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Feasibility Study of Green Harvest Technology in the Sugarcane Farming in Tanzania, under the Accompanying Measures Sugar Protocol (2011 – 13)

REPORT

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1.0 Introduction

Sugarcane is a tall perennial grass of genus *Saccharum.* Plant remnants and DNA evidence suggest that sugar cane evolved in South East Asia (Horton et al., 2015), and it was domesticated in Papua New Guinea around 8000 BC (Hartemink and Kuniata 1996). Over the years, the crop has been distributed in other parts of the world including India, China, Europe, Caribbean, Australia, New Zealand, South America, North America and Africa by seafarers, traders, crusaders, colonialists and missionaries (Fischer et al., 2008).Sugar cane performs well in tropical and subtropical climates. The most common cultivated species are ***S. officinarum*** L., ***S. barberi***, ***S. sinense*** and ***S. edule***. Morphologically, the plant is tall, erecting up to 5 or 6 m with multiple stems, normally branching at the base to make tillers. It is composed of four parts: roots, stalk, leaves and efflorescence (DSD, 2013).

Sugar industry is the largest agro-processing industry in Tanzania (Shaban, 2003). It is a major employer with about 30,000 direct employees and over 80,000 indirect employees (BACAS, 2004). The industry contributes about US$ 123 million annually in GDP and saves the country about US$ 28 million annually (Tanzania Sugar Cane Growers Association, 2007). Most of sugarcane grown in the country is owned by sugar processing factories. Some proportion is owned by small and medium holder farmers known as outgrowers who sign contracts to supply the canes to the factory, sometimes through their associations (UNCTAD, 2006). There are currently five sugar factories: Tanganyika Planting Company (TPC) in Kilimanjaro, Kagera Sugar Limited (KSL) in Kagera and Mtibwa Sugar Estate (MSE) in Morogoro. The other two factories are Kilombero I and Kilombero II, also located in Morogoro Region (Ashimogo and Msuya, 2006). The two Kilombero factories are currently owned by Illovo Sugar Company Limited (ISCL) (Chongela, 2015). Sugar production is still inadequate in Tanzania. The country imports about 200,000 tonnes per annum to satisfy its sugar demand.

In an attempt to cover the deficit, the Tanzanian government has encouraged thesmall-scale producers to undertake sugarcane production through outgrowers’ schemes (Chongela, 2015). Being somehow tied to the processing factories, the sugar cane outgrowers’ agronomic practices including harvesting technologies are influenced by the practices done in the estates owned by the factories. The economic part of sugar cane harvested for sugar production is the stalk. The stalk can be harvested manually or mechanically. Manual harvesting involves use of various types of knives by humans, normally using hands without mounting them on a machine or animals (Carvalho, 2012). Mechanical harvesting involves use of machinery in harvesting (Ma et al., 2013). In most developing countries like Tanzania, most of sugar cane harvesting is still done manually. In Tanzania, over 95% of sugar cane is currently harvested manually.

Sugar canes in the field consist of significant amount of trash and leafy materials which are not needed for sugar production in milling process (Bernhardt et al., 2000; Lionnet, 1986). Sugar cane growers find it necessary to reduce the trash before reaching the factory. The most popular way is to set fire so as to burn the trash (Boeniger et al., 1991; Semenzato, 1995; Lara et al., 2005). Pre-harvest fire has been common, but in some cases, post-harvest fire has been practiced (Ma et al., 2013). Burning of sugar cane has been applied in both manual and mechanical harvesting (Han et al., 2012; Sandhu et al 2013)

Burning of sugarcane for harvesting has become one of the most sensitive environmental issues. Governments are formulating relevant regulations and incentives to help farmers switch from burnt cane harvesting to green cane harvesting (Ma et al., 2013). For example, in Thailand, burning field for harvest and after harvest field management is prohibited (Thai Agricultural Standards, 2010). In South Africa regulations such as need for consent of the neighbourhood community and approval of the reason and timing of burning are being enacted.

In green cane harvesting, sugarcane is harvested without burning. Most of the trash (leafy harvest residue) remains as mulch layer on the soil surface, but some of it is unavoidably carried with the cane to the factory (Sandhu et al 2013). In Australia, one of the key sugar producing countries, sugar cane was harvested green until the early 1940s (Bundaberg CANEGROWERS, 1986). The practice was abandoned due to serious outbreaks of Weil's disease (*Spirochaetal jaundice*), which was spread by rats dwelling in the sugar canes. The green harvesting was reintroduced in 1976 after a very wet season which interfered with the burning.
Harvesting sugarcane mechanically makes green harvesting possible (Han et al., 2012). However, its expansion depends on the improvements of harvesting technology because the machine needs to process more biomass throughput than in the case of burnt cane. The application of new technologies such as Geographical Information Systems (GIS), Global Positioning System (GPS) and remote sensing technologies on sugarcane harvesters makes the machine more cost-efficient, productive, and adaptable to various field conditions (Goswami et al., 2012).

Pre-harvest burning of sugar cane has been a common practice in estates and outgrowers schemes in Tanzania. There has been worldwide pressure for farmers to adopt green cane harvesting due to environmental concerns, changing weather patterns and the potential agronomic gains. Country specific studies have been done in many sugar cane growing countries to analyse the pros and cons of burnt harvesting technology. Such country specific studies have informed Sugar cane harvesting practices in various countries; going further to informing policies and regulations. No such a detailed study has been done in Tanzania to inform farmers, policy makers and other cane growing stakeholders on the current harvesting technologies applied in the country and possible move towards the new ones. This document reports on a feasibility study of green harvesting technology in the Tanzanian commercial sugar cane farming; specifically Kagera, Kilombero, Mtibwa and TPC sugar cane growing areas.

2.0 Methodology

Three steps were followed to achieve the objectives of this study.

The first was to do a global literature search on the commercial sugar cane harvesting technologies. This was achieved through review literature available in hard and electronic resources.

The second step was to conduct situational analysis of the sugar cane harvesting technologies in commercial sugar cane growing areas of Tanzania. This was achieved through discussions and interviews using semi-structured questionnaires with different stakeholders. Discussions were done with ground staff and officials of Sugar Board of Tanzania, millers' representatives dealing with harvesting and outgrowers, and outgrowers associations representatives. Additionally, existing literature on Tanzania sugar cane industry was consulted.

The third step was to perform comparison between the burn and green harvesting technologies with respect to agronomy, environment, and productivity. Semi structured questionnaires were prepared and administered to the outgrowers and millers in order to generate information which was used to come up with the conclusions.

The interviews were done using semi structured open ended questionnaires. Sugar cane outgrowers from Kilombero, Mtibwa and Kagera sugar were interviewed using interviewer's administered questionnaire while with miller's representatives interviews were done using self-administered questionnaire. The numbers of outgrowers interviewed are shown in Table 1. Questionnaires are attached in the appendices (1 and 2).

Table 1: Number of outgrowers interviewed and sex

Location	**Sex**		**Total**
	Male	**Female**	
Kagera sugar	5	1	6
Kilombero sugar	5	1	6
Mtibwa sugar	5	1	6
Total	**15**	**3**	**18**

Further, burnt harvested and green harvested sugar cane samples were collected for lab analysis to determine if there are any differences in sugar content between the two harvesting technologies. Sucrose content of sugarcane for both BH and GH was determined at SUA food Science laboratory using procedure described by Worku and Solomon (2014).

The study was conducted in the major commercial sugar cane growing areas of Tanzania. These are around Kagera Sugar Ltd in Missenyi district (Kagera region), Mtibwa Sugar in Mvomero district, Morogoro; TPC in Kilimanjaro; and Kilombero Sugar located in Kilosa and Kilombero districts of Morogoro region. Figure 1 show the locations of the major commercial sugar cane growing areas.

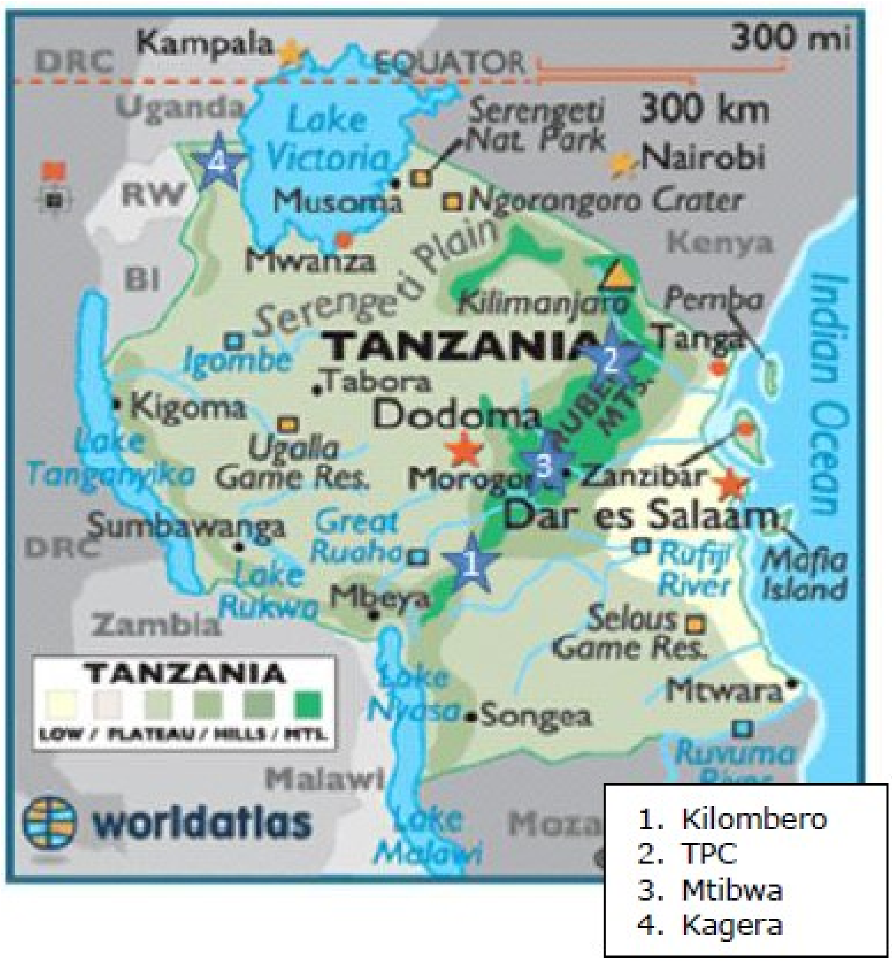

Figure 1: Location of the major commercial sugar cane growing areas in Tanzania (*Image copied from Rabobank, 2013*)

