IOSR Journal of Agriculture and Veterinary Science (IOSR-JAVS)
e-ISSN: 2319-2380, p-ISSN: 2319-2372. Volume 12, Issue 3 Ser. III (March 2019), PP 12-20
www.iosrjournals.org

What Do Data on Dry Bulk Density (BD) And Porosity (P) Tell About The Quality of Soils in the Mumias Sugar Zone, Western Kenya?

Mutonyi, J[1] and Muturi, P[2]
[1]*Mumias Sugar Company Limited, Department of Agriculture, P.O. Private Bag 50137, Mumias*
[2] *Kenya Sugar Research Foundation, P.O. Box 44-40100, Kisumu, Kenya*
Corresponding Author: Mutonyi

Abstract: *A study conducted from 2009-2011 on soils in the Mumias sugar zone of western Kenya involved the determination of dry bulk density (BD), moisture content (MC) and porosity (P) in 31 sites. Bulk density varied from site to site ranging from 1.46 g/cm^3 to 1.81 g/ cm^3; BD was generally higher in the 30-60 cm layer than in the 0-30 cm layer. Soil moisture content varied from one sampling site to another ranging from 17.8 – 37.5 %. Soils were drier in the top 0-30 cm layer than in the lower 30-60 cm layer. Average porosity ranged from 31.9% - 44.5%. Porosity, being inversely related to BD was highest in areas with least BD. Porosity was generally higher in the top soil 0-30 cm layer than in the lower 30-60 cm soil layer. This study demonstrated that the sugarcane production practices in Mumias had led to serious deterioration of two soil physical quality parameters the bulk density (BD) and porosity which may have contributed to sugarcane yield decline over the years. The enhancement of minimum tillage practices, green cane harvesting, trash blanketing, good soil conservation practices and avoidance of heavy machinery on fields in the wet on both the miller owned farm and among smallholder farmers is recommended.*

Keywords: *Sugarcane, Bulk Density, Porosity, Soil Moisture Content, Mumias sugar zone*

Date of Submission: 11-03-2019 Date of acceptance: 28-03-2019

I. Introduction

Sugarcane yields in soils managed conventionally have been observed to plateau or reduce over the longer term with this often being attributed to soil degradation (McGarry and Bristow 2001; Garside *et al*. 1997; Wood 1985; Meyer and van Antwerpen 2001). In Kenya's largest sugar producing zone of Mumias, there are serious concerns around declining sugarcane production on the miller owned Nucleus Estate (NE) and out growers' fields (OG). It is estimated that average cane yields have declined by about 30% from a high of 70-80 tons per hectare (tch) in 2004 to a low of only 55 tch in 2011 (Fig. 1).

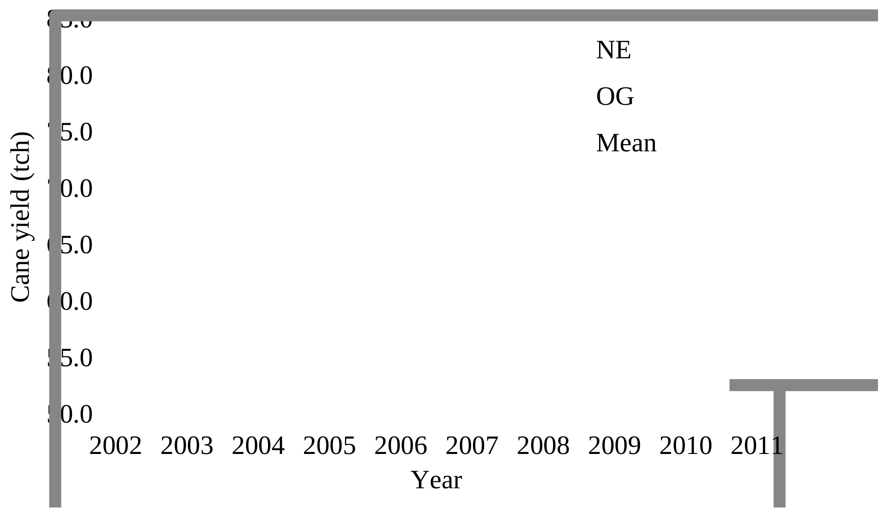

Figure 1: Average sugarcane yields in Mumias Sugar zone (2002-2011)
NE- miller owned farm; OG- out growers

