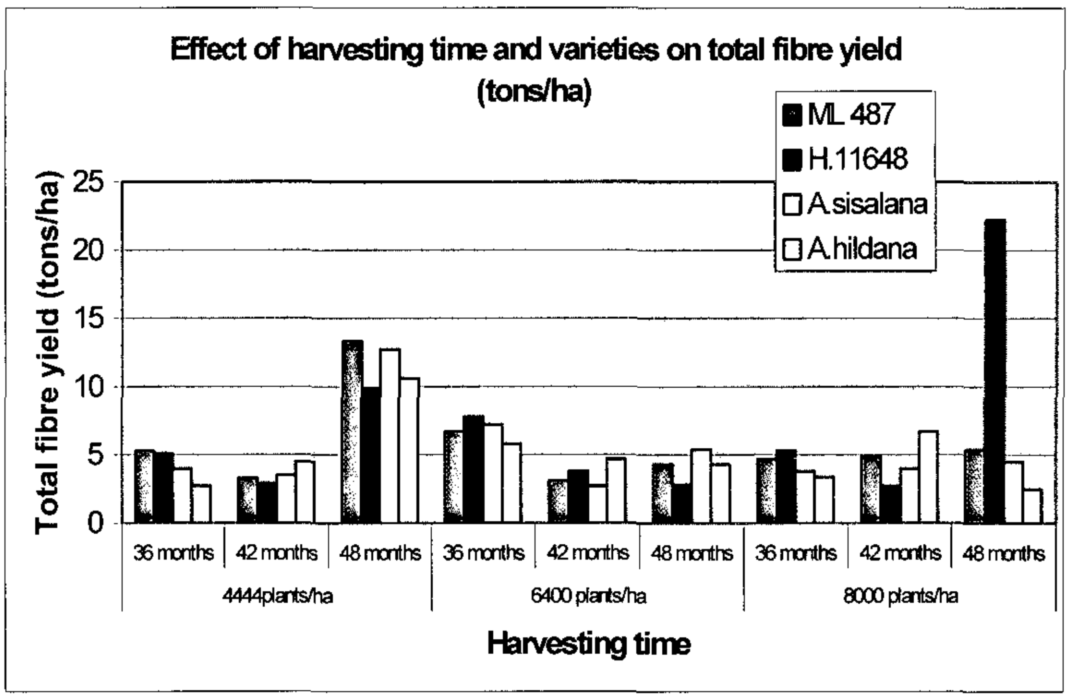
The performance of hybrid 11648 at 48 months after planting at a density of 8,000 plants/Ha was the highest followed by Agave Sisalana at 42 moths after planting at a density of 6,400 plants/Ha (Figure 5). The overall performance of total biomass for the two commercial varieties (Agave Sisalana and Hybrid 11648) was high when compared to the other varieties.

Figure 5. Effect of plant population and sisal varieties on total biomass (tons/Ha)



Variety differences in total fibre yield were observed from different harvesting periods (Figure 6). The yields were however very inconsistent due to different types of decorticators used. During the first and second harvesting periods (36 and 42 months after planting) a stationary decorticator was used while during the third harvesting period 48 months after planting) a hammer mill was used.

Figure 6. Effect of harvesting time and varieties on total fibre yields (tons/Ha)



Comparison of harvesting periods on leaf weight and total biomass

Harvesting time	Leaf weight in (kg)	Total Biomas (kg)
36 months	424.333B	696.1 B
42 months	584.694A	990.7 A
48 months	562.583A	1032 A
Lsd (0.05) =110.9		Lsd (0.05) = 160.1

The effects of varieties on pests and disease incidences. Average disease incidences for sisal with respect to bole rots on Hybrid 11648 and ML.487 was 3% for 4,444 plants/Ha and 4% for higher densities (6,400 plant/Ha and 8,000 plants /Ha) while Agave Sisalana and Agave Hildana were free from the disease (table below). In the first two years sisal weevil infection was frequently suppressed through application of Decis at 7 ml/litre of water. Sisal weevils affected all the tested varieties but at a varying magnitude (table below). Hybrid 11648 had the highest infection level (3-6%) probably because of its high sugar content. Average bole rot infection was serious (10%) during the first year particularly in Hybrid 11648 (8,000 plants/Ha). The disease development was reduced considerably to a constant level (4%) in the third and fourth years.

All sisal plants of Hybrid 11648 and ML.487 had KLS while Agave. Sisalana and Agave Hildana were free from the disease. Purple Leaf Tip Roll, which is a nutritional disease (mainly Potassium), was observed in the fourth year particularly at high densities. It is important that additional fertilizer applications be carried out particularly in high density planting to maintain the soil fertility status.

Bole rot incidences and purple leaf tip roll on the tested varieties

Varieties	Plants sampled	Average percentage of plants affected by sisal rot for each spacing			Average plants affected by Purple leaf tip roll at different spacing		
		1.5 x 1.5m	1.25 x 1.25m	1.25 x 1m	1.5 x 1.5m	1.25 x 1.25m	1.25 x 1m
ML.487	50	3 %	3%	4%	3.3%	5%	9%
Hybrid 11648	50	3%	4%	4%	3.3%	6%	10%
Agave Sisalana	50	0	0	0	4%	8%	11%
Agave Hildana	50	0	0	0	3%	4%	4%

Sisal weevil infection for the sisal varieties in different plant densities

Varieties	Plants sampled	Average percentage of plants with bite marks of sisal weevils in different spacing		
		1.5 x 1.5m	1.25 x 1.25m	1.25 x 1m
ML.487	50	3%	4%	5%
Hybrid 11648	50	3%	5%	6%
Agave Sisalana	50	4%	5%	5%
Agave Hildana	50	4%	4%	5%

IV.1.4 The ultra high density trials

After two years from thinning, all plots having densities higher than 6,666 plants/Ha demonstrated a slowed rate of development. Plant height, leaf length, and leaf number became more or less stagnant.

Observations taken on biomass yield, beginning at the age of 24 months, based on whole-plant harvesting, indicated very little difference in biomass yield between the various densities. Biomass yield varied from 190 to 229 MT/Ha. Examination of fibre content from the whole plant indicated an average fibre content of 5-6% demonstrating an advanced level of maturity in the plantation despite its young age.

The observed results indicate that if whole-plants are harvested, one hectare of high density planting would be expected to produce around 10-12 MT of fibre.

Subsequent observations taken a year later showed more or less the same results, except for the lower density of 6,666 plants/Ha, where the potential mean fibre yield increased up to 16 MT/Ha.

At the age of 36 months, all high density plots having more than 6,666 plants/Ha showed an extreme incidence of KLS, as well as banding disease. Plants had not developed in height and in canopy. Upon examination it was noted that the lowest two rings of leaves on the plants had been desiccated. Weed growth had become rampant and overtaken the plots. Further sampling for measurement of biomass indicated a regression in biomass yield, but not in fibre content as a percentage. Whole-plant fibre obtained from various densities could not be satisfactorily pulped and even if it could, the inevitable inclusion of materials coming from weeds, in a system of whole-plant harvesting, would make it quite impractical, and undesirable.

In addition to that, in the absence of a mechanical system of whole-plant harvesting, harvesting leaf from such plots was quite difficult and undesirable because leaves were quite small and ranged in weight from 60-200 grams. Boles ranged from 2-14 kg, and from 8-15 cm in diameter. The lower numbers always came from the plots with higher density.

With such obvious negative manifestations, it was decided to abandon any further observations from all densities except the 6,666 plants/Ha, which simulated the most promising density in CEPS-1 and CEPS-2 trials.

IV.1.5 The selective leaf defoliation trials

Since the leaf fibre yields at age 24 months were quite impressive, the international consultant proposed to use CEPS also for the production of traditional line fibre. However, as there was no previous experience on the response of plants and their tolerance to aggressive plant defoliation under high density; and since the quality of the fibre that would be produced under such a system was not assured, it was decided to superimpose a trial to measure the effect of intensity of plant defoliation on leaf fibre production potential and persistence of the plantation.

The trial was easily accommodated in the CEPS-1 field and the first observation was taken at age of 24 months. The second observation was taken eight months after the first, at 32 months of age, and the third observation one year after that. The fourth observation was done in March 2004 at 54 months of age, but only in the Hybrid 11648 variety at a density of 6,400 plants/Ha, because it was the most promising among all the treatments in the CEPS-1 trials. The results are shown in Table 6.

Table 6. Potential leaf fibre production capabilities of four sisal varieties under variable occasional leaf harvesting intensities over a period of 30 months (2001-2004).

	Potential leaf fibre production capability (fibre yield) at various leaf harvesting intensities and at various ages (MT/Ha)						
Variety and Density	**Leaf removal intensity**[3]	**1st cut 24 Months**	**2nd cut 32 Months**	**3rd cut 44 Months**	**4th cut 54 Months**	**Total**	**Mean MT/Ha /year**
Hybrid 11648	0	4.8	3.6	5.1	2.67	16.2	*4.04*
6,400 plants/Ha	5		4.0	7.6	5.71	17.3	*5.77*
	10		4.4	5.1	4.57	14.07	*4.69*
% LF=5.75	15		-	3.7	7.99	11.69	*5.84*
	20		3.1	4.6	3.73	11.43	*3.81*
A. Sisalana	0	3.8	3.5	1.6	N/A	8.9	2.96
6,400 plants/Ha	5		2.2	2.2	N/A	4.4	2.2
	10		2.3	3.0	N/A	5.3	2.65
% LF= 5.5	15		2.1	2.0	N/A	4.1	2.05
	20		2.1	1.6	N/A	3.8	1.9
A. Hildana	0	3.7	2.5	1.5	N/A	7.7	2.57
6,400 plants/Ha	5		2.6	4.0	N/A	6.6	3.30
	10		3.0	3.5	N/A	6.5	3.25
% LF= 5.5	15		1.9	4.2	N/A	6.1	3.05
	20		-	5.0	N/A	5.0	2.5
H Mlola	0	4.1	2.5	4.3	N/A	10.9	3.63
6,400 plants/Ha	5		2.3	4.0	N/A	6.3	3.15
	10		-	4.1	N/A	4.1	4.1
% LF=5.75	15		2.1	2.6	N/A	4.7	2.35
	20		1.7	3.5	N/A	5.2	2.6

This trial assumed a higher degree of importance in the R&D program when it became evident that only leaf material would be used for producing fibre for pulping purposes. The trial became the most appropriate source of data for measuring the potential leaf fibre production capability in a CEPS plantation. The first observation from the 8-density /variety treatments was recorded at 24 months, but due to errors in data recording, leaf biomass data was recorded only for the total defoliation intensity. Subsequent observations were taken from the same plants that had been harvested before at periods varying from 8 to 12 months.

However, the above results only demonstrate the *potential* production capacity, without regard to the effect of leaf cutting intensity on plant persistence. During the 30 months from the first harvest to the fourth, it was observed that under severe leaf defoliation, i.e. zero and five leaves left per plant at each harvest, a significant number of plants were stunted and or died completely. Hence, under a large-scale production, this can very

[3] Intensity 0 refers to total plant defoliation except for the unfurled center spike; the remaining intensities refer to the number of unfurled leaves left on the plant around the central spike. The higher the number the less is the number of leaves cut from the plant.

significantly reduce the actual amount of fibre produced per hectare. If the four varieties were to be ranked in descending order of tolerance to severe plant defoliation, the order would be: Hybrid 11648, A. Hildana, A. Sisalana, and H. Mlola 487.

Again Hybrid 11648 at an intensity of 6,400 plants/Ha was the best performer, and hence the recommendation that the cyclical leaf harvesting observations be continued for another 2-3 years but only on this hybrid.

It is important to note that the data on fibre content from the first three harvests is based on the fibre extracted with the traditional leaf decorticator. The fibre produced at 24 months had a high percentage of short fibres. In the second and third harvests, as anticipated, the line fibre was much better in quality, and in fact had a higher amount of long fibres. The fourth observation, done only for the Hybrid 11648 at 54 months, was obtained through hammer milling of chipped leaf material. Considering that the hammer mill has a fibre recovery rate higher than the corona, if the leaf biomass obtained from the first three harvests were chopped and hammer milled, instead of decorticated, the resulting fibre yield would have been higher.

Hence for producing pulpable fibre, if Hybrid 11648 is grown in a well-managed CEPS program it can produce an average of around 4-5 MT of fibre/Ha/year. The plantation, if well managed after each harvest (fertilizer application and weed control), would remain highly productive for at least 5 years.

IV.1.6 The Gomba fertilizer trials

As mentioned in a previous section different parameters were collected monthly from the trials including: leaf length, plant height, leaf number, pests and disease incidences. Other parameters like the number of "cuttable" leaves, leaf weight and fibre yield in tons/Ha were recorded at each harvesting period. Rainfall data for the trial site were also collected. The information included below was reported by ARI, Mlingano. It was not possible to obtain clarifications on it or the complete set of data collected.

Leaf length is an important growth parameter as it affects the quality of traditional long sisal fibre and therefore the profit margin of the grower. Preliminary results over four years indicate that application of 2.5 tons of lime and 100 kg/Ha of CAN, 5 tons of lime and 100 kg/Ha of CAN, and 40 tons of sisal waste with 7 tons of lime produced longer leaves, while the control treatment and 40 tons of sisal waste only had shorter leaves compared to other treatments (Annex 2, Figure 2). Other treatments had medium leaf length as shown in Annex 2, Figures from 3 to 8. As it can be easily inferred, treatments with longer leaves had taller plants. This is shown in Annex 3, Figures from 9 to 14. Raw data is presented in Annex 1, Table 4.