3.0 Sugar cane harvesting technologies: Global context

As described in the introduction section, there are two major harvesting technologies of sugar cane globally. The first one is burnt harvesting, where before cutting the cane, fire is set to burn the trash. In some cases, though not very common, cane can be cut and later burnt to reduce the trash prior to haulage. The second harvesting technology is green harvesting. In this technology, cane is harvested without pre- or post-burning. The trash is left in the field, although some of it can be unavoidably grabbed by the loaders and hauled with the cane to the factory. Pros and cons of the two harvesting technologies are described below:

Plate 1. Sugar cane manual green harvesting in Reunion (*Photo from www.alamy.com*)

3.1 Pros and cons of burnt and green harvesting: global context

3.1.1 Advantages of burnt harvest technology

Generally, the sole purpose of burnt harvest is to lower the amount of trash produced after cane harvest and therefore reducing transportation cost to the mill and increasing harvesting efficiencies (Meyer et al., 2005). Pre-harvest burning of sugarcane leaves enables manual pickers to collect the crop quickly and suffer less personal injury (Ahmed et al., 2013). Records showed that adoption of the method increased the nominal output per cutter from six to about nine tones per day in Australia (Bundaberg CANEGROWERS, 1986).

Apart from production cost, burning sugarcane before harvesting improves soil temperature near the soil surface. This is necessary in areas with seasonal low temperatures. The young sugarcane plants can be very susceptible to freezes when trash blanket is left on the soil surface (Sandhu et al., 2013). Research evidence showed that soil capacity to absorb heat during daylight hours and then transfer this heat back to the air near the soil surface at night is greater in bare soil than for soils covered with mulch or crop residue (Fritton et al., 1976; Sandhu et al., 2013).

Furthermore, the practice is most suitable in poorly drained soils, since the land is left bare to facilitate evaporation. Weed control, soil fertilization and irrigation for ratoon are done easily in the burnt field than in green cane harvest (Bundaberg CANEGROWERS, 1986). Burn harvest was also reported to decrease the incidence of pest and diseases decrease in most cane fields (Semenzato, 1995; Bernhardt et al., 2000).

3.1.2 Advantages of green harvest technology

The main advantages of green cane harvest are mostly associated with agronomic and environmental issues. Some potential advantages may not be realized or even become disadvantages, given existing weather in a particular year (Guest, 2015). In agronomic point of view green cane harvest retain a huge amount of trashes on the surface which increases organic matter content of the soil (Graham et al., 2001). The increased organic matter content and quality may greatly affect other soil properties and processes such as aggregation, soil structural condition, and nutrient cycling (Richard, 2003). Not only do the practice increase organic matter content but also increases trash blanket that help to suppress weed growth as well as reducing the need for frequent cultivation and spraying (Braunbeck et al., 1999). However, due to trash blankets soil loss by erosion as well as water loss through evaporation is prevented (Richard, 2003; Ma et al., 2013).

Green cane harvest has also been reported to increase the rate of infiltration, thus improving soil moisture content. This has a positive effect of reducing irrigation requirement and producing higher cane yield in drier areas (SRA, 2014). With the green cane harvesting approach, harvesting is still possible when wet weather prevents burning and there is no loss when heavy rain delays harvesting of burnt cane for long periods (Bundaberg CANEGROWERS, 1986).

Studies showed that green cane harvesting is environmental friendly practice to biodiversity and ecosystem. With green harvest technology, emission of harmful smoke which would otherwise affect the health of nearby community is eliminated (Ahmed et al 2013). Among other advantages of green cane harvest reported by Richard (2003), is increase in the population of beneficial microorganisms. A study conducted to evaluate the long-term effects of green cane harvesting versus burning on the size and diversity of the soil microbial community in South Africa observed a significant increase in microbial community in green can harvest than burnt cane harvest (Graham et al., 2001). Most of sugarcane fields occupy large plots of land of which provide a fine environment for many ecosystems. The ecosystems include organisms such as snakes, insects, microorganisms and small wild animals. Therefore, green can harvest is probably the best harvesting technology in protection of the biodiversity.

In addition, sugarcane straw left in the field could be used for bioelectricity cogeneration and cellulosic ethanol production (Lisboa et al., 2017). The sugarcane industry is now investing in the use of sugarcane straw as a feedstock to produce 2G-ethanol and cogenerate bioelectricity (Franco et al., 2013; Khatiwada et al., 2016).

3.2 Disadvantages of burnt harvest technology

Reports from different researches showed that burning of the sugar cane crop produces large amounts of particles and toxic gases such as carbon monoxide into the air which may pose health issues to nearby community (Hashem et al., 2015). For example, the burning of sugar cane crops has been linked to; irritation of the airways such as coughing or difficulty breathing, decreased lung function, aggravated asthma, development of chronic bronchitis, irregular heartbeat, heart attacks, and premature death in people with heart or lung disease (University of Florida Research Project, 2009).

In the burning process the land is left bare thus increases the surface runoff (Davies, 1998), consequently, it may carry suspended soil particles, dissolved inorganic nutrients, and other materials into river streams and lakes reducing water quality. Thus both the quality and quantity of the most productive portion of the soil profile are directly diminished through burning. Over time this, of course, reduces the agricultural productivity (Brady and Weil, 2010). The temperature within a moderate cane fire can quickly reach 400 degrees C (Davies, 1998). This temperature is sufficient to cause volatilization of some nutrients such as nitrogen and sulphur to the atmosphere. The burning also kills beneficial microorganisms and worms living in the surface layers of the soil (CannavamRípoli et al., 2000). This affects decomposition and mineralization of dead materials to plant nutrients, thus reducing productivity of the soils and increase demand for industrial fertilizers (Havlin et al., 2005).

The smoke produced by burning can be nuisance and a source of health problems. Recent research done in the State of São Paulo Brazil has also indicated huge amount of air pollutants such as aerosols, fine and coarse particulate matter, gases such as carbon monoxide and carbon dioxide aldehydes (acrolein, formaldehyde), methane nitrogen oxides, nitrous oxide, other hydrocarbons and polycyclic aromatic hydrocarbons generated from pre-harvesting straw burning of sugarcane (Arbex et al., 2007). Once some of these gases such as methane, NO_2 and hydrocarbons enter in the atmosphere, may produce secondary pollutants through photochemical reaction (Paraiso and Gouveia, 2015). Furthermore, in Glades, Hendry and Palm Beach counties, it was observed that sugar cane burning emits more than 2,800 tons of hazardous air pollutants per year. The burning accounted for 86 percent of Palm Beach County’s emissions of formaldehyde, a probable carcinogen, and 69 percent of emissions of toxic acenaphthylene, a pollutant linked to genetic mutations and cancer (Lara et al., 2005).

3.3 Disadvantages of green harvest technology

Adoption of green harvest technology has been so slow by most of cane growers in the world due to several challenges encountered by this technology:
Most of cane growers complain about increase in cost of production for both manual and mechanical harvesting when using green harvesting technology. The cutting rates are lower compared to the burnt cane, thus increasing the time and maintenance costs. In Australia, it is reported that the cutting rates in green harvest using harvesters in only 60% to 70% of those in burnt cane, and may go to 50% if the canes are very large or lodged (Ma et al., 2013)

Green house gas emissions have been reported in green cane harvesting for the areas which are poorly drained. The emissions may be higher than the one caused by burnt harvesting. The trashes in poorly drained and cold areas may also result to poor germination, slow growth and poor ratoon performance. Oliveira et al. (2001) reports that in cold regions trash blanket seemed to lower soil temperature which in turn delays re-growth of ratoon cane. Crop failures resulting from cane trash blanketing have been reported in the Southern region of Australia.

It has been observed that the trash blanket makes tillage operations more difficult, interferes with fertilizer and herbicide applications and can immobilize N and P (Ng KeeKwong et al. 1987). In a study done by Wiedefeld (2009) in semi arid Texas, he found that effects due to green harvesting on soil properties and crop growth were relatively minor, but the residue remaining on the soil presents considerable challenges in cultivation, weed control and irrigation.

Fire risk is another challenge when doing green harvesting. Dry vegetation on the ground may accidentally catch fire and cause a very big loss. Compared to the controlled pre-harvested burning which are short lived, seasonal and monitored, the fires in the green harvest can move quickly and are very difficult to extinguish. The fires may cause extensive damage in immature crops, retarding maturity and resulting in lost fertilizer and other inputs.