The cause of yield decline in Mumias Sugar Zone (MSZ) and other sugar factory zones in Kenya has been researched for a long time and is known to encompass soil, crop, environmental and social factors (KESREF, 2002): Land degradation, declining soil fertility, poor performing varieties, high dependence on unreliable rainfall, inadequate extension services and low age at harvest among many others have been highlighted. However, the main cause of yield decline is thought to be deterioration of soil quality due to continuous unsustainable sugarcane production practices. No research had recently been done to quantify the contribution of various factors to the decline occasioning the need for this study.

Objectives

- To establish the current sugarcane production practices in MSZ and infer their impact on specific soil physical quality parameters, bulk density (BD), moisture content (MC) and porosity (P),
- To survey selected sites across MSZ and measure the levels of bulk density (BD), moisture content (MC) and porosity (P),
- To recommend possible best management practices (BMPs) to restore and maintain the soil quality.

II. Current Sugarcane Production Practices And Challenges

The Sugar belt area served by Mumias Sugar Company (MSC) covers about 60 sq. km with 43,000 ha under sugarcane grown in the company owned Nucleus Estate (NE) and nine Out growers (OG) sub-zones. The sub-zones fall in four Counties namely Kakamega, Bungoma, Siaya and Busia. Small hold farms in the target area average 0.4 ha ranging in size from 0.2 - 3.5 ha. Out growers who number about 84,000 supply up to 97% of the cane milled in the entire sugar zone (MSC, 2014).

2.1 Land preparation

The Kenya Sugar Industry practices conventional tillage which involves mechanical ploughing, harrowing and furrowing. The number of tillage operations and implements used in MSZ depend on soil type. For heavy clay soils (Vertisols) the tendency is to use heavy mouldboard ploughs hitched to heavy 200-250 HP prime movers that may achieve up to 40-60 cm depth. This is followed by one or two harrows before furrowing using 80-90 HP tractors. For light soils (Acrisols, Nitosols etc.), there is a tendency to use disc ploughs to a depth of 20-30 cm followed by light harrowing and furrowing with 80-90 HP tractors. Land preparation on small hold farms averaging 0.4 ha presents the possibility of soil compaction by frequent maneuvers of the machines.

Conventional tillage has attendant challenges. The number one challenge is high cost of land preparation due to high cost of machinery, equipment, spare parts and fuel. Challenge number two is soil degradation. Many areas in the world where it is practiced suffer from soil structural degradation and poor fertility, which result in decreased and unstable crop yields. Many researchers have demonstrated that the excessive tillage of conventional system seriously degrades soil structure, accelerates soil erosion, and reduces crop yields (Chan and Heenan 2005; Fabrizzi *et al*. 2005). To address the above challenges, most sugarcane producers in the world have shifted to minimum or conservation tillage. Conservation tillage is defined as any tillage and planting system that leaves greater than or equal to 30% of crop residue. It has also been designed to decrease the manpower and energy required for crop production (Zhang *et al*. 1997) and offers long-term benefits from improved soil structure (Wang *et al*. 2008), decreased traffic, and reduced soil erosion. Conservation tillage has often shown higher efficiency than conventional tillage in improving soil properties and crop yields (Lal, 1989).