Leaf production is also an important yield parameter of economic relevance. The trials proved that the application of 2.5 tons of lime and 100kg/Ha of CAN, of 5 tons of lime & 100 kg/Ha of CAN and of 7 tons of lime and 100kg/Ha of CAN gave the highest cumulative leaf number in four years (Annex 4, Figure 15). The control treatment and application of decomposed sisal waste (40 tons/Ha) & 100kg of MOP/Ha gave the lowest number of leaves. The effects of other fertilizer combinations on leaf production were better than the traditional practice (control) as shown in Annex 4, Figures from 16 to 20. These results suggest the need for fertilizer application to improve sisal productivity and reduce the production costs of the sisal grower. Raw data is presented in Annex 1, Table 4.

Fibre yield was also considered a major parameter. According to the data collected in the treatments, 2.5 tons of lime & CAN 100kg/Ha, 5 tons of lime & CAN 100kg/Ha and 10 tons of lime & MOP 100 kg/Ha had higher yields as compared to unfertilized treatments (Annex 5, Figure 20). Results also indicated that fibre yield from the third cut were generally lower than the second cut probably due to lower leaf production attributed to drought which persisted in 2003 (Annex 6). Other results are presented in Annex 5, Figures from 21 to 27. Raw data is presented in Annex 1, Table 5.

Disease and pest incidences were monitored during the experiments. Normally cutting the trial after six months has reduced disease incidences and initially (in 2000 and 2001) all plants were clean from KLS disease. The disease development started in 2002, and it affected between 50% and 100% of the plants. In 2004 the KLS disease affected all plants.

Regarding sisal weevil infestation, the attack was more severe in 2000 and 2001 probably due to application of sisal waste, which is a breeding site for the weevils. As the sisal waste was depleted in the field and considering that plants became older (normally sisal weevils prefer young sisal plants of less than 2 years), the severity of weevil infestation also decreased. It is therefore important to plan ahead strategies for sisal weevil control in immature sisal particularly when sisal waste is used as fertilizer. The severity of KLS disease and sisal weevil infection in the sisal demonstration trial is presented in Annex 7.

IV.2 Development lessons

The implemented activities met the main sub-component objective of evaluating the performance of the different varieties and of confirming the benefits, in terms of productivity and cost reduction, of the CEPS system. Unfortunately the variety evaluation part was done mainly through literature research as the results obtained by the 3-factor variety trials, in which the influence of the variety was to be specifically determined, were not as expected.

As for other sub-components, changes and adjustments were necessary during implementation in order to meet the main objective of improving planting material to produce sisal fibre at competitive prices for both the traditional and the pulp and paper market. In particular it was set as target for CEPS trials the production of sisal pulping fibre at about US$ 100 per MT. The CEPS trials were made large enough to simulate commercial scale application and therefore the related costs.

Because of many factors related to unavailability of resources or of timely funding, some interventions were either inadequately conducted or not done on time. This is clearly reflected in the performance of the trials as well as in the efficiency in the use of the funds. Nevertheless it was possible to estimate the costs involved in the different phases (nursery – field) to demonstrate the adequacy of the CEPS program to be used in the feasibility analysis for a Fibre Extraction Plant.

With respect to the Gomba fertilizer trials it should be noted that the bulk nature of lime and sisal waste causes higher transport costs, which is a major limitation for their application in sisal fields. Mining activities (removing of sisal waste from the collecting pit) of sisal waste and its application also is a major problem for its application. The industry should therefore look for alternative equipment for application of sisal waste. The system used at Rea Vipingo in Kenya, where excavators and muck spreaders are used in mining and spreading of the waste in the sisal field, needs to be further evaluated.

The advantages of sisal waste application include its high content of nitrogen, improvement of soil structure and water holding capacity. Similarly planting of cover crops between the broad lanes should be encouraged to improve soil fertility (soil nitrogen and organic matter improvement).

Application of cover crops in sisal plantations has not been adopted. Research for other cover crops, beside tropical kudzu, which can be consumed as food, are likely to be adopted particularly by smallholder sisal growers to improve soil nitrogen and organic matter. Gomba sisal estate has started using Dolichos lablab (Fiwi), which is consumed or sold for making biscuits. Such cover crops can significantly reduce the production costs and improve the soil fertility status for sisal production.

The deficiencies in managerial approach towards the project objectives and activities at the ARI Mlingano institution affected the performance of the 3-factor trials, the data collection and data exchange with the national and international agronomists. The fertilizer trials also experienced, to a certain extent, the same problem.

Consequently, an integrated and comprehensive review of the results achieved in the CEPS trials, 3-factor trials and fertilizer trials was not possible. In terms of cost reduction, the information utilized to perform the feasibility analysis was obtained from the CEPS trials only.

IV.3 Operational Lessons

As mentioned and pointed out in the A.5 Tanzania report, problems were experienced with ARI, Mlingano. Lack of commitment from the management resulted in communication problems with the PEA and the international expert. Despite the tentative corrective actions taken, no satisfactory results were obtained in particular for the 3-factor variety trials. Changes at the management level would have been necessary and were promised by the Tanzania Sisal Board but never implemented. Considering the key role of local experts and contractor in project success, in the future a more careful evaluation of the proposed collaborating institution should be done at the beginning of project implementation, as taking corrective actions when the activities are ongoing is hardly possible.

The implementation arrangements with Katani Ltd. for the CEPS trials proved to be satisfactory, despite the fact that because of delays in reporting that caused unavailability of resources or of timely funding, some interventions were either inadequately conducted or not done on time (see section IV.2).

V. Conclusions and Recommendations

Technical conclusions are included in sub-sections IV.1, and for the results of the pulping trials reference should be made to the report of sub-component C.2. In this section only a few points presented by ARI, Mlingano as Mlingano's team conclusions are reflected and a sub-section which includes a summary of the costs of CEPS I and CEPS II, as the agricultural component in fibre production represents a major contribution to fibre costs. Katani Ltd. incurred these costs in the preparation of the feasibility analysis for a FEX plant included in the report of sub-component C.1.

V.1 Conclusions from ARI Mlingano

At higher plant densities, due to competition for available space and nutrients, plants tend to produce fewer leaves than at lower densities. Similarly at higher densities plants tend to be shorter due to competition for moisture and nutrients.

In this study the third harvesting period (48 months after planting) produced more total biomass than the first and second harvesting time (42 months after planting). This implies that the longer the plants stay in the field the more they tend to increase both in size and weight.

Hybrid 11648 is susceptible to bole rot, zebra disease and KLS disease while A. sisalana and A. hildana are resistant to the above diseases. These observations have been experienced as reported in previous studies. However all varieties were equally affected by sisal weevil particularly during the first two years which called for integrated sisal weevil control at immature stage.

Since pulping tests have indicated lower costs in terms of chemicals when using fibre from the leaves, it is important that farmers concentrate on selective leaf harvesting as opposed to whole plant harvesting as earlier envisaged. However pulping studies to optimize pulp yield from the boles should be undertaken to increase total utilization of the sisal plant.

V.2 Costs for CEPS-1 and CEPS-2

CEPS-1

Item/Description	**Cost (USD/Ha)**
The field for this trial and the 3-factor trial had 12-year old sisal, which had been brush-cut and burned in December 1998.	40
Manual cutting of trees & bushes and collection and burning of debris was repeated first week of March 1999	50
Primary tillage with Rome plough followed	40
As soils were acidic (pH of 4.5 to 5.5), an application of 8 MT/Ha of dolomitic limestone was mechanically done using an Amazone spreader [4]	250
As the soil analysis done at Ari-Mlingano (Cost = $15/Ha) indicated the need for phosphate but not for potassium, and as TSP was not available, a combination of available fertilizers (a 6-20-18 compound fertilizer and di-ammonium phosphate was physically mixed for manual application). The equivalent of 20 kg N, 34 kg P_2O_5 and 14 Kg K_2O was used/Ha. (Cost + application = $44/Ha) Half of the amount was manually dispensed and the other half was placed in the planting holes immediately before planting using a pre-calibrated measuring plastic cap	59
After the manual broadcast of the mixed fertilizer the field was disc-harrowed using a wheeled tractor.	20
The field was then marked by a team of five labourers employing a chain link pre-marked at the required within row spacing, and shallow planting holes were dug using hoes	--
The plant material used to plant the trial was from a nursery started by the project in March 1998 at Mazinde sisal estate 85 km away from the planting site. Some 32,000 plants were needed for the various trials.	--
Nursery lifting and transport was contracted to the estate manager at Mwelya. Plants were lifted using manual labour and hauled using a truck at an approximate cost of 3 TZS/plant or $21/Ha. Transport to site cost an average of US$ 55/Ha.	76
Field marking and planting required a team of labourers a period of five days. This was done over a period of one week in March 1999.	37
During the following two months some plants did not take root and had to be replaced	15
After field establishment the following field and crop management operations were undertaken:	--
Sisal weevil control using traps and Decis insecticide was undertaken occasionally during the first two years after planting	42
Manual weed control was done every 4-6 months during the first two years of the trial in the un-harvested sections and throughout the remaining two years in the harvested sections.	75
Maintenance of plot roads was done manually over a period of three years.	39
Manual fertilizer (Urea) application was done in March-April 2000 and another in February 2001 at 100 Kg/Ha of urea (46%N)	87
No fertilizers were applied subsequently as the plantation was not accessible except after leaf cutting.	--
Throughout the life of the trial it received supervision from a labour Headman and the field technician at the rate US$ 89 /year/Ha	128
Total direct costs for CEPS-1 until 1st harvest in March 2001	**958**

CEPS-2

Item/Description	Cost (USD/Ha)
After terminal 12-year old sisal brush cutting and burning in December 1998, the plot was ploughed and cross-ploughed using a D6-Rome plough team	120
Manual planting of maize by estate workers followed in April 1999, and the maize was harvested in July-August 1999. Yields of 1500 kg/Ha were reported, but not verified	--
In September 1999, the maize stalks were cut down using a tractor-mounted rotary cutter	20
As soils were acidic (pH of 4.5 to 5.5), an application of 8 MT/Ha of dolomitic limestone was mechanically done using an Amazone spreader [4]	250
Both blocks were ploughed using a D6-Rome plough team to prepare for legume seeding including trash collection and burning	40
Then both blocks received 50 kg/Ha of P_2O_5 as TSP through manual broadcasting	32
Field and main plot road grading was done prior to planting	30
Because there was a delay in the onset of the short rains, cowpeas were hand-seeded in Block A in early October 1999. The crop did not fully develop because of little rainfall, and no weed-control, and was manually harvested in February 2000.Yields were very low at 63 kg/Ha	--
In early October 1999, half of Block B was seeded with an early-maturing soybean variety recommended by the Selian Agricultural Research Institute in Arusha, after having inoculated the seed with *Rhizobium* bacteria (Biofix). The other half was seeded with Bonaviste bean (Lablab niger), which grew vegetatively and did not produce any seed	--
The plot seeded with soybeans was well maintained, but both crops suffered from lack of rainfall	--
Soybeans were harvested in the first week of January 2000 and returned a small yield of 175 kg/Ha	--
Block B was ploughed under using a D-6 Rome plough team in March 2000	50
Half of Block A was ploughed and cross-ploughed while the other half was kept without ploughing, but the stubble had been gathered and burned	80
Both blocks then received a manual broadcast application of TSP at 100 kg/Ha	32
Both blocks were then marked using the implement designed for the job (furrowing-marker mounted on a 65 HP wheeled tractor, which furrow marked the whole field in less than 2 hours. Efficiency was measured at 3 Ha/hr. (Cost for 2 tractors at US$ 20/hr =US$ 40 or US$6/Ha)	6.5
Then a team of two nursery-lifting labourers, two carriers-distributors, and six planters were able to plant the plot in 3.5 days	7
Plants were manually realigned in the rows, and some planting replacement was made in the month following planting	25
Due to breakdown in tractor, no between-row cultivation was done after planting, and weed growth had to be controlled manually	
A side dressing of 50 Kg N/Ha, which was to be made in two equal split applications, once at the time of first cultivation, and another before the onset of the short rains, was instead done all at once using manual labour before the rains in September	35
Manual weed control had to be done twice between May and December 2000	100
Manual sisal weevil control using traps and Decis was done during the first six months after establishment	30
Manual weed control was also done occasionally in 2001 and 2002	153
Trial supervision by Headman and field assistant during execution of planting and during first three months was most intensive	100
Supervision to first harvest in January 2003 by headman and field assistant was also provided	50
Except for occasional road maintenance, no other interventions were done in the fields until the first harvest	--
Total Direct costs for CEPS-1 (excluding rotational crops) until first harvest in January 2003	**1,160.5**

Annex 1. Data on Gomba fertilizer trials

Table 1. Chemical composition of the fertilizer trial site soil before the beginning of the experiments (1999).