4.0 Factors contributing to the choice of harvesting technology

The choice of sugarcane harvest method mainly varies with location because of differences in soil type and environmental conditions (Sandhu et al., 2013). Abiotic factors such as temperature, drought, relative humidity, texture of the soils may influence the choice of harvesting technology. For instance, air and soil temperature are microclimatic factors, which influence the re-emergence growth of ratoon cane (Oliveira et al., 2001). Beater and Maud (1962) observed that frost damage to sugarcane occurs far less frequently on bare soil compared to soils covered with harvest residue. Therefore, trash blanketing in these regions might cause delay of ratoon growth and thus burning of could be the option. Additionally, green cane trash blanketing is not suitable in poorly drained soil due to the fact that the condition may result into yield loses resulted from poor germination and slower growth (Bundaberg CANEGROWERS, 1986).

However, in tropical regions cane growers opt for cane burnt harvest simply because the method is thought to be an efficient method in reducing production cost and thus, an economic factor for the survive of individual farmer and the sugarcane industry (Legedre, 2000). For example, the sugarcane consist of 75 to 80 percent net cane from which the juice is and the sugar crystallized while the rest parts are trash such as leaf material and tops, from which little or no sugar is produced. Burning helps to remove these trashes and make the harvesting and transportation processes easier. It is estimated that, by not burning this trash, the industry would spend more than $24 million in transportation and processing costs. Research data show that there is an actual reduction of 3 pounds in the yield of recoverable sugar per gross ton of sugarcane for each 1 percent of trash processed by the factory in Luciana (Legendre, 2000).

Availability of labour is another factor contributing to the choice of harvesting technology. Sugarcane cutting is a tough nature of work which requires a physical strength of an individual. In Sudan for example, introduction of green cane led to shortage of labour, since most of them preferred to work in other type of crops rather than in sugarcane fields (Ahmed et al., 2013). Therefore, companies shifting from burnt to green cane harvest should incur cost of mechanical harvesting machine to cover the uncertainty of manual cane harvesting. Although pre-harvest burning of sugarcane is known to reduce local air quality, it is thought to be an efficient method for harvesting sugarcane and many plantations therefore opt for it over manual green cane (Le Blond et al., 2017).

5.0 Tools used in sugar cane harvesting

Sugarcane can either be harvested green or burnt and three different harvesting methods can be chosen. These include; manual, semi mechanized and mechanical harvesting methods. Tools used are based on the three methods (Langton, 2004). For example, in manual harvesting method cutters uses machete-type knives, also known as cutlass. This method is very labor-intensive and cutters are subjected to stooping in order to cut canes at the lower length desired for optimal sugarcane harvest. Sugar plantations in most developed countries evolved from the manual harvesting method to the use of modern machinery such as whole stalk harvesters and chopper harvesters (Peter, 2008).

6.0 Sugar cane in Tanzania

6.1 Production system

The sugar industry started in Tanzania in early 1924 when TPC factory started followed by two other sugar factories situated in Kilombero and Mtibwa in 1961 and 1962 (Matango, 2006). The fact that outgrower schemes started at Kilombero and Mtibwa after the first two years of sugar production indicates their importance in sugar cane production systems of Tanzania, especially in supplementing sugarcane needed for crushing in the processing mills. Thenumber of outgrowers has significantly increased especially after privatization of the sector in 1998, and their contribution in the sugar industry have been increasing. For example, in Kilombero alone, there are 8500 outgrowers, supplying 43% of the sugar cane crushed in its two factories (Sulle and Smalley, 2015.)

The expansion of the outgrower schemes have allowed many households to benefit from the proceeds of sugarcane. The schemes have stimulated business in townships around the farms, and the payments have helped them to build better houses, fund other crops and educate their children. Further improvement on outgrowers' productivity will therefore improve socio-economic status from individual small holder levels, community, and national level. This can be done through improvement of their agronomic practices.

6.2 Sugar cane harvesting in Tanzania

One of the agronomic practices that are posing challenges to the sugar cane growers in Tanzania and worldwide is harvesting. Except for machine harvesting, the sugarcane harvesting is labor-intensive which is done manually by various types of hand knives leading to fatigue due to excessive stress on the joints and muscles (Clementson and Hansen, 2008). Given the nature of the canopy of sugar cane, the crop harbours harmful pests and animals thus presenting safety issues to the workers (Carvalho, 2012). This has necessitated use of harvesting techniques which might compromise with quality of the end product and the environment – the pre-harvest burning.

6.2.1 Sugar cane harvesting technology at Mtibwa growing area

At Mtibwa Sugar Estate, the current harvest technology is pre-harvest burning and manual. This technology is applied in both the factory owned sugar cane fields and the outgrowers' sugar cane fields. The factory currently has no any plans to move to mechanical and green harvesting, citing their goal of employing as many local people as possible. The only time they will consider mechanical harvesting will be when the source of local labour dries up.

Other huddles preventing Mtibwa Estate from going to mechanical harvesting are the high capital costs and high maintenance costs. The field layout must change to allow head room at the end of each field for the machine to turn, and the will need to purchase and maintain the machine. They also claim that the machine cut cane quality is not as good as hand cut. The factory at Mtibwa has not been crushing green cane. To do so, they report that they will need to replace the shredder at the mill to allow for the milling of more trashy cane. Another setback is the higher labour demand for green cane cutting. They report that cutter output falls dramatically when trashing. They also report that they cannot effectively flood cane after harvest through a heavy trash blanket.

Given the market relationship between the miller and the outgrowers, unless the miller's policy and crusher are modified, the outgrowers will not adopt another harvesting technology i.e. will not turn from burnt harvesting to green harvesting technology. The miller demands the cane be burnt for trash removal before they are crushed.

6.2.2 Sugar cane harvesting technology at TPC growing area

At TPC, the sugar cane harvesting technology is also currently pre-harvest burning. During the discussion with Company representative, he made it clear that, given the canopy and other challenges, the only way to make green harvesting profitable is by mechanization. It will be difficult to realize profit with the current manual harvesting. TPC pointed out that they have recently started mechanical harvesting trials. However, they could not present any data to conclusively decide if it is feasible or not because they are still in early stages of the trials. They are yet to see regrowth of fields, do measurement of losses, and calculation of costs. Challenges they are facing so far are the costs. Field has to be prepared to suit mechanical harvesting – row spacing; wide enough roads etc… at the edge of the fields, absence of obstacles within the fields like irrigation lines and need for flat fields edges at the end of the lines. There are no outgrowers' schemes at TPC, thus, any adoption of new harvesting technology will be within the sugar cane fields owned by the factory.

6.2.3 Sugar cane harvesting technology at Kagera sugar

In Kagera Sugar, the sugar cane harvesting technology is currently pre-harvest burning. The same harvesting technology is used by the outgrowers. The outgrowers get support on hauling the harvested cane. The opinion from the interviewees in Kagera Sugar is that crushing of green cane will require some modifications of the processing machinery because of the amount of the trash and its effects on the colour of the final product.

With this concern, the outgrowers might not have any other option currently, but to follow the harvest technology adopted in the sugar cane fields owned by the factory. Interviewees also were of opinion that mechanization is needed in order to do green harvesting profitably. They indicated a concern on how the labour will be replaced because the machines will require just a few people to man them, thus replacing hundreds of labour hands.

6.2.4 Sugar cane harvesting technology at Kilombero sugar growing area

Currently, both plants of Kilombero (Kilombero I and II factories) are doing burnt harvesting. For five years between 2009 and 2013, the factories were also doing mechanical and green harvesting. The mechanical harvesting was applied both on burnt and unburnt cane. However, the mechanical harvesting stopped in 2013 because of cost of operation being higher per ton and low productivity. According to their records, the cost per ton was 40,000Tsh.
Other challenges with mechanical harvesting were reported as low cutter productivity, low pay load during haulage, poor cutting quality, possibility of wild animal in the field during cutting, huge difficulties in crushing and processing and large amounts of baggase to be disposed of at enormous cost to the company

Currently, Kilombero Sugar is not planning to revert to mechanical and green harvesting. Reasons mentioned are: the cost of mechanical harvest is too high compared to manual cutting, current field layout and configuration (irrigation and drainage structures, headland, and leveled land) is not friendly for mechanical harvest, currently cane yield per hectare does support cost per ton. Cost of labour will determine when this becomes viable. They are also concerned about labour which will be laid down if mechanical harvesting is applied in their fields. Processing difficulties of green cane (resulting to darker sugar colour) was also mentioned as a bottle neck.

Plate 2. A harvester used for mechanical sugar cane harvesting in Kilombero *(Photo: Boniface Massawe, 2017*)

7.0 Involvement of outgrowers in the choice and implementation of harvesting technology

The concept of sugarcane outgrower's schemes is based on contract farming with the main purpose of creating a market for smallholders to sell their products to the millers (Glover, 1990). Generally, the buyer makes a deal with farmers, often a contract with fixed prices, and requests a certain quality and quantity of product (Ohlsson, 2014).