2.2 Crop management

Many varieties new and old have been planted in MSZ over the years. They include CO 945, CO 421, D8484, EAK 73-335 and recently the locally bred KEN 83-737 among others. Cane is planted and managed as per standard agronomic practices for MSZ that include: planting cane setts either end-to-end or overlapping in furrows, 25-30 cm deep and spaced at 1.2 m (out-growers) and 1.5 m (miller owned farm); application of P-based fertilizers (usually DAP) as basal during planting; application of N-based fertilizer (usually Urea) as top dressing 3-5 months after planting and controlling weeds manually or by use of herbicides. Control of pest and disease is uncommon as the varieties are selected on the basis of pest and disease tolerance/resistance. Many smallholder farmers do not practice soil conservation which has tended to accelerate soil degradation (Wawire *et al*., 1987).

2.3 Cane harvesting and transport

Cane is harvested from 14-20 months depending on the variety planted. Green cane harvesting is generally practiced; however, cases of burnt cane occur over the dry season particularly in the miller owned fields. The main mode of harvesting is manual due to abundant labour; cane is arranged in stacks and/or windrows for subsequent mechanical loading into the haulage vehicles to the mill. Cane harvesting, transport and milling are year-round operations except in April-May each year when the mill is stopped for planned annual maintenance.

To increase efficiency and profitability, mechanization of cane loading and haulage operations has increased significantly in Mumias in the last 10-15 years (Wawire *et al*., 2007). This period has seen the introduction of high payload units like heavy double basket trailers with capacity of up to 20- tons and high capacity mechanical grab cane loaders which could cause deterioration of soil quality with concomitant yield decline.

III. Methodology

3.1 Study area

The study was conducted from 2009-2011 in the Mumias sugar zone (MSZ) situated 0^o21'N, 34^o 30'E and 1314 m above sea level. The zone receives bi-modal rainfall ranging from 1500-2000 mm per annum with long rains peaking in April-May and short rains in September-October each year. The dominant soil type in the zone is Orthic Acrisol (60%) followed by Ferralsol, Nitosol, Cambisol and Planosol (40%) (Jaetzold *et al*., 2005).

3.2 Survey sites

The survey on BD, P and MC covered 31 sites as shown in Table 1. For each selected site, undisturbed soil samples were collected from two layers: 0-30 cm and 30-60 cm using Soil Bulk Density Kit as described in Isjelkamp Manual (2004). The kit consisted of 100 cc stainless steel cylindrical core rings and a core driving mechanism. The core rings were sharpened on one side to facilitate soil penetration. The undisturbed core samples were weighed and dried in an oven at uniform temperature of 105^oC for 24 hours. After drying, the samples were weighed and the data was used to compute bulk density (BD), porosity (P) and moisture content (MC %) of the soils according to standard formulae. Chemical characteristics of soils from the study sites were analyzed to enrich the discussion of findings. The data collected was analyzed using Excel Microsoft Suit to obtain the means and trend curves while ANOVA was used to check significance levels.

Table 1: Survey sites covered

Site	Sample (No.)	Main Soil type	Soil texture	Remarks
Musanda 22	4	Ferralsol	SCL	Fallow, previous ratoon 3 crop, use of organic manure evident
NE A28	3	Acrisol	SC	Fallow; had previous ratoon crop
NE A1	2	Acrisol	SC	Fallow, had previous ratoon crop
Eluche 8	2	Ferralsol	SCL	Fallow, had previous ratoon crop
NE D51	5	Ferralsol	SCL	Fallow, had previous ratoon 13 crop
NE E35	6	Ferralsol	SCL	Fallow, had previous ratoon crop
Khalaba 110	4	Acrisol	SC	Fallow, had previous ratoon crop
Khalaba 49	5	Ferralsol	SCL	Fallow, had previous ratoon 7 crop
Total	31			

Source : MSC Agronomy Laboratory ; Key : SCL – sandy clay loam ; SC – sandy clay ; NE – miller owned farm and field number.