ID	Sample depth (cm)	pH water	Org. C (%)	Total N (%)	C/N ratio	Available P (mg/kg)	CEC (Cmols (+)/kg)	Exchangeable Bases (Cmols (+)/kg)				BS (%)
								Ca	Mg	K	Na	
1	0-20	5.8	0.82	0.06	14	6.75	6.26	2.1	1.7	0.05	0.03	62
2	0-20	5.7	0.99	0.08	12	17.34	6.69	2.2	1.6	0.05	0.04	58
3	0-20	5.9	1.11	0.08	14	32.47	9.84	2.0	1.8	0.06	0.03	40
4	0-20	5.8	0.91	0.05	18	18.10	8.45	2.1	1.6	0.07	0.03	45
5	0-20	5.7	0.99	0.08	12	17.33	6.68	2.3	1.5	0.05	0.03	58
6	0-20	5.6	0.86	0.06	14	9.41	7.79	3.1	2.2	0.06	0.05	69
7	0-20	5.8	0.92	0.05	18	18.10	8.45	3.0	2.1	0.06	0.05	62
8	0-20	5.7	0.99	0.08	12	17.34	6.69	3.3	2.3	0.07	0.06	86
9	0-20	5.8	0.92	0.05	18	18.00	8.40	3.1	2.2	0.06	0.05	64
10	0-20	5.8	0.92	0.05	18	18.10	8.45	3.2	2.2	0.07	0.06	65
11	0-20	5.9	1.11	0.08	14	32.47	9.80	3.0	2.2	0.06	0.05	54
12	0-20	5.9	1.11	0.08	14	32.47	9.84	3.7	2.4	0.05	0.05	63
13	0-20	6.0	1.12	0.06	19	32.50	10.10	3.6	2.3	0.05	0.05	59
14	0-20	5.8	0.92	0.05	18	18.10	8.45	3.8	2.4	0.06	0.05	75
15	0-20	5.2	0.81	0.05	16	6.80	6.80	3.7	2.4	0.05	0.05	91
16	0-20	5.1	0.80	0.05	16	6.75	6.40	3.8	2.4	0.06	0.06	98
17	0-20	5.3	0.83	0.05	17	6.85	6.50	3.6	2.3	0.05	0.05	92
18	0-20	5.6	0.86	0.06	14	9.41	7.79	1.2	1.1	0.08	0.07	31
19	0-20	5.5	0.73	0.05	15	8.65	8.89	1.3	1.1	0.08	0.07	28
20	0-20	5.7	0.99	0.08	12	17.34	6.69	1.1	1.1	0.07	0.06	35

ID = Sample identification number
C = Carbon
N = Nitrogen
P = Phosphorus
CEC = Cation exchange capacity
Ca = Calcium
Mg = Magnesium
K = Potassium
Na = Sodium
BS = Base saturation

Table 2. Fertilizer applied in each treatment/trial.

Treatment (or Plot) No.	Fertilizers applied
1	Decomposed sisal waste 40 tons over 4 years & 100kg MOP /Ha
2	7 tons lime & 100kg MOP /Ha
3	100kg CAN & 10 tons lime/Ha
4	2.5 tons lime & tropical kudzu 3kg/Ha
5	5 tons lime & tropical kudzu 3kg/Ha
6	7 tons lime & tropical kudzu 3kg/Ha
7	10 tons lime & tropical kudzu 3kg/Ha
8	2.5 tons lime & MOP 100 kg/Ha
9	5 tons lime & MOP 100 kg/Ha
10	10 tons lime & MOP 100 kg/Ha
11	2.5 tons lime & CAN 100 kg/Ha
12	5 tons lime & CAN 100 kg/Ha
13	7 tons lime & CAN 100 kg/Ha
14	40 tons of sisal waste only
15	40 tons of sisal waste & 50 kgMOP/Ha
16	40 tons of sisal waste & 75kgMOP/Ha
17	40 tons of sisal waste & 2.5 tons lime/Ha
18	40 tons of sisal waste & CAN 100kg/Ha
19	40 tons of sisal waste & 5 tons lime/Ha
20	40 tons of sisal waste & 7 tons lime/Ha
21	40 tons of sisal waste & 10 tons lime/Ha
22	40 tons of sisal waste & CAN 25kg/Ha
23	40 tons of sisal waste & CAN 50kg/Ha
24	40 tons of sisal waste & CAN 75kg/Ha
25	40 tons of sisal waste & CAN 100kg/Ha
Control	--

Table 3. Chemical composition of the fertilizer trial site soil after the experiments (2003)

ID	Sample depth (cm)	pH water	Org. C (%)	Tot al N (%)	C/N rati o	Available P (mg/kg)	CEC Cmols (+)/kg)	Exchangeable Bases (Cmols (+)/kg)				BS (%)
								Ca	Mg	K	Na	
1	0-30	6.6	1.93	0.12	16	22.09	16.74	11.9	1.8	0.96	0.70	88
2	0-30	6.4	1.46	0.11	13	9.76	15.54	8.0	3.7	0.67	.06	80
3	0-30	6.1	1.59	0.10	16	9.81	12.07	6.6	1.5	0.50	0.09	72
4	0-30	6.6	2.11	0.18	12	33.27	17.30	12.0	2.1	0.69	0.09	86
5	0-30	6.5	1.43	0.11	13	22.75	11.55	7.9	1.3	0.33	0.06	83
6	0-30	6.3	1.64	0.13	13	14.81	16.00	9.4	1.7	0.83	0.04	75
7	0-03	6.3	1.74	0.12	15	8.90	17.14	10.5	2.0	0.64	0.06	77
8	030	6.3	1.51	0.11	14	12.91	14.65	8.4	1.6	0.77	0.07	74
9	0-30	6.2	1.42	0.11	13	10.83	12.73	6.8	1.6	0.83	0.06	73
10	0-30	6.3	1.35	0.10	14	31.88	15.73	9.4	1.9	0.91	0.06	78
11	0-30	6.6	1.64	0.12	14	20.33	16.31	11.7	2.1	0.65	0.07	89
12	0-30	6.6	1.36	0.11	12	17.86	15.18	10.0	2.4	0.74	0.07	87
13	0-30	6.6	1.44	0.10	14	11.06	17.48	12.2	1.8	0.76	0.10	85
14	0-30	6.5	1.81	0.14	13	13.97	15.74	10.1	1.9	0.85	0.06	82
15	0-30	6.2	1.47	0.13	11	9.18	10.92	5.3	1.8	0.58	0.07	71
16	0-30	6.4	1.53	0.14	11	15.00	13.06	7.4	1.8	1.05	0.07	79
17	0-03	6.3	1.56	0.12	13	10.46	11.53	6.5	1.4	0.66	0.09	75
18	0-30	6.3	1.24	0.10	12	18.88	12.55	7.1	1.8	0.70	0.06	77
19	0-30	6.4	1.49	0.11	14	16.44	12.80	9.1	0.5	0.58	0.06	80
20	0.30	6.6	1.61	0.14	12	13.75	16.16	12.2	1.0	0.96	0.06	88
21	0-30	6.5	1.06	0.10	11	13.21	16.56	12.0	1.1	0.75	0.06	84
22	0-30	6.6	1.98	0.17	12	33.72	16.29	12.2	0.6	1.14	0.07	86
23	0-30	6.5	1.68	0.15	11	19.21	14.06	9.3	1.3	1.14	0.07	84
24	0-30	6.2	1.61	0.14	12	34.47	10.58	5.3	1.5	0.75	0.07	72
25	0-30	6.5	1.35	0.10	14	2.85	17.56	12.6	1.6	0.80	0.10	86
26	0-30	6.5	1.44	0.10	14	19.21	14.80	8.7	2.5	1.02	0.06	83

ID = Sample identification number
C = Carbon
N = Nitrogen
P = Phosphorus
CEC = Cation exchange capacity
Ca = Calcium
Mg = Magnesium
K = Potassium
Na = Sodium
BS = Base saturation

Table 4. Growth parameters recorded from the fertilizer trial at Gomba Estate from 2000-2004

Plot No.	Fertilizer types applied (treatments)	Leaf length (cm)				Plant height				Cum. Leaf No.			
		Mar 2001	Mar 2002	Mar 2003	Mar 2004	Mar 2001	Mar 2002	Mar 2003	Mar 2004	Mar 2001	Mar 2002	Mar 2003	Mar 2004
		Year 1	Year 2	Year 3	Year 4	Year 1	Year 2	Year 3	Year 4	Year 1	Year 2	Year 3	Year 4
1	Decomposed sisal waste 40 tons over 4 years & 100kg MOP /Ha	40.2	72.7	74.7	89.5	78.0	102.2	104.3	120.3	35	89	151	200
2	7 tons lime & 100kg MOP /Ha	42.0	74.5	77.9	91.6	79.0	102.8	114.4	120.7	36	97	157	206
3	100kg CAN & 10 tons lime/Ha	43.2	80.7	82.7	92.4	85.0	106.3	114.2	136.7	34	86	151	203
4	2.5 tons lime & tropical kudzu 3kg/Ha	42.6	79.1	80.5	95.0	81.0	106.4	114.7	127.5	34	86	158	210
5	5 tons lime & tropical kudzu 3kg/Ha	43.9	83.3	82.8	93.6	82.0	112.1	117.4	130.8	35	90	161	215
6	7 tons lime & tropical kudzu 3kg/Ha	44.1	96.6	81.0	93.7	71.0	111.1	127.3	131.4	35	92	161	217
7	10 tons lime & tropical kudzu 3kg/Ha	43.8	81.2	89.5	102.5	76.0	113.0	113.1	141.4	34	86	162	218
8	2.5 tons lime & MOP 100 kg/Ha	42.8	79.6	78.4	97.3	82.0	102.0	126.2	125.3	34	87	158	210
9	5 tons lime & MOP 100 kg/H a	43.5	83.6	88.5	103.0	90.0	117.1	132.4	141.1	36	100	181	237
10	10 tons lime & MOP 100 kg/Ha	44.0	87.3	93.5	110.6	88.0	118.0	151.9	150.1	34	92	178	227
11	2.5 tons lime & CAN 100 kg/H a	44.6	93.7	104.6	114.3	89.0	122.5	134.4	170.4	36	111	205	261
12	5 tons lime & CAN 100 kg/Ha	43.9	83.5	98.1	115.3	82.1	108.6	128.6	153.0	34	93	178	240
13	7 tons lime & CAN 100 kg/Ha	43.7	82.1	87.1	110.4	82.0	108.5	124.7	141.4	36	100	189	235
14	40 tons of sisal waste only	38.5	69.4	73.5	93.1	55.0	96.1	103.9	122.0	33	87	175	209
15	40 tons of sisal waste & 50 kgMOP/Ha	43.7	85.4	86.1	97.2	77.0	112.7	121.1	134.5	35	95	149	204
16	40 tons of sisal waste & 75kgMOP/Ha	43.5	81.7	86.5	103.5	78.0	109.9	122.0	141.2	34	92	168	227
17	40 tons of sisal waste & 2.5 tons lime/Ha	46.4	89.4	87.5	102.0	79.0	108.3	121.8	135.2	34	93	148	203
18	40 tons of sisal waste & CAN 100kg/Ha	43.7	81.7	88.3	97.2	74.0	106.9	123.7	138.1	35	82	152	203
19	40 tons of sisal waste & 5 tons lime/Ha	45.5	88.9	92.4	107.0	84.0	118.9	129.2	145.2	34	96	169	223
20	40 tons of sisal waste & 7 tons lime/Ha	47.1	90.9	97.3	113.2	88.0	121.2	138.1	152.0	34	97	170	225
21	40 tons of sisal waste & 10 tons lime/Ha	42.2	80.1	88.8	106.1	78.0	106.3	123.9	135.0	34	96	174	231
22	40 tons of sisal waste & CAN 25kg/Ha	43.6	83.1	93.4	109.2	67.0	110.2	128.4	147.0	33	84	156	213
23	40 tons of sisal waste & CAN 50kg/Ha	42.8	79.6	74.1	102.0	64.0	107.1	103.6	132.2	33	80	151	208
24	40 tons of sisal waste & CAN 75kg/Ha	42.1	77.8	89.2	102.7	67.0	105.2	125.5	144.0	32	84	160	218
25	40 tons of sisal waste & CAN 100kg/Ha	44.5	85.0	91.6	108.3	75.0	110.1	129.2	144.5	34	88	158	219
26	Control	34.0	60.0	72.5	84.4	48.0	94.1	101.6	120.1	30	71	114	167

Table 5. Fibre yield from the fertilizer trial at Gomba estate for the three cuts