In Tanzania sugar cane industry, the buyers, normally large scale farmers owning sugar processing plants enter into contract with the farmers around the estate to grow and sell the cane to the processing plant (Smalley *et al*., 2014). The buyers in Tanzania normally have larger land, capital and more technology than the outgrowers. As part of the deal, buyers support the outgrowers technically and capitally to a certain level. Part or all of the support costs are then deducted when the farmers are selling the crop to the buyer. Because the buyers have the technology and own the milling plant, they also dictate the harvesting technology to suit their requirements. The canes from a farmer who does not follow the protocol are rejected. Therefore, the outgrowers are generally unable to choose the harvesting technology under this type of relationship.

8.0 Harvesting costs: Burnt vs green harvesting in Tanzania

During the study, the harvesting costs were listed as being related to the following activities performed specifically for cane harvesting:

a. Road repair
b. Firebreak
c. Burning
d. Cutting
e. Loading
f. Transportation
g. Cleaning and leveling of stumps

Plate 3: A grab loader at Kilombero II factory (*Photo: Boniface Massawe, 2017*)

Plate 4: Burnt harvested sugar cane ready for loading in an outgrower's farm in Kilombero (*Photo: Boniface Massawe, 2017*)

8.1 Harvesting costs in the outgrowers farms

There was no clear basis for comparing green harvesting with burnt harvesting in the outgrowers fields, since all outgrowers apply burnt cane harvesting technology. Therefore, there was no data for green cane harvesting. The discussion below highlights on the differences of harvesting costs and specific operations for outgrowers from different commercial cane growing areas.

The average cost for burnt cane harvesting technology for each area is expressed in Fig 2, 3 and 4. The burnt harvest (BH) costs varied from one commercial cane growing area to another. In Kagera sugar, transportation cost was much higher compared to other sugar industries. More than 50 % of the total harvesting cost goes to transporting cane from field to miller (Fig 2). In Kilombero and Mtibwa transportation costs were 46 and 31 %, respectively. Costs of transportation were charged based on the kilometers. Between 1- 10 km costs were Tsh. 6 500, 7 000 and 8 500 per ton in Mtibwa, Kilombero and Kagera, respectively. These costs rise to Tsh.25 000 per ton if the farm is located >40 km away from the factory. Most of cane outgrowers in Kagera sugar are far (>10 km) from the factory. This attributed to Kagera cane outgrowers paying more percent of the total harvest cost in transportation compared to Mtibwa and Kilombero (Fig 2,3 and 4).

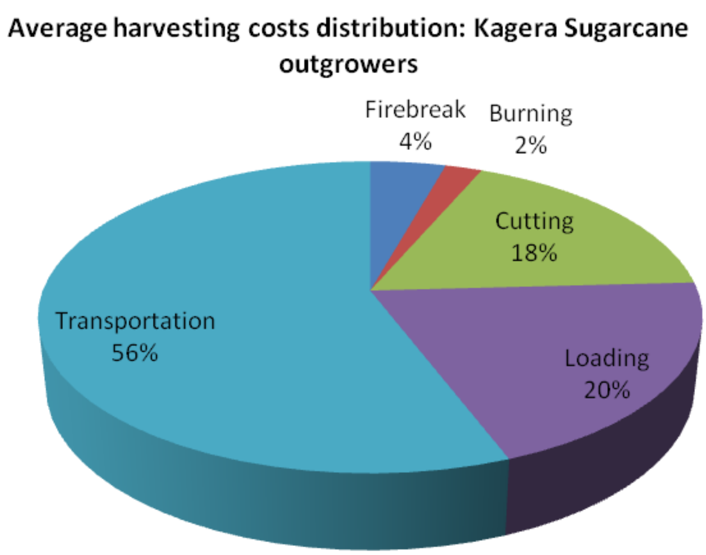

Figure 2: Average harvesting distribution cost for Kagera outgrowers

Firebreak and burning cost were almost the same in all locations. In Kagera, firebreak and burning constitute about 6 % of the total harvesting cost (Fig. 2). The same was observed in Kilombero 6 % of the total harvesting cost goes for firebreak and burning (Fig 3), whist in Mtibwa the value of firebreak and burning was a little bit high (9 %) compared to other locations. Cutting and loading costs were 18 %, 39 % and 28%, respectively in Kagera, Mtibwa and Kilombero. The variation of cutting cost observed was due to access of labour between the locations. In Kagera for instance cutting cost were the same (Tsh.6500 per ton) for all out growers since labours (cane cutters) are provided by miller. In Mtibwa and Kilombero, millers do not provide labour for cane cutting thus outgrowers seeks for their own way to get cane cutters. In Mtibwa cost of cane cutting ranges from Tsh. 6 500 to 8 500 while in Kilombero cost ranged from Tsh.6500 to 7000. For that reason cutting costs in Mtibwa and Kilombero sugar were much high (39 % and 28 %, respectively) compared to Kagera sugar (18 %) of the total harvesting cost (Fig 2, 3 & 4).

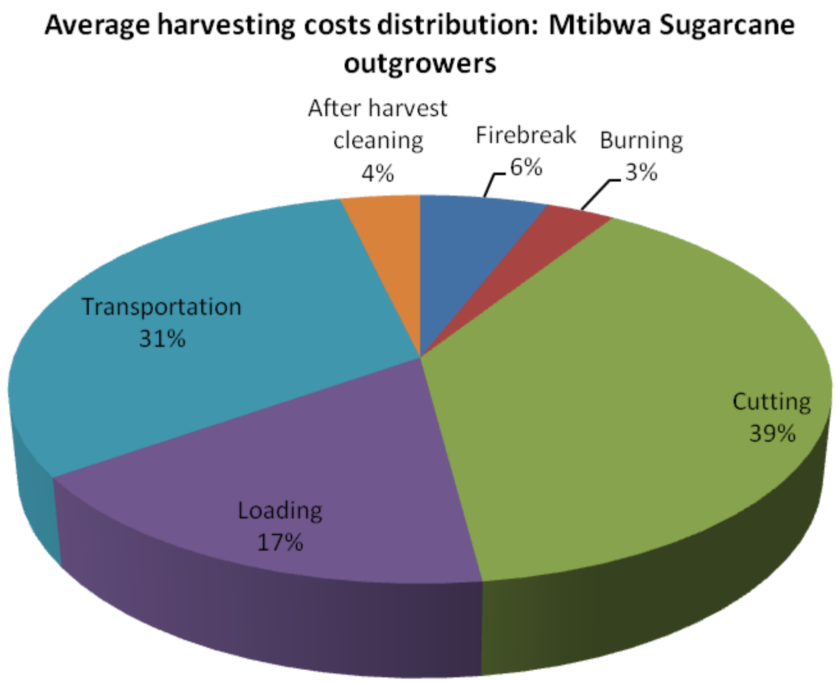

Figure 3: Average harvesting distribution cost for Mtibwa outgrowers

Loading cost were almost the same in all locations, 20, 17 and 20 % in Kagera, Mtibwa and Kilombero, respectively. Loading is done using machines known as grab loader loaders and the charges varies from Tsh. 4 650 to 5 000 per ton. Other cost includes after harvest cleaning. This kind of cost was reported only in Mtibwa sugar which constitute 4% of the total harvesting cost (Fig. 2)

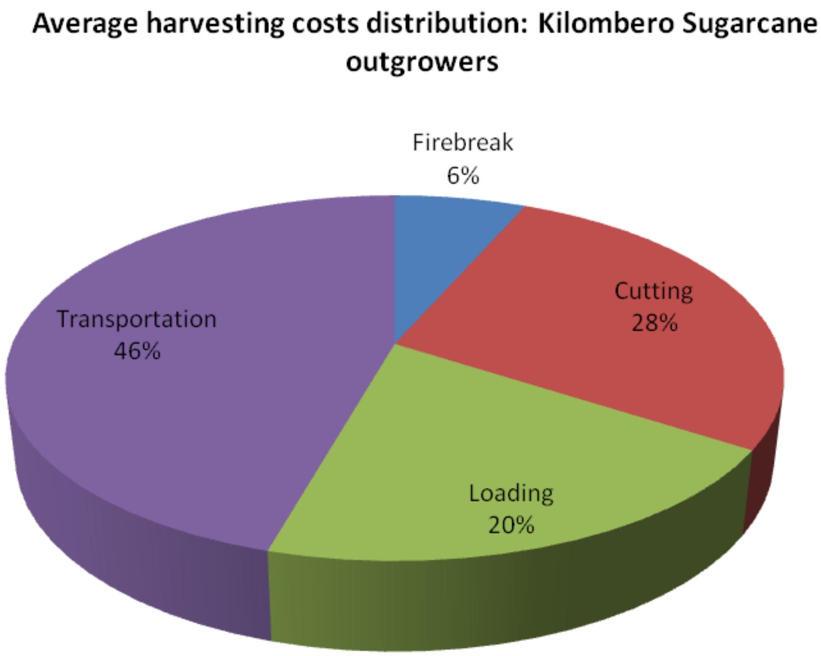

Figure 4: Average harvesting distribution cost for Kilomberooutgrowers

Generally, the average harvesting cost was observed to be high in Kagera with the average of about Tsh. 660,000 per acre while in Mtibwa and Kilombero had an average harvesting cost of around Tsh. 427000 and 540000 per acre, respectively (Table 2 & Fig 4). The highest cost observed in Kagera was due to transportation cost since most of outgrowers farms are located far >10 km from miller. In Mtibwa and Kilombero sugar most outgrowers are within 10-20 km with exceptional few who are located >40 km, this led to low harvesting cost.