Plot No.	Fertilizer types applied (treatments)	First harvest (August 2002 - 28 months)	Second harvest (April 2003 - 36 months)	Third harvest (February 2004 - 46 moths)	Mean production in kg/Ha for the three cuts
		Fibre weight kg/Ha	Fibre weight kg/Ha	Fibre weight kg/Ha	
1	Decomposed sisal waste 40 tons over 4 years & 100kg MOP /Ha	700	880	600	726.7
2	7 tons lime & 100kg MOP /Ha	800	960	1200	986.7
3	100kg CAN & 10 tons lime/Ha	700	1360	900	986.7
4	2.5 tons lime & tropical kudzu 3kg/Ha	700	1200	1100	1000.0
5	5 tons lime & tropical kudzu 3kg/Ha	1100	1360	1200	1220.0
6	tons lime & tropical kudzu 3kg/Ha	900	1200	1000	1033.3
7	10 tons lime & tropical kudzu 3kg/Ha	1000	1600	1000	1200.0
8	2.5 tons lime & MOP 100 kg/Ha	1000	1200	1000	1066.7
9	5 tons lime & MOP 100 kg/Ha	1200	1480	1300	1326.7
10	10 tons lime & MOP 100 kg/Ha	1000	1720	1840	1520.0
11	2.5 tons lime & CAN 100 kg/Ha	1500	2200	2700	2133.3
12	5 tons lime & CAN 100 kg/Ha	1200	1800	2100	1700.0
13	7 tons lime & CAN 100 kg/Ha	700	1760	1280	1246.7
14	40 tons of sisal waste only	1000	880	600	826.7
15	40 tons of sisal waste & 50 kg MOP/Ha	800	1320	1200	1106.7
16	40 tons of sisal waste & 75kgMOP/Ha	980	1520	1200	1233.3
17	40 tons of sisal waste & 2.5 tons lime/Ha	1100	1800	1600	1500.0
18	40 tons of sisal waste & CAN 100kg/Ha	700	1600	1300	1200.0
19	40 tons of sisal waste & 5 tons lime/Ha	1100	1360	1400	1286.7
20	40 tons of sisal waste & 7 tons lime/Ha	1400	1720	1400	1506.7
21	40 tons of sisal waste & 10 tons lime/Ha	1000	1360	600	986.7
22	40 tons of sisal waste & CAN 25kg/Ha	900	1720	900	1173.3
23	40 tons of sisal waste & CAN 50kg/Ha	600	1000	1200	933.3
24	40 tons of sisal waste & CAN 75kg/Ha	800	1360	1300	1153.3
25	40 tons of sisal waste & CAN 100kg/Ha	1000	1800	1600	1466.7
26	Control	0	720	560	640.0

Annex 2. Effects of different fertilizer treatments on leaf length

Figure 2. Average performance of three outstanding fertilizer combinations on leaf length of hybrid sisal (H.11648) in 2000-2004

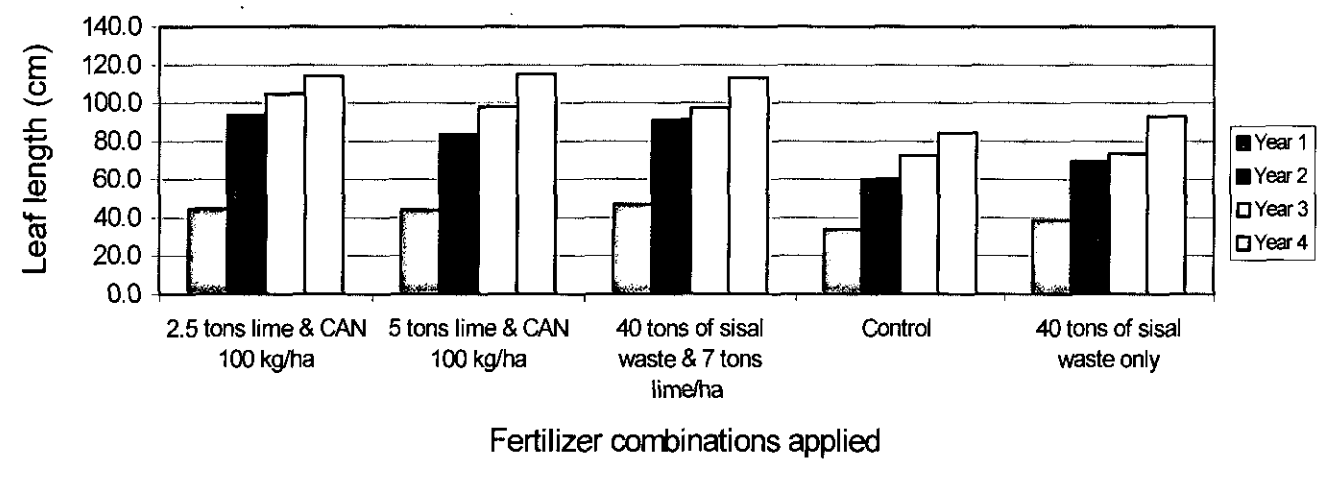


Figure 3. Effect of lime and tropical kudzu application on leaf length of hybrid sisal (H.11648)

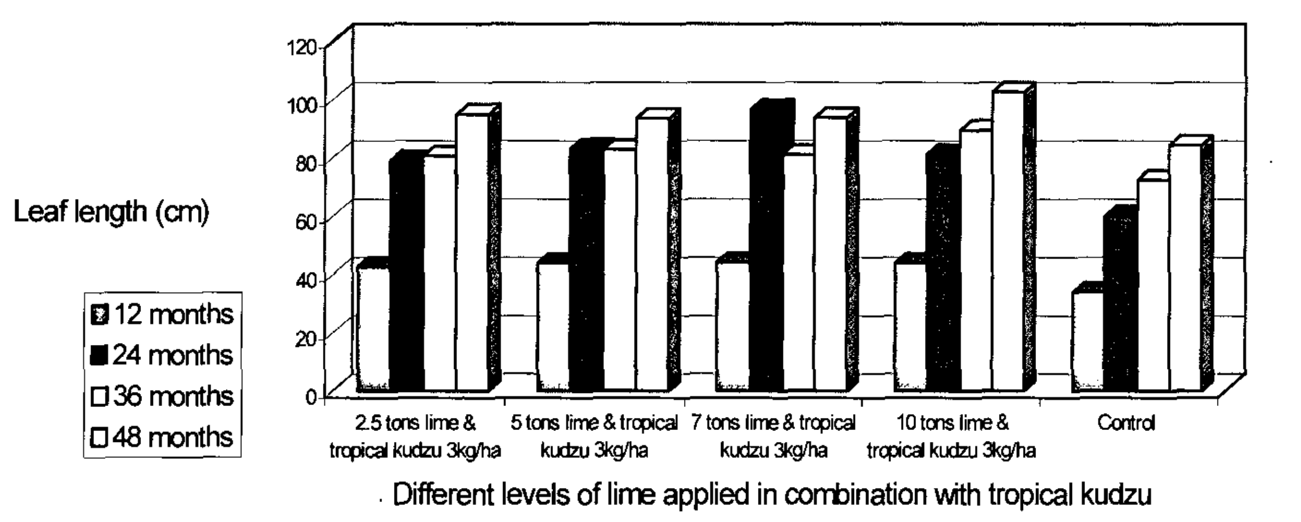


Figure 4. Effect of lime and MOP on leaf length of hybrid sisal (H.11648)

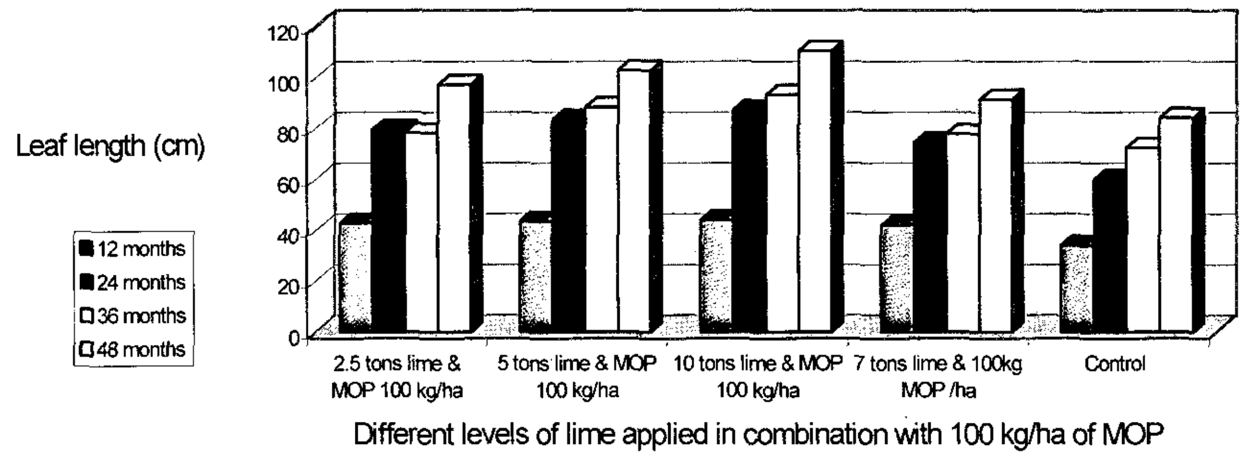


Figure 5. Effect of lime and CAN application on leaf length of hybrid sisal (H.11648)

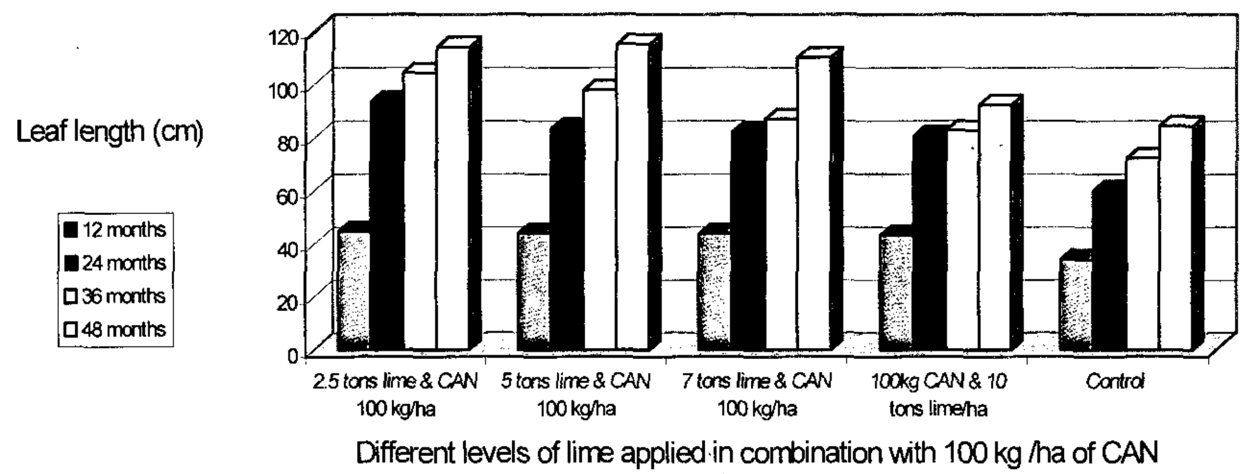


Figure 6. Effect of sisal waste and MOP application on leaf length of hybrid sisal (H.11648)

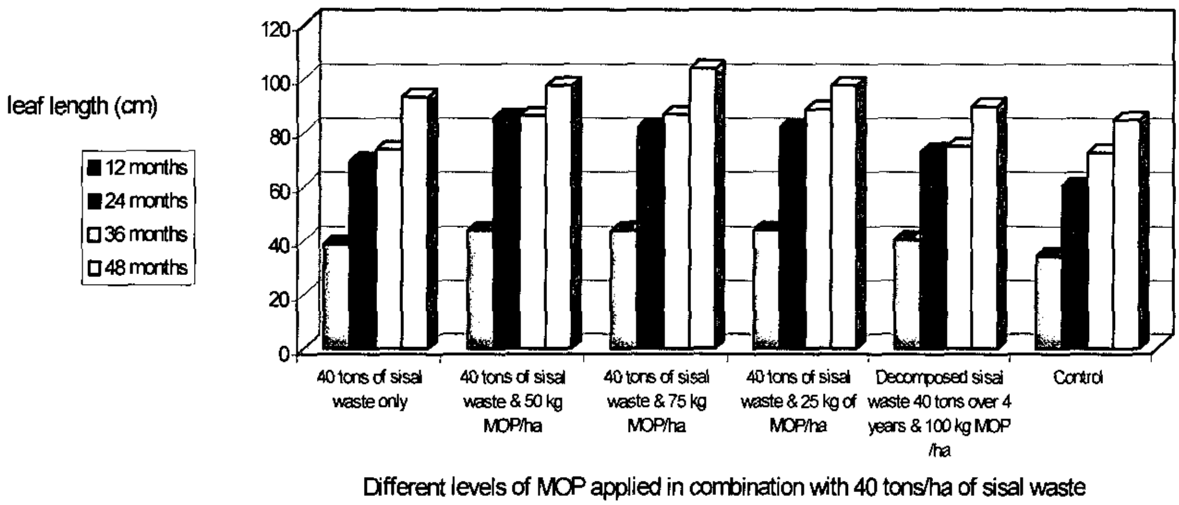


Figure 7. Effect ofsisal waste and lime application on leaf length of hybrid sisal (H.11648)