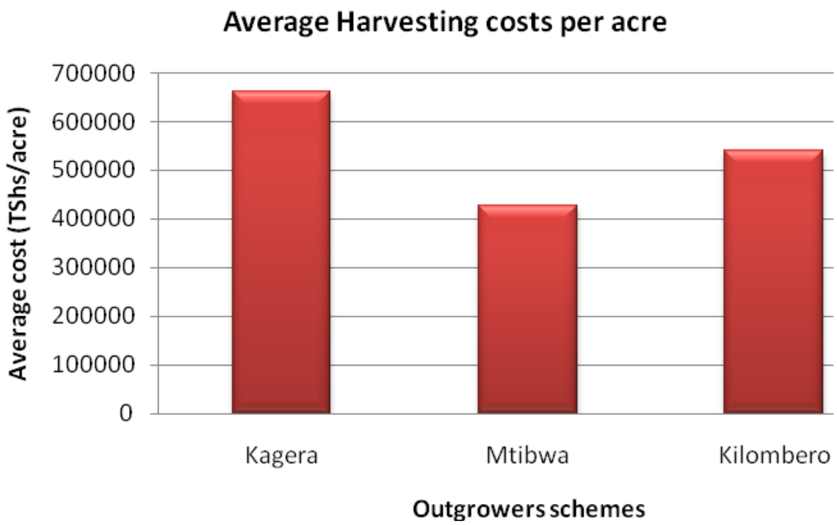

Figure 5: Average harvesting cost per acre for Kagera, Mtibwa and Kilombero outgrowers

Table 2: Detailed average costs of harvesting operations in outgrowers' farms

Cost area	Average costs of harvesting operations in outgrowers' farms (TShs/acre)								
	Mtibwa outgrowers			Kagera outgrowers			Kilombero outgrowers		
	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
Firebreak	20,000	40,000	25,667	10,000	50,000	28,833	20,000	100,000	40,000
Burning	10,000	20,000	13,750	5,000	20,000	14,000	-	-	-
Cutting	90,000	297,500	168,917	34,000	280,000	117,608	136,000	195,000	168,375
Loading	44,000	133,000	75,167	100,000	200,000	133,333	100,000	150,000	123,750
Transportation	72,600	210,000	135,017	300,000	450,000	370,833	238,000	300,000	278,500
After-harvest clearing	10,000	20,000	16,000	-	-	-	-	-	-
Total	**250,100**	**680,500**	**427,267**	**515,000**	**913,000**	**662,275**	**335,000**	**730,000**	**541,000**

8.2 Cost analysis for green harvest technology

The cost analysis for green harvesting (GH) technology was not captured from outgrowers under this study since all outgrowers in Tanzania perform burnt cane harvesting technology. However, all of them responded that GH will cost more due to challenges in the sugar cane farms. Most of outgrowers argued that if GH is to be implemented the number of cutters per acre may probably increase to a range of 15 to 20 cutters compared to the current situation where only 7 cutters are needed per acre. This argument is in line with the study conducted in Zimbabwe 20 years ago where labour requirement for GH was reported to be more than twice that required for BH (Murombo et al., 1997). In addition, trash management (windrow) is anticipated to be more costly (approximately 3 times higher) than for BH. Other outgrowers said that cost of transportation will increase due to decrease in tonnage per vehicle. Therefore, this situation may lead to doubling of harvesting costs.

Some millers have tried to implement the mechanical and green harvesting in their company. In Kilombero for example, the trial was done for 5 years (2009 – 2013) but didn't work out because the practice seemed to be more costly than the current harvesting technology (BH). The estimated cost for GH (mechanical) was Tshs 40,000/= per ton compared to BH (manual) which costs around Tsh 27,000/= per ton for an average yield of 30 tons cane per acre. Most of this cost goes to cutting and transportation (Table 3). Figure 6 shows the distribution of harvesting costs in burnt harvesting by the miller in Kilombero. Loading and transportation accounts for two thirds of the total harvesting costs, with cutting and trash management accounting for almost a quarter of the total harvest costs (Figure 6). Translating this information to green harvesting – there will be increase in cost due to higher amount of trash.

Cutters will have to spend more time harvesting equal amount of cane because of dealing with trash which hinders cutting speed. This can be solved when manual harvesting is not applied. However, mechanical harvesting requires high investment costs (purchasing the machines, and re-doing farm infrastructure such as roads, row spacing), and additional machinery maintenance costs. Because green harvest will result to higher trash, the cost of after harvest trash management will also increase. More trash will be loaded and transported to the factory, thus increasing loading tonnage and transported tonnage.

Another possible increase in cost not directly related to trash is field inspection. Mechanical harvesting requires a flat land for efficient harvesting. Increased field inspections under heavy canopy will be required to deal with unexpected growths of anthills.

Table 3: Burnt harvesting technology costs at Kilombero (miller's farm)

Activity	Cost per acre (TShs)
field inspection	725
fire break	90,468
burning	725
cutting and windrowing	171,000
loading and transportation	537,000
Total	799,918

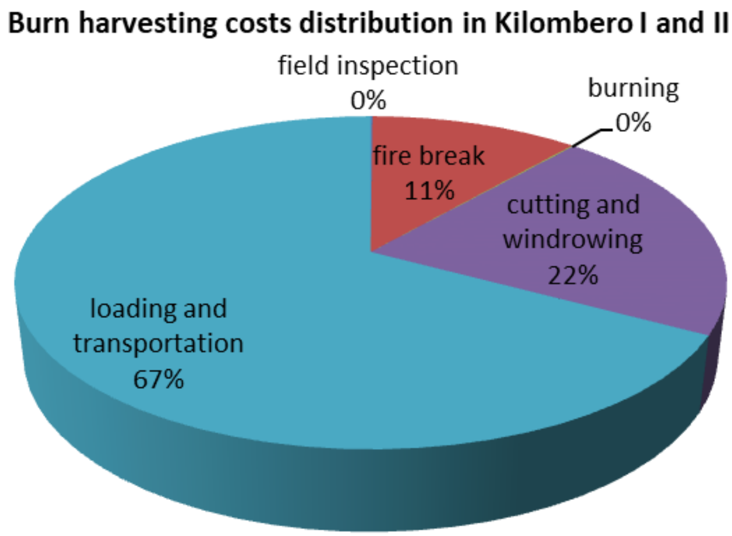

Figure 6: Cost distribution for Kilombero burnt harvesting technology (miller's farm)

In TPC the mechanical cane harvesting trial is ongoing and it was too early for the company to estimate the cost. Other challenges for GH reported by Kilombero and TPC include: low cutter productivity, low pay load during haulage, poor cutting quality, difficulties in crushing and processing and large amounts of baggase, the field should be level with wide roads and free from irrigation line. These challenges for GH bring enormous cost to the company compared to burnt harvesting.

9.0 Comparison of sucrose content between burnt and green harvested cane

Table 4 shows the comparison of sucrose contents between BH and GH sugarcane samples from Kilombero and Mtibwa cane outgrowers. Outgrowers in Mtibwa grow only one variety (NCO376) while in Kilombero two varieties are grown (NCO376 and N41). The contents of sucrose in sugar cane from Kilombero outgrowers were 11.92 and 12.52 % for BH and GH, respectively in NCO376 variety while in N41 variety the values of sucrose contents were 12.26 and 13.03 % for burnt and green harvest, respectively (Table 4). Sucrose contents for sugarcane grown by outgrowers in Mtibwa were 10.90 and 11.10 % for BH and GH respectively. A bit higher contents of sucrose were observed in GH cane in all cane varieties. However, the variation was quite small to justify the significant difference. Sugarcane with a sucrose percentage closer to 23 % is considered to produce the highest quality of cane sugar (Hanna Institute, 2014). Based on this observation sucrose contents in both GH and BH cane varieties were below the potential value (i.e. below 23% sucrose content).

Table 4: Sucrose contents of BH versus GH cane from outgrowers' farms of Kilombero and Mtibwa sugar

Location	Variety	Sucrose content (lab analysis) (%)		Average sucrose content (%)	
		BH	GH	BH	GH
Kilombero	NCO376	12.02	12.97	11.92	12.52
		11.81	12.06		
	N41	11.97	13.04	12.26	13.01
		12.55	12.98		
Mtibwa	NCO 376	11.00	11.04	10.90	11.10
		10.79	11.13		

The sucrose content obtained under this study for BH and GH did not differ from those recorded by millers (TPC and Kilombero sugar). The data for sucrose content for BH in Kilombero sugar varied from one variety to another (Table 5). The sucrose content ranged from 10.98 to 12.98 %. The lowest and highest value was reported for N27 and N12 varieties, respectively. One variety (N41) used as a trial for green harvest, and result showed that sucrose content increased from 12.37% for BH to 13.0 % for GH harvest cane. In TPC the average sucrose content of sugar cane under BH was a bit higher (12. 43 %) compared to that of GH (11.22 % and 11.35 % for 11B1 and N53 varieties, respectively). Therefore, this indicates that there is no difference in sucrose content between BH and GH cane if processing of sugar cane is done properly and on time. Research demonstrates that no differences in sucrose recovery between canes harvested green and burned if care will be taken for all practices (Núñez and Spaans, 2007). However, other factors such variety, field conditions, climate soil nutrients and delayed cane processing could contribute to variation of sucrose content in sugar cane (Cardozo and Sentelhas, 2013; Pereira et al., 2017; Kenta et al., 2016)

Table 5: Sucrose contents of BH versus GH of different varieties grown in TPC and Kilombero sugar

Location	Variety	Sucrose %	
		BH	GH
Kilombero	N12	12.98	
	N23	12.95	-
	R579	12.86	-
	MN1	12.85	-
	N30	12.70	-
	R570	12.54	-
	N19	12.39	-
	N41	12.37	13.00
	N25	12.16	-
	MIX	12.12	-
	N36	11.89	-
	N47	11.74	-
	NCO376	11.20	-
	N27	10.98	-
			-
TPC	11B1	-	11.22
	N53	-	11.35
		*12.43	-

*The average content of sucrose content for BH in TPC

10.0 Comparison of agronomic impact from burnt cane harvest technology against green cane harvesting technology

The comparison of the agronomic impact of the two sugar cane harvesting technologies was done using information collected from the millers and the outgrowers. Since green agriculture has not been practiced by commercial outgrowers, the information from the outgrowers based on their understanding of the two harvesting methodshave been used. Likewise, some of the information from the estates bases on their understanding of the two methods and on-green harvesting trials (in case of TPC) and abandoned mechanical harvesting (in case of Kilombero).The agronomic impacts from burnt cane harvest technology against green cane harvest technology are discussed under the agronomic practices below.