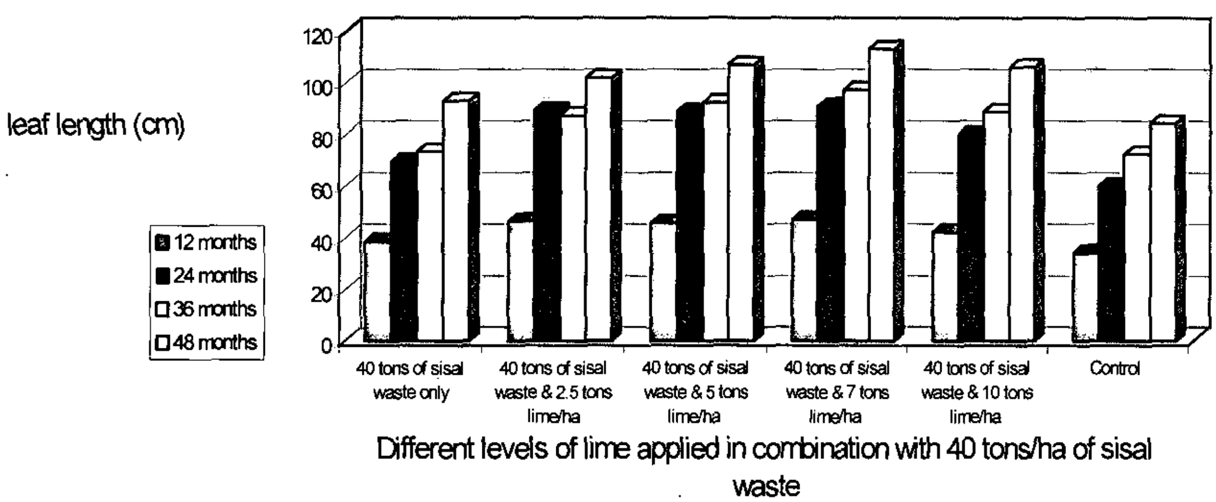
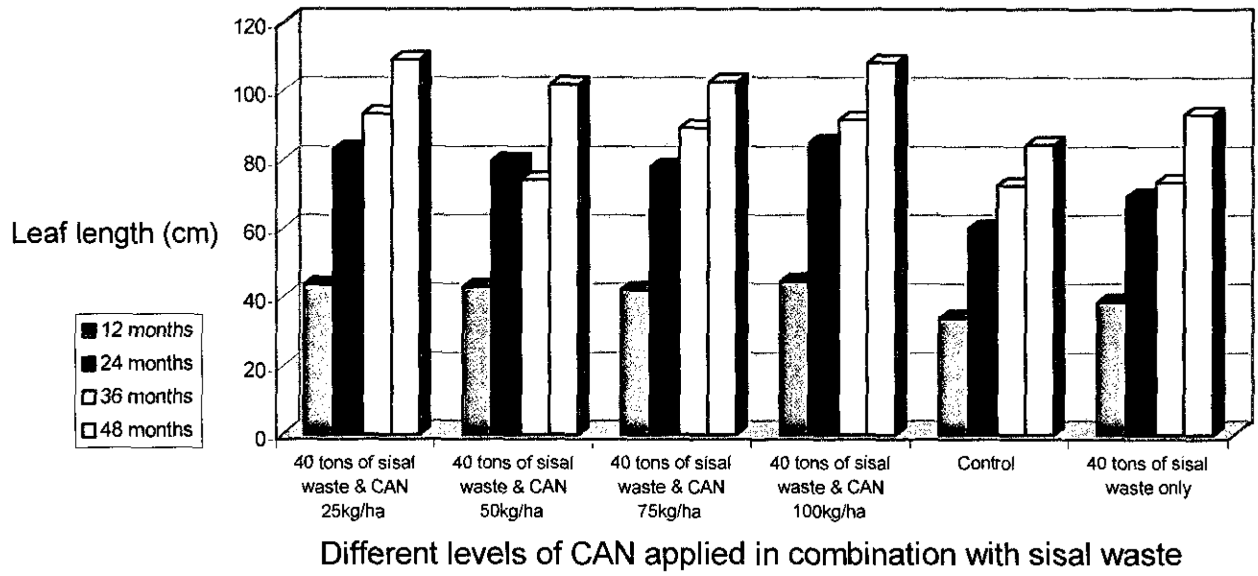


Figure 8. Effect of sisal waste and CAN application on leaf length of hybrid sisal (H.11648)



Annex 3. Effects of different fertilizer treatments on plant height

Figure 9. Effect of lime and tropical kudzu on plant height of hybrid sisal (H.11648)

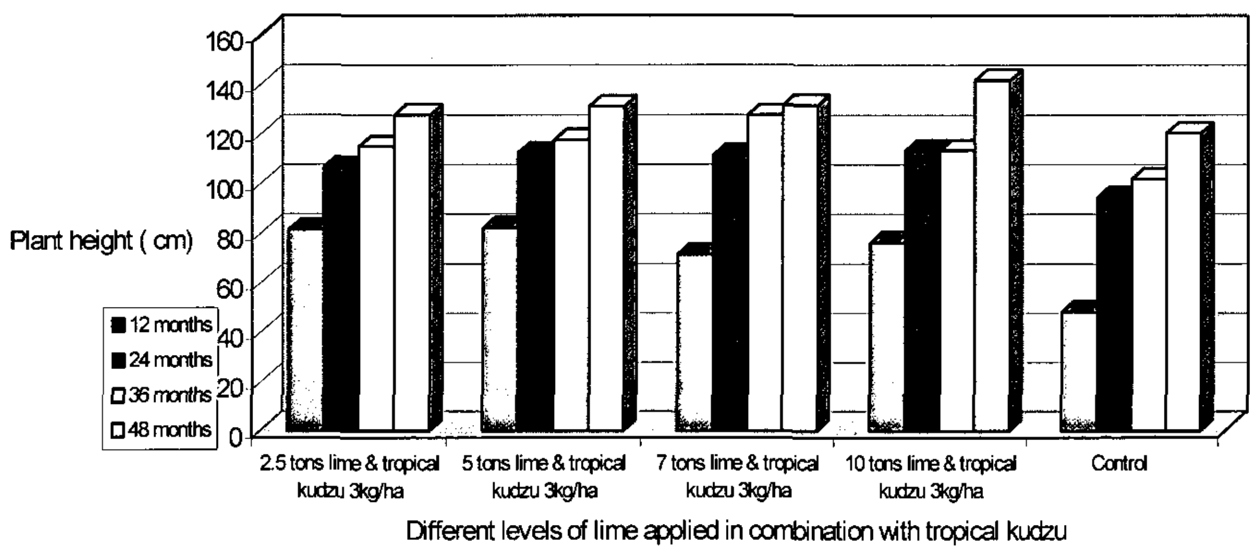


Figure 10. Effect of lime and MOP on plant height of hybrid sisal (H.11648)

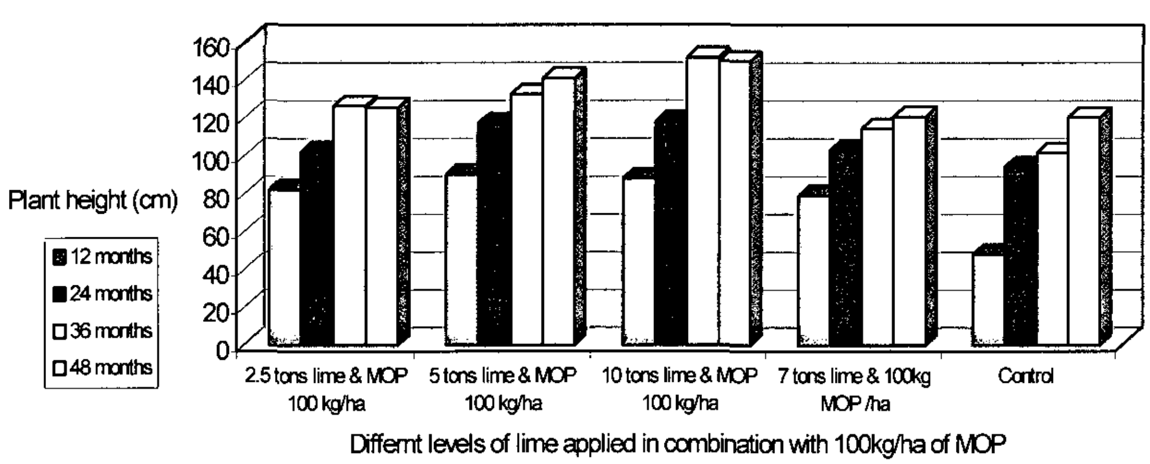


Fig.ure 11. Effect of lime and CAN on plant height of hybrid sisal (H.11648)

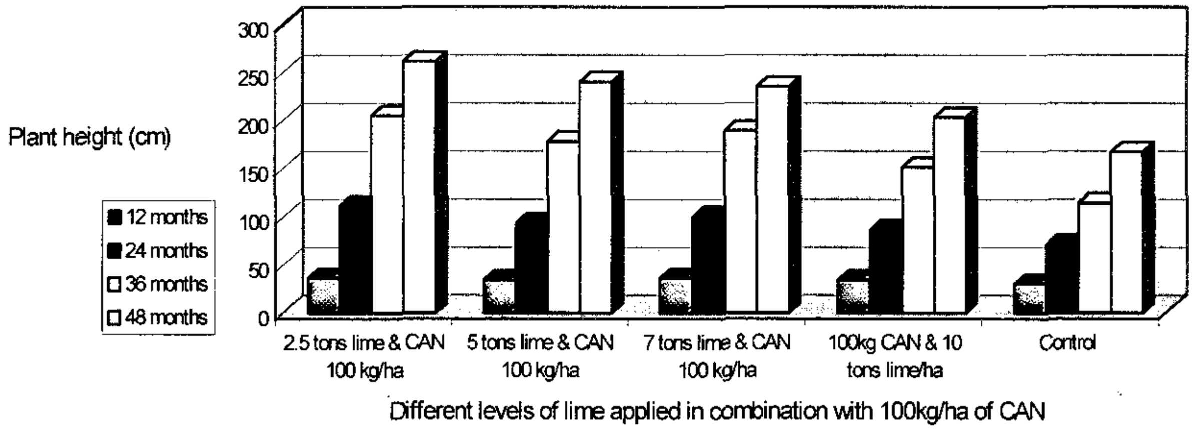
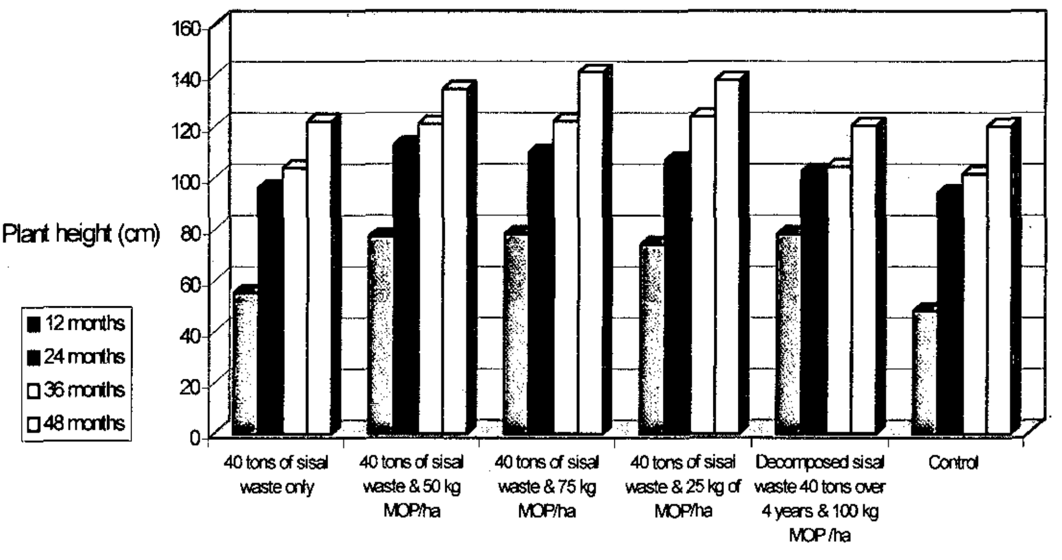


Figure 12. Effect of sisal waste and MOP application on plant height of hybrid sisal (H.11648)



Annex 4. Effects of different fertilizer treatments on leaf production

Figure 13. Effect of sisal waste and lime application on plant height of hybrid sisal (H.11648)

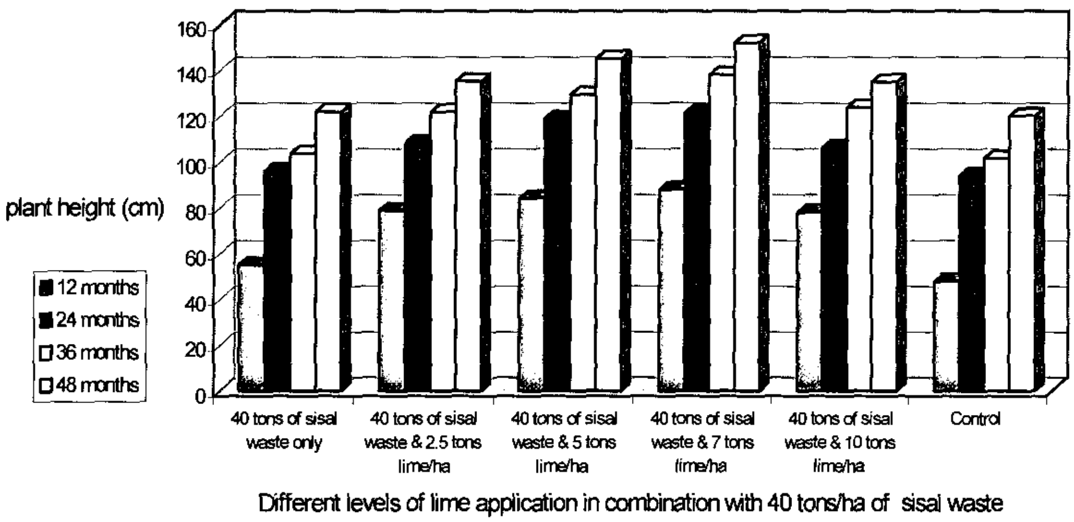


Figure 14. Effect of sisal waste and CAN application on plant height of H.11648

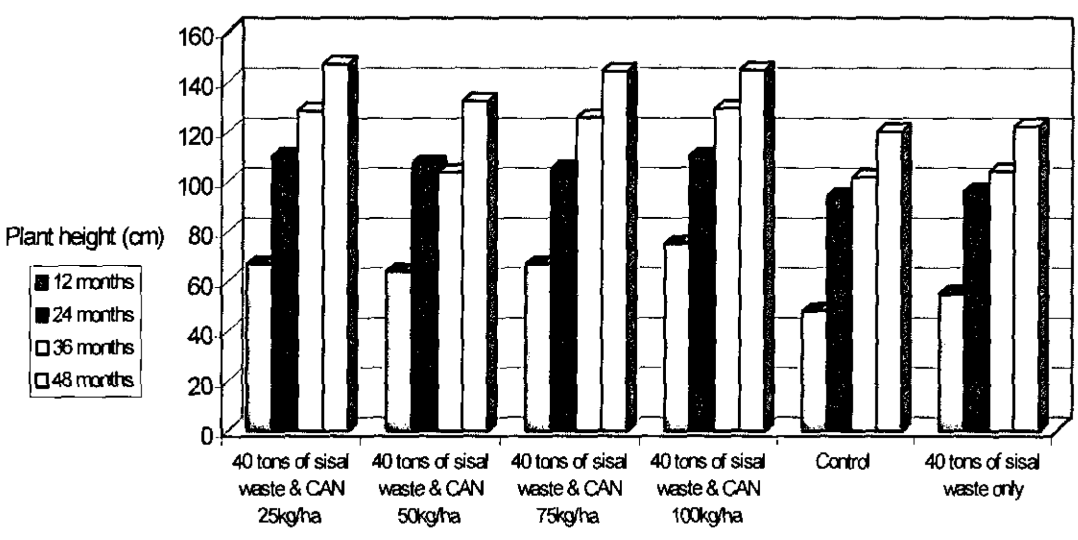


Figure 15. Average performance of three most outstanding fertilizer combinations on leaf production of hybrid sisal (H.11648) from 2000-2004

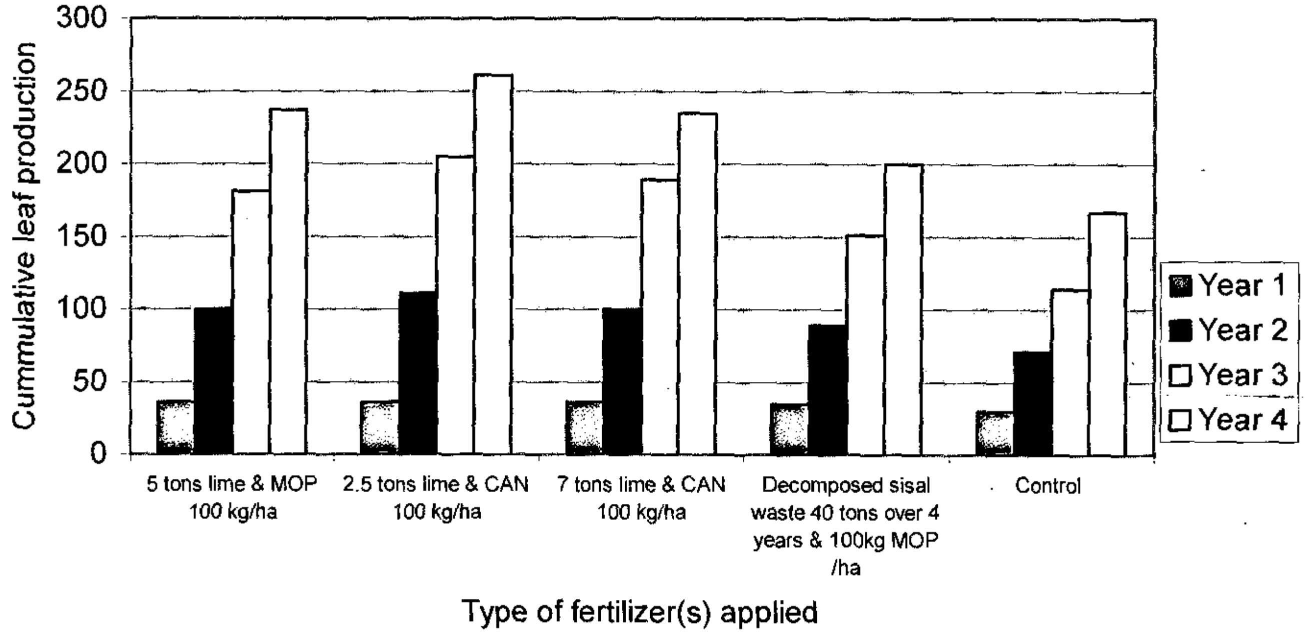


Figure 16. Effect of lime and tropical kudzu application on leaf production in hybrid sisal (H.11648)

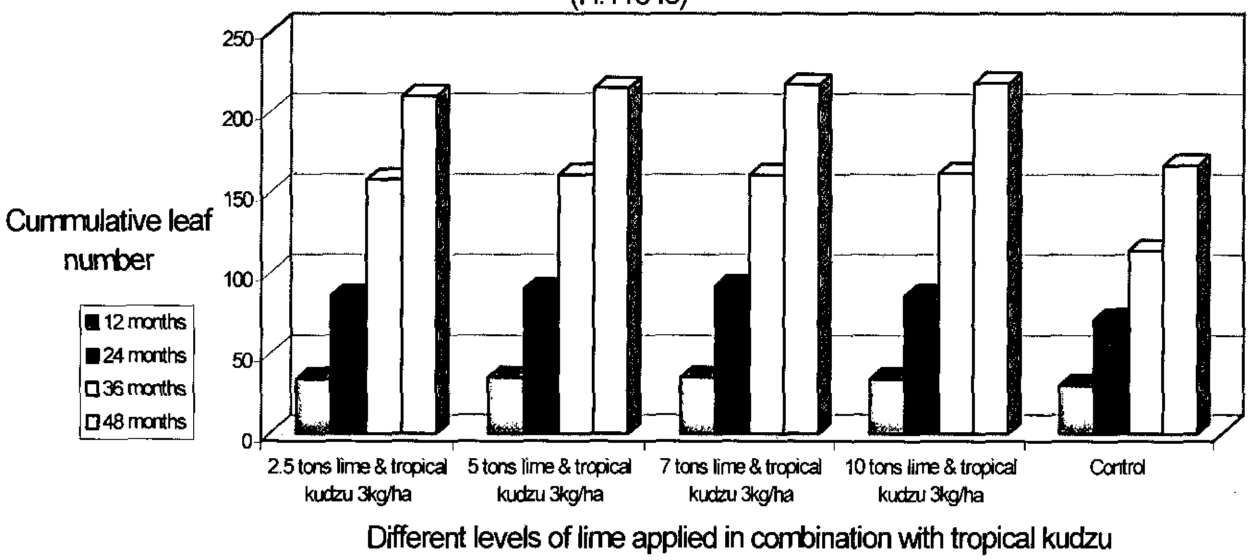


Figure 17. Effect of lime and MOPon leaf production of hybrid sisal (H.11648)

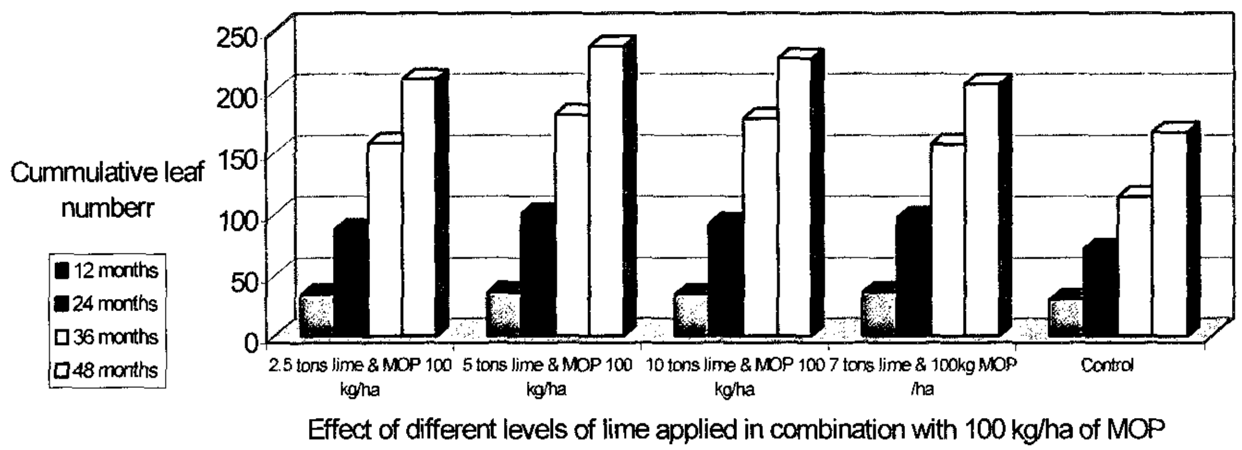


Figure 18. Effect of lime and CAN application on leaf production of hybrid sisal (H.11648)

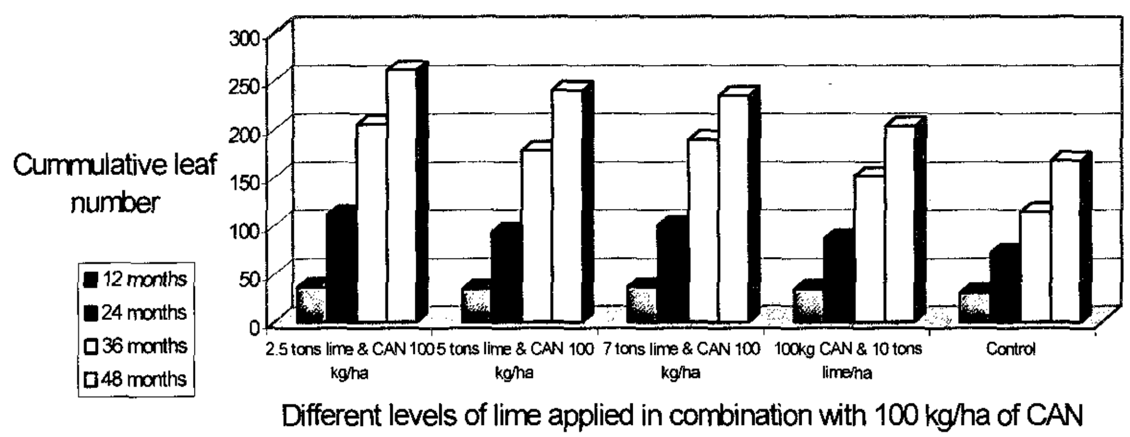
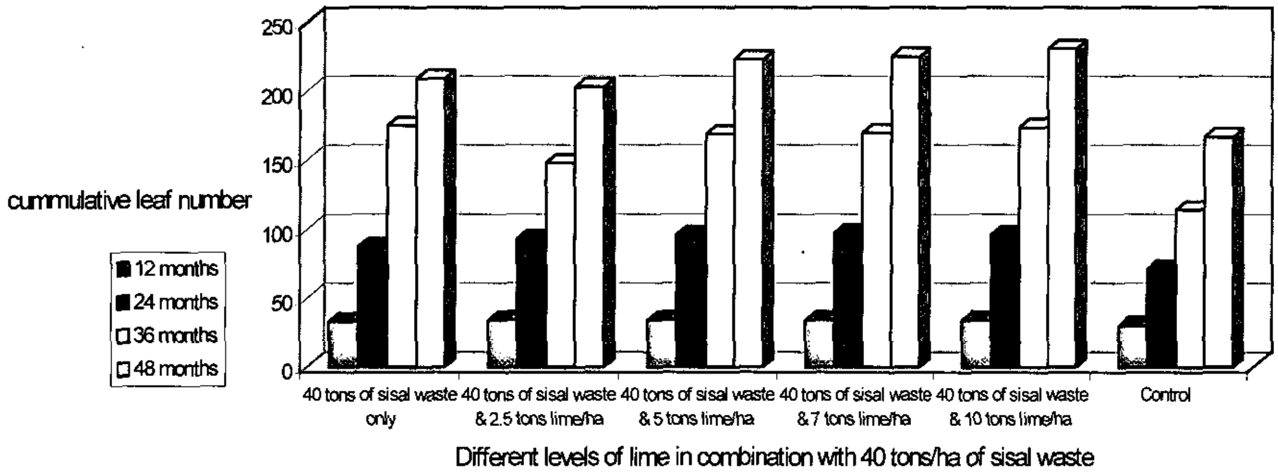


Figure 19. Effect of sisal waste and lime on leaf production of hybrid sisal (H.11648)



Annex 5. Effects of different fertilizer treatments on fibre yield

Figure 20. Average performance of the best three fertilizer combinations on sisal fibre yield