10.1 Land preparation

For the newly opened cane fields, there is no influence of cane trash on the land preparation. In case of replanting new cycles of cane crop in the old cane fields, the trashes were said to interfere with the land preparation. They choke the discs and harrowing implements. In Kilombero, the outgrowers reported that trash in green harvested cane would hinder ‘middle bursting’ (opening) of the land between the cane rows normally done after harvesting in the ratoon.

However, in land preparation, presence of trash was seen as an effect which will affect mostly the outgrowers who use normal tractors and implements. For the estates or factories which normally use modernized tractors and implements, trash will not cause serious setback. In TPC for example, they reported that land preparation techniques have been chosen/developed to ensure that trash is left in the fields while minimizing tractors power requirements, and hence diesel requirements.

10.2 Planting

On planting, the outgrowers were in favour of burnt harvest technology. They reported that presence of trash may hinder ridging. They also reported that it may results to difficulty in monitoring if seeds have been placed. They also reported that trashes will affect gap-filling and heavy trash may interfere with seed emergence and regeneration in case of ratoons.

10.3 Weed management

Green harvesting was favoured by both outgrowers and millers for its contribution in weed management. It was reported that the trash cover will suppress weeds and thus reduce costs which would have been incurred in weed management. Mtibwa estate, for example, are reporting that a good trash blanket can save up to 2 weeding per ha which is 15 – 20 man days/ha (around Tshs 120,000 per ha). They further report that a good trash blanket can save up to 2 herbicides g per ha (around Tshs 500,000 per ha).This is a cost that is incurred with burning.

In Kilombero, the miller reported that trash blanket may lead to skip one round of weeding, saving about 18,840Tsh/ha. However, it was reported that presence of trash may hinder herbicide application, especially the pre-emergent herbicides. There will be no even distribution of the herbicide on the soil surface. It was also reported that trash has affinity to some chemicals hence may reduce its efficiency. Burnt harvesting was said to have ability to stimulate some weed seeds to germinate by breaking dormancy

Plate 5: Trash management for weed control in burnt harvesting in an outgrowers farm of Kagera (*Photo: Boniface Massawe, 2017*)

Plate 6: Trash management for weed control in burnt harvesting in Kagera Sugar miller's farm (*Photo: Boniface Massawe, 2017*)

10.4 Soil fertility management

Green harvest again was favoured in case of soil fertility management. Arguments were on improvement of nutrient status of the soil through decomposition and mineralization of the trash. Another argument was on improvement of soil structure through additions of the soil organic matter. An outgrower in Kilombero witnessed how he sees difference in soil colour, crop vigour and soil moisture differences between the rows he covers with trash compare to those which are bare. The practice in all outgrowers is that after burnt harvesting, the remaining trash is distributed over a few rows in the field while other rows are left bare. The Kilombero millers estimated that they put extra 2 bag of urea/ha, equal to 90000Tsh/ha for not applying sufficient trash in their farms. They cannot get sufficient trash because they are burn during the harvesting process.

Negative effects of trash resulting from green harvesting were mentioned as impairment of fertilizer penetration to the soil. To help solve this, irrigation is needed within a short time. This might not be possible with the outgrowers. Most of the outgrowers do not have irrigation infrastructure, and hence depend entirely on rainfall.

But also, for decomposition of the trash, extra nitrogen is needed for bacterial activity. The ratio of % C to % N (C:N ratio) determines whether the N is mineralized or immobilized from a decomposing material. Materials with C:N ratio above 20:1 may lead to immobilization of N (Havlin et al., 2005). Sugar cane trash generally has C:N ratio higher than 20:1, thus need additional external source of nitrogen for mineralization by microbial activities. The problem of placement of fertilizer would mostly affect the outgrowers. The larger scale farmers eg TPC have fertilizer applicators equipped with coulter discs to cut through the thrash left after burnt cane harvesting. The large scale farmers also apply foliar fertilizers through aerial spray by airplanes. It was noted that there is little experience with use of fertilizers by the outgrowers, especially those in Kagera.

10.5 Soil moisture management

The trash cover on the soil surface was reported to conserve soil moisture. This is done by acting as a shield which prevents the sun from directly hitting the soil surface, and by blanketing the soil thus reducing the rate of soil moisture evaporation. Trash was especially important to the ougrowers who are relying on rainfall for their crops performance. Some outgrowers mentioned negative effects of trash on soil moisture as being a barrier when they get small amount of rains. In such cases, the rein is absorbed and evaporated over the trashes, with very little going to the soil to benefit the crop.

In the estates, trash was reported to assist to retain moisture which positively affects irrigation scheduling by increasing the days between irrigation cycles. The retained soil moisture was also reported to assist in reducing the amount of water used in irrigation if the cycle lengths remained the same. In Mtibwa it was reported that it is possible to extend the irrigation interval in the early ratoon stage from around a 7 day cycle to up to 10 days per cycle due to the trash blanket.

10.6 Pest management

It was reported that trash harbors insect and pests – hence transmission to the next crop. It was also reported it is difficult to identify disease in the field covered with trash. An example was given of red rot in stumps in Kilombero. But also burning was reported to have influence on army worms in Mtibwa. According to them, Army worm can be a pest in burnt and rationed cane in some season which does not happen in a trashed field.

10.7 Harvesting

In the harvesting, it was generally suggested that burnt harvesting technology was comparatively cheaper, faster, and safer than green harvesting technology in Tanzania. Some of the responses are listed below:

- Burning during burnt harvesting controls weeds
- Burning reduces the amount of trash which would otherwise be transported with the cane to the factory. Burning thus reduces loading and transport costs
- Burning reduces risks to the cutters which are posed by presence of potentially harmful animals such as snakes. Potentially harmful animals have been reported in all commercial cane growing areas covered by the study
- Burning removes harmful vegetation such as the itchy *Mucuna spp.*This, therefore helps to protect the cutters
- Burning removes the canopy, thus makes cutting easier and speedier. This reduces the cutting costs
- Millers claim that it is easier and cheaper to process burnt cane than green harvested cane. Some of the reasons for this include old technology of some crushers.
- Burning was reported to help in assuring uniform harvesting.

Some disadvantages of burnt harvesting were mentioned as:

- Nutrient loss due to high runoff from bare soils and volatilization from soil and burnt trashes
- Fire risk (burning of unintended fields)
- Shortening time of fermentation, thus putting pressure on burnt harvest to crushing time
- Increase costs of soil fertility management
- Increase costs of weed management
- Increase costs of soil moisture management
- Increase vulnerability to land degradation eg soil erosion
- Killing of beneficial organisms such as soil microbes
- Environmental pollution (air, water, soil)
- Loss of cane weight (if paid per weight not per sugar content)
- Health hazards to cutters due to high exposure on soot and ashes
- Ratoon development may be affected, especially if followed by a prolonged dry spell

11.0 Comparison of pollution impact for deploying burnt cane harvest technology against green can harvesting technology

Pollution has been a major concern for burn cane harvesting technology. In this study pollution by burn cane harvesting was looked in the areas of soil erosion, nutrient leaching, soil pollution, air pollution, water contamination and green house gas emissions.

11.1 Soil erosion

Soil erosion entails detachment of soil particles and subsequent transportation of the particles from one area to another. The transportation may be due to water, wind, or any other moving agent. Soil erosion was put into this section due to its contribution to downstream water pollution and dust depositions in areas with low wind speed.

Burning harvesting technology was reported by the interviewee from all sites as resulting to more chances of soil erosion than green harvesting. The reason given was that during burning the land is left bare, thus exposing it to agents of soil erosion such as rain drops, surface run off, wind, and animal hooves. The effects were said to be highest just after burning and decrease when the cane grow to provide canopy. The canopy acted as a shield against erosion agents and reduces direct contact between the agents and the soil.

With the green harvesting, it was reported that the trash left in the fields shield the soil from the erosion agents, thus result to less vulnerability compared to burnt harvesting technology. The effectiveness depends on the amount of trash and how they are distributed over the land. Patches with higher amount of trash are less vulnerable to soil erosion compared to their counterparts.

In Tanzania, commercial sugar cane growing for sugar production is generally done in the alluvial plains where the slopes are generally gentle. This results to less vulnerability to soil erosion, except in case of flooded irrigation, and flash floods from rainfall storms.