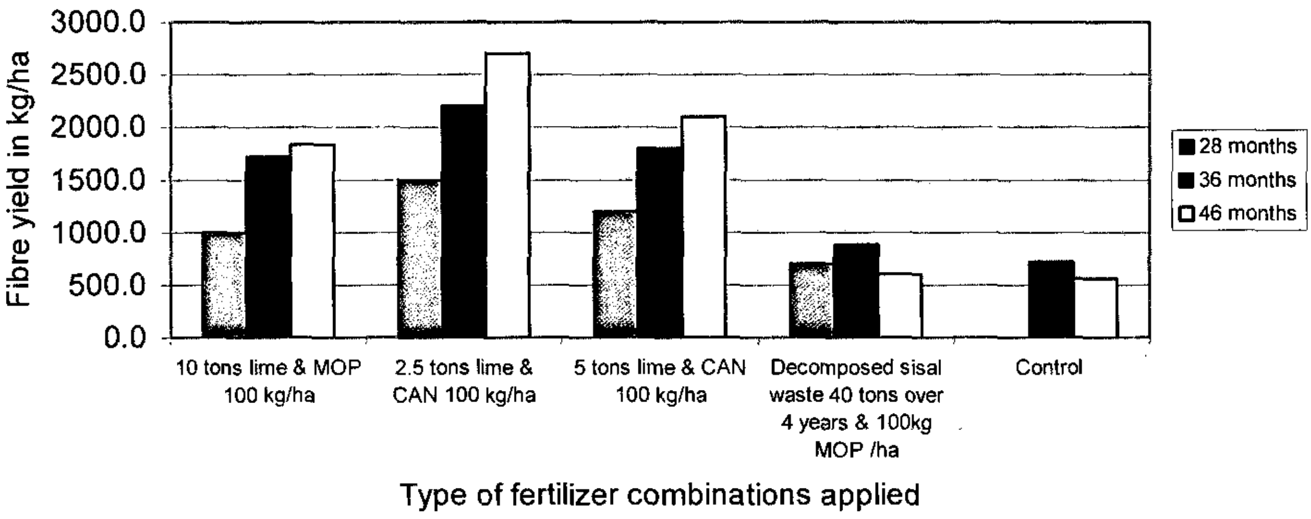


Figure 21. Effect of lime and CAN application on sisal fibre yield of H.11648

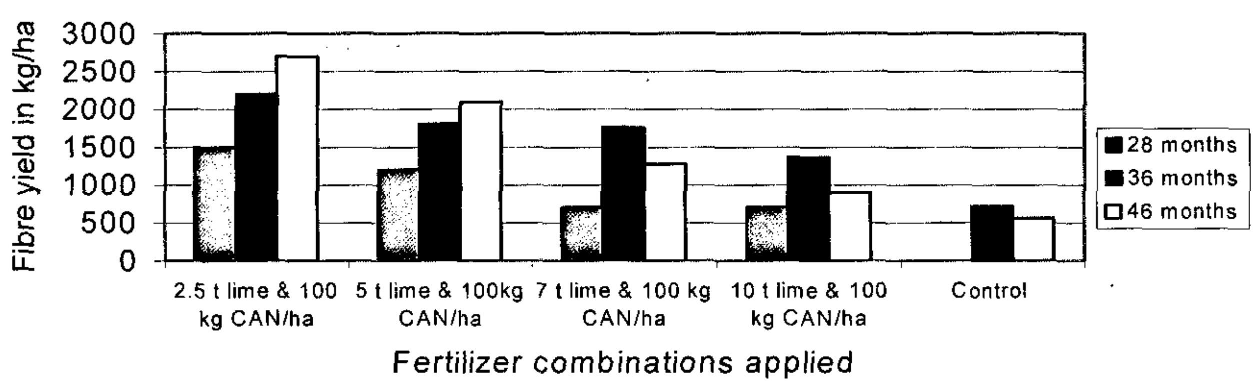


Figure 22. Effect of lime and tropical kudzu application on sisal fibre yield of H.11648

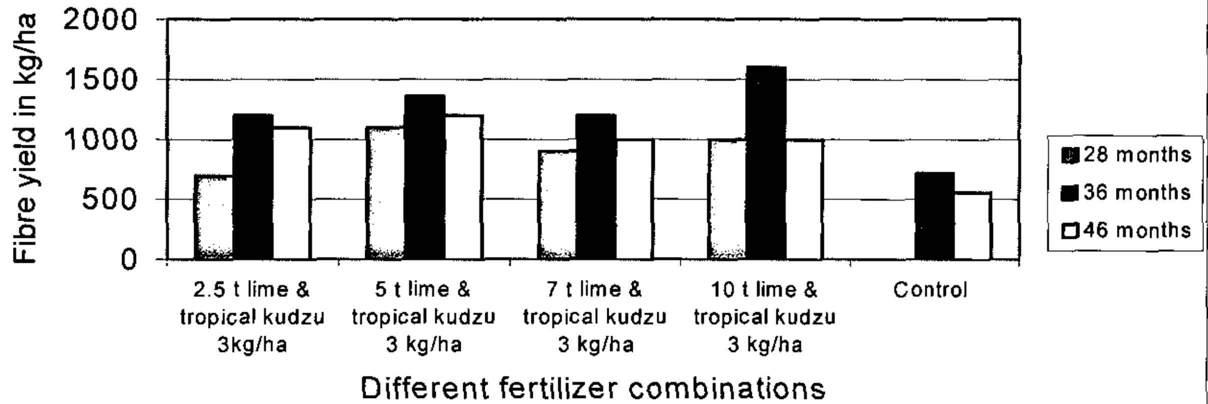


Figure 23. Effect of sisal waste and CAN application on sisal waste application on fibre yield of H. 11648

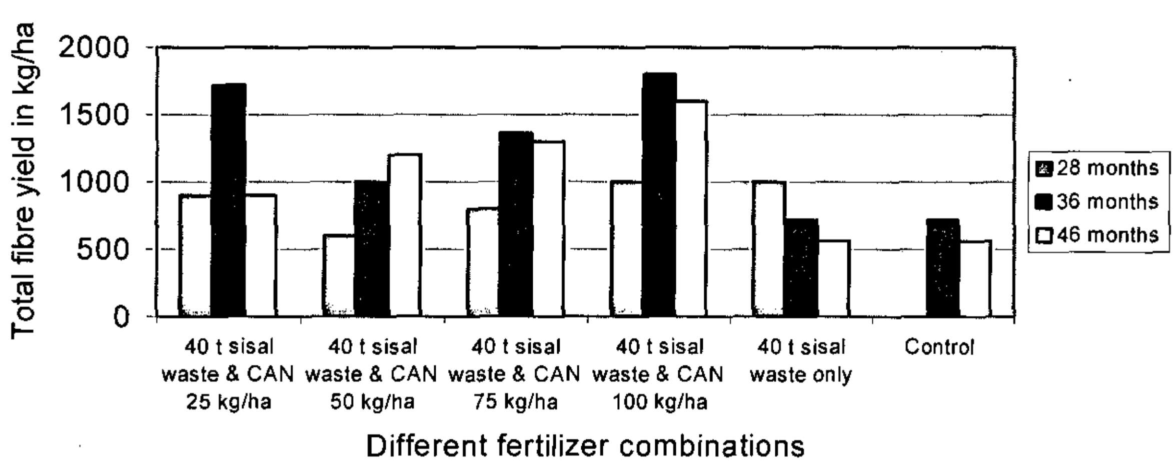


Figure 24. Effect of sisal waste and MOP on fibre yield of hybrid sisal

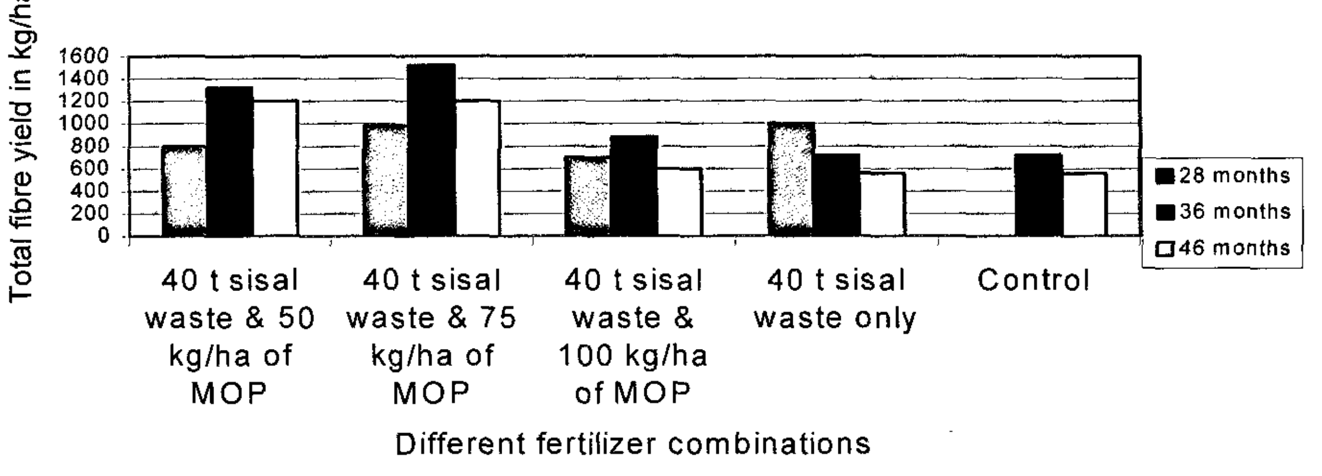


Figure 25. Effect of sisal waste and lime application on sisal fibre yield of H.11648

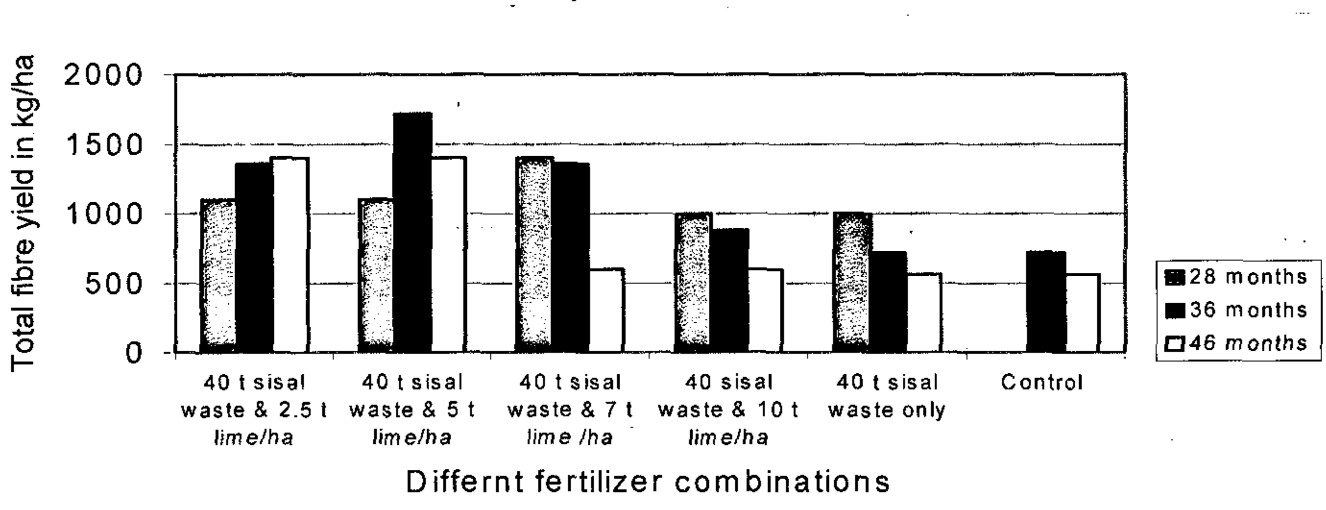


Figure 26. Effect of sisal waste and lime application on sisal fibre yield of H. 11648