Plate 7: Vertiva grasses grown on sloping areas in Kagera Sugar miller's farm to control soil erosion and water contamination (*Photo: Boniface Massawe, 2017*)

11.2 Nutrient leaching

Nutrient leaching was included in this study due to its contribution to underground and subsequent surface water pollution. The surface water recharges from underground water, and sometimes it is exploited through pumping in irrigation and household consumptions. Nutrient leaching is the vertical (downward) movement of chemicals meant for plant uptake. When these nutrients held by the soil colloids of opposite charge cannot resist down ward movement of infiltrating or percolating water, they find their way to underground water, thus causing contamination.

Nutrient leaching was said to be high in the burnt harvesting than the green harvesting due to bare surface of the burn field. However, leaching is more a function of the soil type and the nature of the nutrient in relation of how strongly they are attached to the soil colloid. The strongest point as to why there will be more leaching in the burn harvesting technology was on the amount of fertilizer applied and frequent irrigation schedules in the burnt harvesting fields as compared to the green harvested fields. It was urged that in green harvesting the soils are kept more fertile due to decomposition of trash, thus less chemical fertilizers are applied as compared to burnt harvesting. It was also urged that trash in the green harvesting keeps soil moisture from evaporating resulting to less demand of irrigation. Thus more leaching from burn harvesting may be coming from excessive fertilizer application and irrigation.

11.3 Soil pollution

Soil pollution in sugar cane fields is generally a result of applications of agro-inputs and deposition of burnt materials such as ashes. In this study it was observed that there are more chances of soil pollution in burnt harvesting than in green harvesting. One of the reasons is more need for fertilizers application in the burnt harvesting as a result of less soil organic matter. Decompositions and mineralization from trashes adds nutrients in the soil. High amount of trash in the green harvest thus reduces requirements of industrial fertilizers. There are some arguments, however, that the sugar cane trash are difficult to decompose, especially if they don't get enough moisture. However, evidence shows improvement of soil structure and fertility where trashes are applied in the sugar cane fields. In Kilombero, for example, the outgrowers reported that the sugar cane rows where trashes are arranged after burnt harvest show different soil characteristics such as higher moisture content and darker colour as opposed to those which are left bare.

Another reason is application of herbicides. Burning generally encourages regeneration of vegetation, especially the weeds. This necessitates application of herbicides to control the weed, thus increasing chances of soil pollution. It was however, noted that many outgrowers still don't use herbicides, but manual weeding using hoes. The miller's farms, however, use herbicides of varying effects to the environment, including concoctions.

Use of pesticides is also a reason for soil pollution. In this case, it was urged that trash hosts a lot of pests, and may pass it from one crop cycle to another. It is therefore possible that more pesticide may be applied when green harvest will be applied as compared to burnt harvesting.

Another source of pollution with the burnt harvesting was mentioned as the depositions of burn materials. During burning, smoke and other lighter materials are normally blown up to the air, but finally the heavier particles such as soot land on soil. These are new materials, and pollute the soil and the environment. The smoke may also dissolve in precipitation and land on soil and water bodies, thus polluting the environment.

Plate 8: Improvement of soil fertility using organic sources in Kagera Sugar (*Photo: Boniface Massawe*)

11.4 Air pollution

On air pollution, burnt harvesting was undoubtly contributing more to air pollution than green harvesting. A farmer remarked from Kilombero that, “when they set fire for cane harvesting, the whole of Kidodi village is affected by soot and smoke”. In built up residential areas the soot fall-out from cane fires has been a source of major irritation to residential areas. Washing is dirtied by the fall out and some houses are covered in this soot. The effects of air pollution include health issues such as respiratory system diseases and littering on compounds. Despite the understanding that ponding on trashes may result to emissions of methane, a green house gas, none of the interviewees could link the two harvesting technologies with green house emission

Plate 9: Air pollution during burning of cane for harvesting (*Photo: Boniface Massawe, 2017*)

11.5 Water contamination

Burnt harvesting was also noted as contributing more to water contamination than green harvesting. This was explained being because of the soot from the burning which may fall in the water bodies, also the gases which can dissolve in the rain water during precipitation. The higher requirements of industrial fertilizers and herbicides by the burnt falling soot contaminates water

12.0 Conclusions and recommendations

12.1 Conclusions

The following are the conclusions from this study:

12.1.1 Conclusions from global perspectives

i. Sugar cane harvesting is the most costly operation in the sugar industry
ii. Both manual and mechanical harvesting are currently applied worldwide in the sugar industry
iii. In the developed world, mechanical sugar cane harvesting is replacing manual sugar cane harvesting
iv. In the developing world, manual harvesting is still dominant
v. Both pre-harvesting burning and green harvesting technologies are applied worldwide
vi. Green harvesting needs mechanization more than burnt harvesting to be profitable
vii. Burnt harvesting is simpler and cheaper than green harvesting
viii. Invention of new harvesting machines applying GIS and GPS technology are making mechanical harvesting cheaper and more efficient
ix. The major reason for green harvesting to replace burnt harvesting is the global outcry of effects it is causing in the environment

12.1.2 Conclusions from Tanzania perspectives

i. Still there is a sugar deficit in Tanzania, despite the efforts to solve the problem.
ii. Outgrowers productivity is still very low compared to the estates because of lack of agronomic skills, capital and irrigation facilities
iii. Manual harvesting is dominant in Tanzania
iv. Growers prefer manual harvesting to mechanical harvesting because it is cheaper and flexible
v. Original set up of sugar cane fields in Tanzania (drainage system, road infrastructure, terrain, row spacing, etc) makes it difficult and costly to move to mechanical harvesting since they all need to be changed
vi. Over 98% of harvesting is done through pre-burnt harvest technology. the remaining percent is harvested green only when conditions such as heavy rainfall do not favour burning
vii. All outgrowers do burnt harvesting technology
viii. Outgrowers harvesting technology is influenced by the millers they are in contract with (through their associations)

ix. Despite negative results in some mechanical and green harvesting technology trials, some estates are still interested in such trials
x. People around the sugar cane estates are not adequately aware of the pollution and the effects caused by burnt harvesting

12.2 Recommendations

The following are the recommendations

i. There is a need to follow the global trend in moving from burnt harvesting to green harvesting technology
ii. The basis for the change should be environmental pollution and health effects caused by the burning harvesting. This is because cost-wise, green harvesting is currently more expensive than burnt harvesting technology in our commercial sugar cane growing
iii. However, our pace to green harvesting should put into consideration the issue of labour (manual sugar cane cutters) which will be laid down and investment needed by the growers to do the green harvesting
iv. Sugar cane harvesting is among the major agricultural contributors of air pollution through the current burn harvesting technology in our country. The national environmental policy (URT, 1997), does not have statements targeting the pollution happening due to burnt harvesting in the sugar industry. The policy under agriculture (section 46) talks about control of agricultural run-offs of agrochemicals to minimize pollution of both surface and ground water, but it is quiet about air pollution
v. There is a need to develop a policy which will guide the implementation of the move from burnt harvesting to green harvesting so as to reduce environmental pollution, specifically air pollution.
vi. To help in the transition from burnt to green harvesting, the National Environmental Standard Committee, as mentioned in the Environmental Management Act 2004 (URT, 2004), should research and set standards regarding the amount of air pollution caused by sugar cane burnt harvesting technology.
vii. Most of the major sugar cane estates are generally not planted with enough trees. Responsible government authorities should encourage the estates management to plant trees which are not going to interfere with their mechanization and which must be protected from burning during burn harvesting. The trees will help in mitigating the carbon dioxide gases generated from burnt harvesting
viii. Green harvesting is easier done through mechanization. Mechanization works efficiently when the plots have a reasonable size and shape for minimum and easy

maneuvering. Outgrowers farms are fragmented. There is a need to find a way such that outgrowers' farms are synchronized. Otherwise, it will be difficult and costly to apply mechanical harvesting in such a fragment system.

ix. Efforts are needed to make ougrowers more influential players in the sugar industry through strengthening their associations, good governance, capital, technical know-how of cane production and management and access to extension services. This will help them to have influence on the harvesting technology. Currently, harvesting technology is dictated by the millers

x. There is a need to test and introduce self trashing varieties. R579, a somewhat self trashing variety outperforms other varieties in Kilombero and TPC in production. This invites more research to get a more self trashing variety which will make cutting manually and mechanically easier

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14.0 Appendices

Appendix 1: Questionnaire used to collect information from millers

FEASIBILITY STUDY OF GREEN HARVEST TECHNOLOGY IN SUGAR CANE FARMS

INFORMATION COLLECTION FROM MILLERS

NOVEMBER, 2017

Please provide the information requested below by typing your answer after the question. Feel free to use as much space as necessary. Also feel free to provide any additional information after the answer to clarify or make the information more useful. We will be glad to get your response by 28th November, 2017.

For any questions or clarification regarding the content of this questionnaire, please contact Dr. B. Massawe: email bonmass@yahoo.com; mobile: 0682 192 352, 0767 822 247. Thank you in advance for your contribution in this study. Please mail back your response to bonmass@yahoo.com copying sbt@cats-net.co.tz

Questions

1. Please mention the cane varieties you grow in your farm

2. What is the cane's average yield per acre or hectare you get in your farm? If the yields are significantly different between varieties you grow, please indicate.

3. Are any of sugar cane varieties you are growing self detrashing? If yes, please mention them

4. If the answer for the question above is yes, how do you compare the productivity of the self detrashing cane to the rest of the varieties you grow?

5. It is reported that TPC is currently doing trials on mechanical harvesting. Are you in position to share some preliminary results?

6. If the answer for the question above is yes, please give estimate costs of harvesting per acre, or per hectare, or per ton. (Please break down the cost e.g. fuel, maintance, operators, loading, haulage etc)

7. So far, what are the challenges you are facing with the mechanical harvesting comparing to the manual harvesting?

8. So far, what advantages you are getting with the mechanical harvesting comparing to mechanical harvesting?

9. Please mention the steps/activities you follow in the burn harvesting technology you use

10. Please give the cost of each step during the harvesting process (eg. From creating fire breaks to haulage in burnt harvesting technology) per acre or hectare or ton

11. Are there any conditions which sometimes force you to do green harvesting? If Yes, please mention them

12. Have you ever milled/crushed green harvested cane?

13. If the answer to above question is yes, what were the challenges or advantages compared to milling/crushing burnt harvested cane

14. What was the sucrose content for the green harvested cane? If you have data for different varieties please provide

15. What is the sucrose content for burnt harvested cane? If you have data for different varieties please provide

16. Are there any plans for your farm to go for green harvesting? If yes please explain the plan/steps and timing. If no, please explain

17. How do you manage cane trash after harvesting

18. What is the cost per acre or hectare you incur in managing trash after harvesting

19. How is the trash interfering with the following agronomic practices?

a. Land preparation

b. Planting

c. Re-emergence of cane for ratoon crops

d. Fertilizer application?

e. Weeding?

f. Herbicide application?

g. Irrigation scheduling?

h. Amount of irrigation water?

i. Insects pests management?

j. Disease management?

k. Harvesting

20. Please estimate how much money you are saving in the following agronomic practices due to the presence of sugar cane trash in your farm per acre or hectare?

a. Land preparation

b. Planting

c. Ratoon regrowth

d. Fertilizer application?

e. Weeding?

f. Herbicide application?

g. Irrigation scheduling?

h. Amount of irrigation water?

i. Insects pests management?

j. Disease management?

k. Harvesting?

21. Please estimate how much money you are additionally incurring as a cost in the following agronomic practices due to the presence of sugar cane trash in your farm per acre or hectare?

a. Land preparation

b. Planting

c. Ratoon regrowth

d. Fertilizer application?

e. Weeding?

f. Herbicide application?

g. Irrigation scheduling?

h. Irrigation amount?

i. Insects pests management?

j. Disease management?

k. Harvesting?

22. How is the burning in burnt sugar cane harvesting technology interfering with the following agronomic practices?

a. Tillage

b. Planting

c. Ratoon regrowth

d. Fertilizer application?

e. Weeding?

f. Herbicide application?

g. Irrigation scheduling?

h. Irrigation amount?

i. Insects pests management?

j. Disease management?

k. Harvesting

23. Please estimate how much money you are saving in the following agronomic practices in the burn harvesting technology per acre or hectare?

a. Land preparation

b. Planting

c. Ratoon regrowth

d. Fertilizer application?

e. Weeding?

f. Herbicide application?

g. Irrigation scheduling?

h. Irrigation amount?

i. Insects pests management?

j. Disease management?

k. Harvesting?

24. Please estimate how much money you are additionally incurring as a cost in the following agronomic practices in the burnt harvesting technology per acre or hectare?

a. Tillage

b. Planting

c. Ratoon regrowth

d. Fertilizer application?

e. Weeding?

f. Herbicide application?

g. Irrigation scheduling?

h. Irrigation amount?

i. Insects pests management?

j. Disease management?

k. Harvesting?

25. Have you noted any environmental pollution (air, water, soil pollution) concerns/complaints from your workers, neighbours, downstream water users, or any organization as a result of burning during harvesting? Please explain

26. Have you noted any health related concerns/complaints from your workers, neighbours, downstream water users, or any organization as a result of burning during harvesting? Please explain

Thank you very much for your valuable contribution to this study. Please mail back your response to bonmass@yahoo.com copying sbt@cats-net.co.tzby 28th November, 2017

Appendix 2: Questionnaire used to collect information from outgrowers

A FEASIBILITY STUDY OF GREEN HARVEST TECHNOLOGY IN THE SUGARCANE

Part 1: Respondent's information:

Name of respondent____

Sex__________________ Age__________________ Size of farm___________________

Village_________________ Ward__________________ District___________________

When started to be an outgrower____

Member of outgrower association? ____________ Since when? ____________________

PART 2. General information regarding sugarcane harvesting technologies in Tanzania

Q1. What kind of sugarcane harvesting technology is currently in use? Mark from the choices below

- Pre-burnt harvesting
- Post-burnt harvesting
- Green harvesting

Q2. If you are doing more than one harvest technology, please assign proportions of each in your total harvesting operation

----

Q3. When did you start using the harvest technology you are currently using?_______________

Q4. What factors did you consider when choosing the harvest technology you are currently using?____

____

____

Q5. Is the harvesting method manual or mechanical? _________________________________

Q6. If both manual and mechanical harvest methods are used please give the proportion

____

____

____

Q7. Apart from harvesting, what other agronomic activities you do in your sugar cane and when?

____

____

____

Q8. Is there any relationship between millers/outgrowers?

Yes

No

If Yes or No explain your answer

____

____

____

____
____

Q9. How does the relationship affect harvesting technology you are using?

____
____
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____

Q10. What advantages do you get by using the current harvesting technology?

____
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____

Q11. What are the disadvantages of using the current harvesting technology?

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Q12. Will it be difficult to move to another harvesting technology? Explain?

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Q13. How is the current harvest technology implemented?

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Q14. Mention the tools used for the current harvesting technology

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Q15. What is the proper time for harvesting sugarcane using the current harvesting technology? Explain why?

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PART 3. Cost analysis for burnt cane harvest VS green cane harvest

Q1. What preparations and activities you need to do before and during burnt harvesting of your field? Mention them sequentially

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____

Q2. How much does each of the preparation and activities cost per acre in TShs?

____
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____
____

Q3. How much sugar cane do you harvest per acre in tons?

Q4. What is the average price you get per ton of sugar cane?

Q5. Could the cost be the same if a new harvesting technology (green harvest) is adopted? Explain

____
____

____
____
____
____

Q6. How much does burnt cane technology cost in each of the following post harvest operations?

a. Cost of weeding and number of weeding

----

b. Cost of soil moisture management (irrigation scheduling)

----

c. Cost of managing soil fertility (fertilizer use)

----

d. Cost of effect of fire on microbial populations and soil organic matter
----
----

e. Cost of pest and disease control

----

f. Trash management cost

Q7. Will the above [Q6 (a-e)] identified cost reduced or increased if a new technology (green cane harvest) was adopted? Explain.

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PART 4. Agronomic impact of burnt cane VS green cane harvesting technology

Q1.What is the effect of burnt cane technology on the following agronomic activities?

a) Land preparation

----

b) Planting

----

c) Weeding

----

d) Fertilization

----

e) Irrigation/soil moisture management

----

f) Harvesting and transportation

Q2. What is the impact of sugar cane trash (under green cane harvesting technology) on the following agronomic activities?

a) Land preparation

----

b) Planting

----

c) Weeding

----

d) Fertilization

----

e) Irrigation/soil moisture management

----

f) Harvesting and transportation

Part 5.**Environmental impact of burnt cane VS green cane harvesting technology**

Q 1. What is the impact of burnt cane harvest on the following environmental aspects?

a) Soil erosion

----

b) Nutrient leaching

----

c) Soil pollution

----

d) Air pollution

----

d) Water contamination

----

f) Green house gas emission

Q 2. What is the impact of green cane harvest on the following environmental aspects?

a) Soil erosion

----

b) Nutrient leaching

----

c) Soil pollution

----

d) Air pollution

----

d) Water contamination

----

f) Green house gas emission

General comment?

____
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Appendix 3: Green and Burn harvested cane sucrose content lab results

SOKOINE UNIVERSITY OF AGRICULTURE
FACULTY OF AGRICULTURE
DEPARTMENT OF FOOD TECHNOLOGY, NUTRITION AND CONSUMER SCIENCES
P.O. Box 3006, MOROGORO – TANZANIA
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TELEGRAMS: UNIAGRIC – TELEX: 55308. E-mail

Our ref.: DFTNCS/0017/230086 **Date:** 17th November 2017

LABORATORY REPORT FOR SUCROSE CONTENT IN SUGAR CANE SAMPLES

1.0 Analytical method

The samples were analysed following the method by D. Worku Batu (2014).

2.0 Results

Location	Variety	Duplicate %sucrose content		Average %sucrose content	
		BH	GH	BH	GH
Kilombero	NCO 376	12.02	12.97	11.92	12.52
		11.81	12.06		
	N 41	11.97	13.04	12.26	13.01
		12.55	12.98		
Mtibwa	NCO 376	11.00	11.04	10.90	11.10
		10.79	11.13		

3.0 Reference

D. Worku Batu and T. Wunesh Solomon (2014). Quantitative Determination of Sugar Levels in Natural Plants of Cactus Pear (Opuntiaficus indica) and Votre-Coach Alimantaire Cultivated in Adigrat, North of Ethiopia. International Journal of Innovation and Scientific Research. ISSN 2351-8014 Vol. 10 No. 1 Oct. 2014, pp. 125-134

Supervise and reported by

……………………………………

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