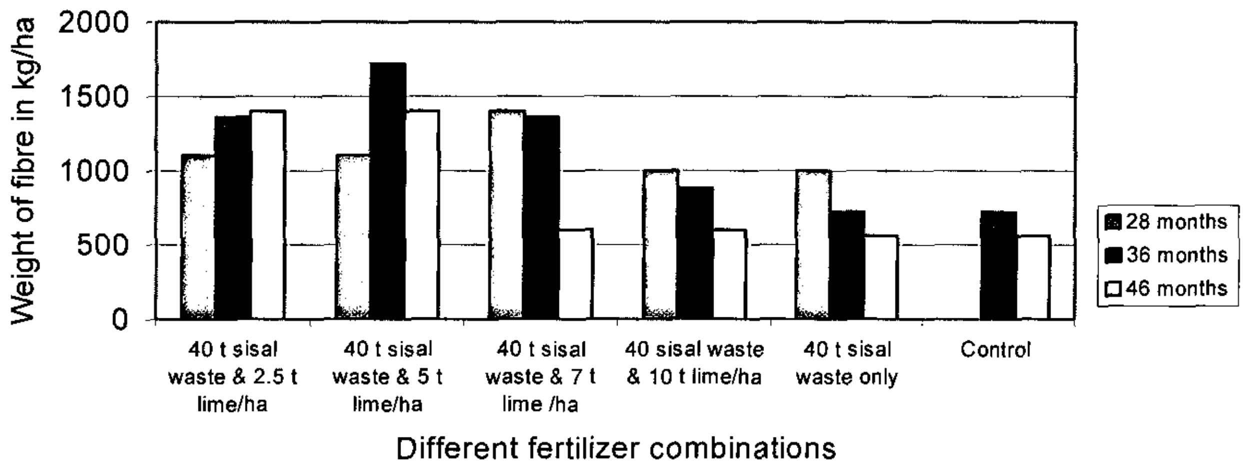
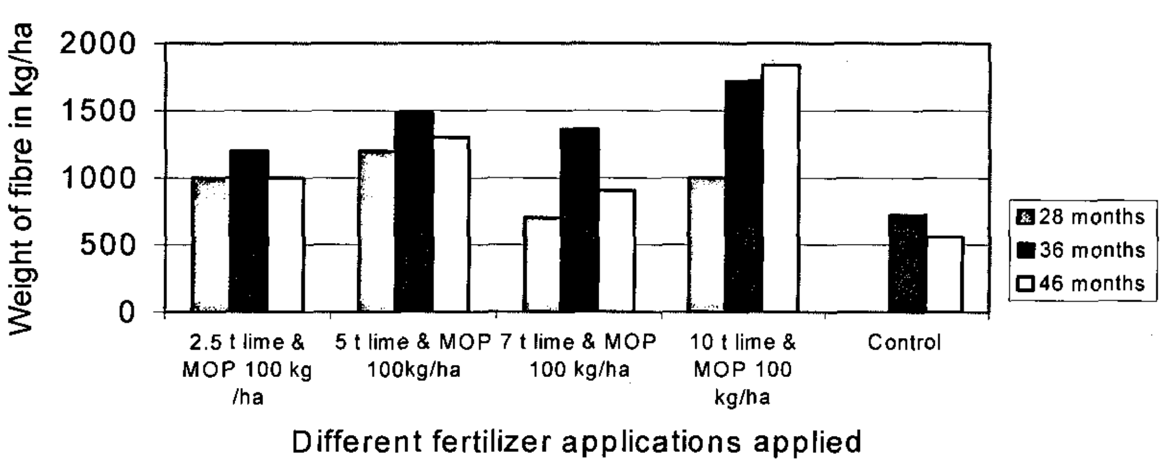
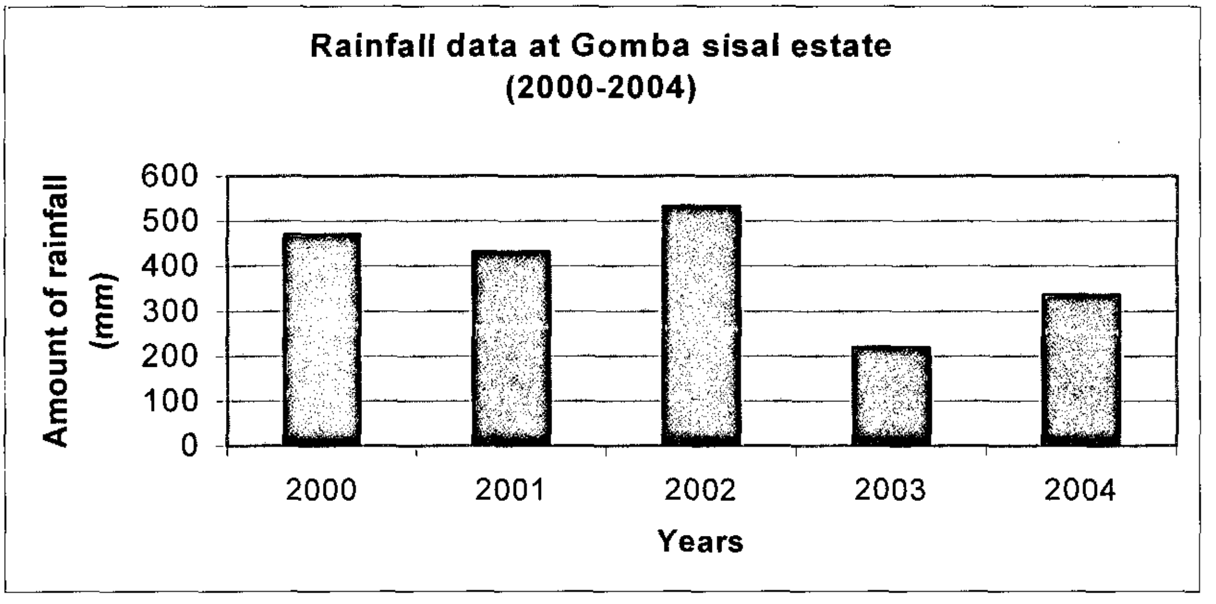


Figure 27. Effect of lime and MOP application on sisal fibre of H.11648



Annex 6. Total rainfall at Gomba sisal estate (2000-2004)



Annex 7. The severity of KLS disease and sisal weevil infection in the fertilizer trial

Fertilizer types applied (treatments)	Plants affected by KLS (%)		Plants with bite marks of sisal weevils (%)			
	2002	2003	2000	2001	2002	2003
Decomposed sisal waste 40 tons over 4 years & 100kg MOP /Ha	90	95	60	50	-	-
7 tons lime & 100kg MOP /Ha	70	74	58	50	-	-
100kg CAN & 10 tons lime/Ha	70	73	50	30	10	3
2.5 tons lime & tropical kudzu 3kg/Ha	100	100	50	60	10	2
5 tons lime & tropical kudzu 3kg/Ha	100	100	55	60	30	8
7 tons lime & tropical kudzu 3kg/Ha	100	100	50	60	-	-
10 tons lime & tropical kudzu 3kg/Ha	100	100	56	80	30	9
2.5 tons lime & MOP 100 kg/Ha	90	96	59	80	20	4
5 tons lime & MOP 100 kg/Ha	80	84	58	50		6
10 tons lime & MOP 100 kg/Ha	70	75	40	30	-	-
2.5 tons lime & CAN 100 kg/Ha	80	87	58	40	20	6
5 tons lime & CAN 100 kg/Ha	70	75	56	40	10	2
7 tons lime & CAN 100 kg/Ha	60	64	53	10	30	8
40 tons of sisal waste only	100	100	60	40	-	-
40 tons of sisal waste & 50 kgMOP/Ha	90	98	61	40	-	-
40 tons of sisal waste & 75kgMOP/Ha	90	97	63	30	40	11
40 tons of sisal waste & 2.5 tons lime/Ha	80	87	66	30	-	-
40 tons of sisal waste & CAN 100kg/Ha	100	100	64	20	-	-
40 tons of sisal waste & 5 tons lime/Ha	80	86	60	30	-	-
40 tons of sisal waste & 7 tons lime/Ha	70	78	40	30	-	-
40 tons of sisal waste & 10 tons lime/Ha	50	57	45	30	-	-
40 tons of sisal waste & CAN 25kg/Ha	60	69	50	10	-	-
40 tons of sisal waste & CAN 50kg/Ha	80	87	56	20	-	-
40 tons of sisal waste & CAN 75kg/Ha	100	100	57	20	-	-
40 tons of sisal waste & CAN 100kg/Ha	100	100	56	40	-	-
Control	100	1000	40	35	-	-

Annex 8. Chemical composition of the soils at the site of the 3-factor variety trial before trial establishment and in 2003

Before trial establishment (year 2000)

Sample No.	Depth	pH water	Organic C (%)	Total N (%)	C/N	Available P (mg/kg)	CEC	Ca	Mg	K	Na
							(Cmols (+)/kg)				
1	0-20	6.5	1.32	0.16	8	1.28	5.08	2.2	1.9	0.14	0.03
	30-60	6.1	0.54	0.04	14	0.37	3.04	1.2	0.8	0.05	0.05
2	0-20	6.6	1.24	0.15	8	1.24	5.87	2.4	2.2	0.18	0.03
	30-60	6.5	0.83	0.11	8	0.41	4.09	1.8	1.7	0.08	0.02
3	0-20	6.7	1.23	0.15	8	0.85	4.89	2.0	2.1	0.16	0.05
	30-60	6.1	0.46	0.06	8	0.31	3.10	1.0	1.1	0.08	0.05
4	0-20	6.8	1.88	0.16	12	0.56	5.53	2.6	2.5	0.12	0.03
	30-60	6.0	0.30	0.04	8	0.01	4.31	1.4	1.0	0.05	0.05
5	0-20	5.5	0.94	0.11	9	0.15	4.18	1.1	0.8	0.13	0.06
	30-60	5.8	0.17	0.02	9	0.15	1.80	0.6	0.4	0.03	0.05
6	0-20	5.7	0.85	0.11	8	0.15	3.25	0.9	0.7	0.14	0.08
	30-60	5.3	0.35	0.04	9	0.44	2.65	0.7	0.6	0.05	0.08

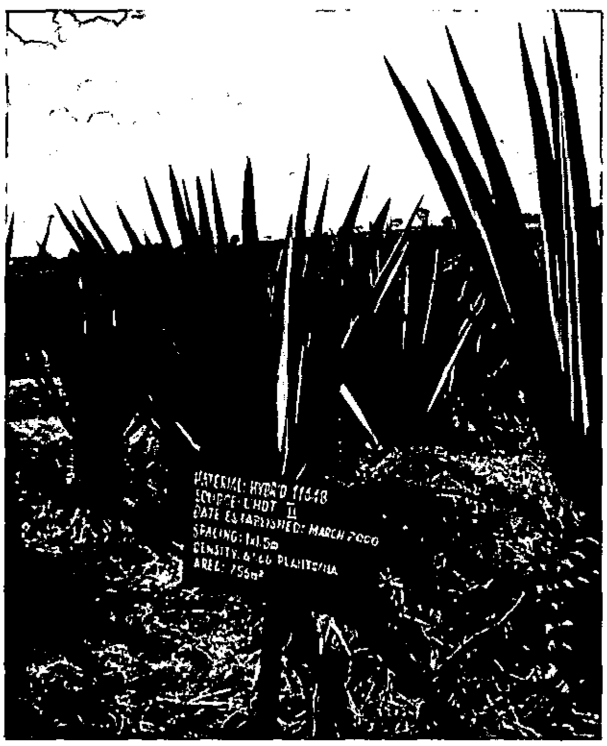
Three years (2003) after establishment of the trial

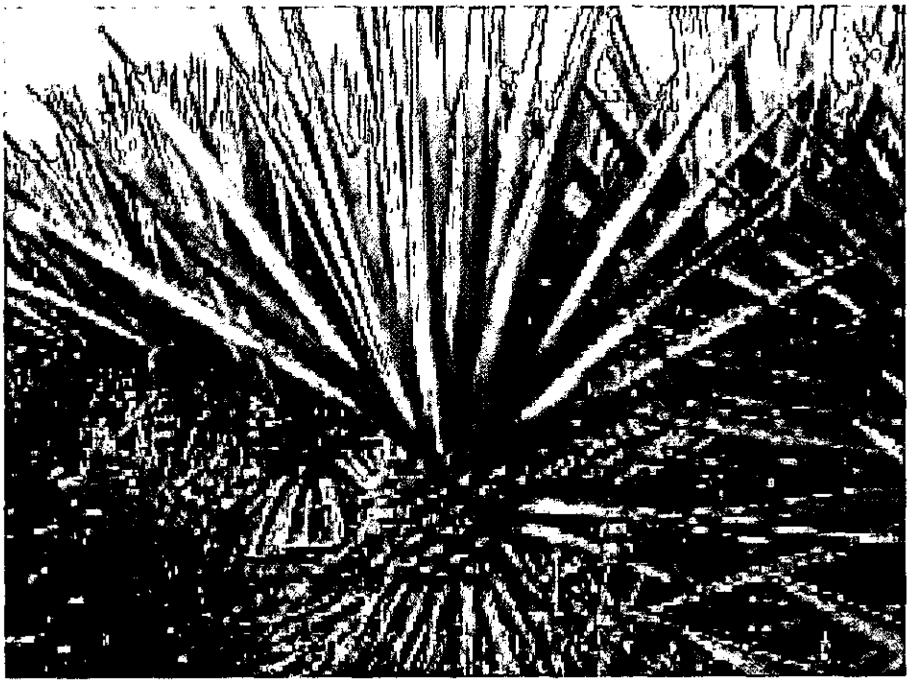
Sample No.	pH water	Organic C (%)	Total N (%)	C/N	Available P (mg/kg)	CEC	Ca	Mg	K	Na
						(Cmols (+)/kg)				
PL 4/78	5.8	1.78	0.16	11	17.47	9.18	4.5	0.6	0.32	0.09
PL 16/29	5.7	1.66	0.16	10	34.65	7.49	3.6	0.3	0.28	0.09
„ 57/99	6.2	1.93	0.18	11	2.60	14.89	9.2	0.9	0.83	0.09
„10/45	6.0	1.38	0.12	12	1.40	12.63	5.2	1.2	1.96	0.10
„56/36	5.4	1.46	0.13	11	1.57	8.79	2.4	0.6	1.04	0.09
„53/25	5.5	1.59	0.15	11	1.29	11.13	3.8	0.7	0.61	0.12
„3/47	5.7	1.36	0.13	10	1.39	9.71	4.0	1.1	0.44	0.09
„74/14	5.6	1.53	0.13	12	1.81	4.22	1.8	0.2	0.28	0.04
„101/14	5.2	1.52	0.14	11	0.90	8.95	2.8	0.4	0.58	0.07
„ 107/35	5.4	1.34	0.12	11	1.53	10.48	3.1	0.6	0.96	0.37
„64/1	5.2	1.63	0.15	11	1.53	12.80	2.8	1.6	0.63	0.09
„62/28	6.8	1.34	0.12	11	1.30	14.40	10.6	1.8	0.87	0.12

C = Carbon
N = Nitrogen
P = Phosphorus
CEC = Cation exchange capacity
Ca = Calcium
Mg = Magnesium
K = Potassium
Na = Sodium

Annex 9. Photographs

VARIETIES





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