IV. Results

4.1 Bulk Density (g/cm^3)

Bulk density (BD) varied from site to site ranging from 1.46 g/cm^3 to 1.81 g/ cm^3 (Figure 2a). Overall, Musanda 22 had the lowest soil BD (1.46 g/cm^3) followed by NE fields E 35 and A 28. The site with highest BD was NE field D51 with BD reaching 1.81 g/cm^3. Results for Khalaba 49 were not determined. Apart from NE field A28; BD was generally higher in the 30-60 cm layer than in the 0-30 cm layer. High values of BD in the lower layers is an indication of possible presence of hardpan caused by intensive machine utilization during land preparation or in-field cane loading and haulage operations in wet soils. The high BD in top soil in NE A28 could be an indication of surface crustation of the soil caused either by intense use of cane transport machinery or high raindrop impact on soil surface. Surface soil crustation is common in soils with uniformly graded surface soil texture and with poor soil cover. There was evidence of farmyard manure application on the soils by the grower in Musanda 22, the site that recorded favourable bulk density. Further investigation was necessary to ascertain the high BD values in field D51.

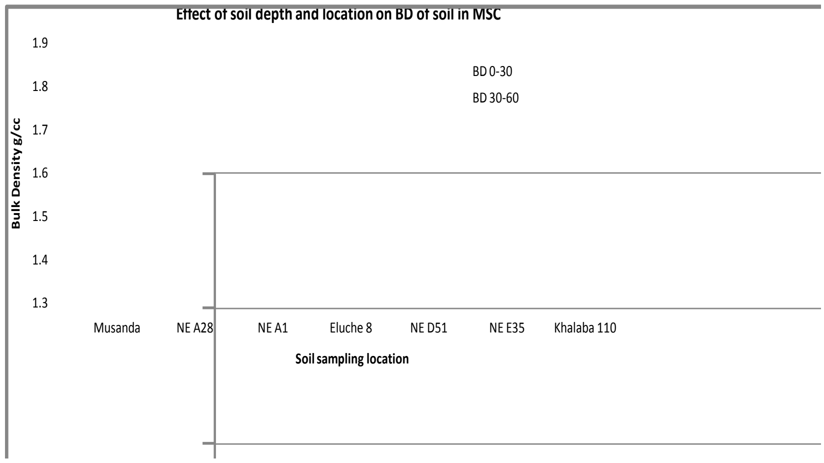

Figure 2a: Variation in soil Bulk Density with soil depth (cm)

Overall, the analysis of variance showed that there was significant difference in BD between top soil (0-30 cm) and subsoil (30-60 cm) (Figure 2b).

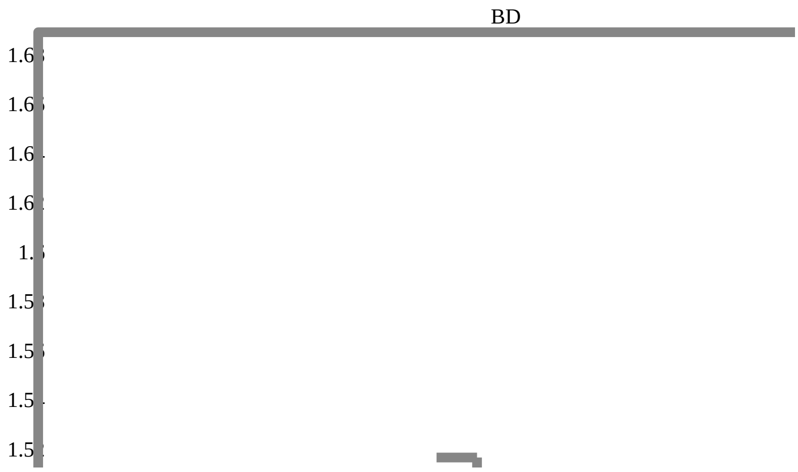

Figure 2b: Overall variation of BD with depth in MSZ

4.2 Moisture content (%)

As in the case of BD, soil moisture content varied from one sampling site to another depending on the prevailing weather conditions at the time. Sampling started in December 2010 at Musanda 22 when the soil was slightly wet and ended in January 2011 at Khalaba when soils were appreciably dry. As expected, soils were drier in the top 0-30 cm layer than in the lower layers due to direct exposure from the sun.

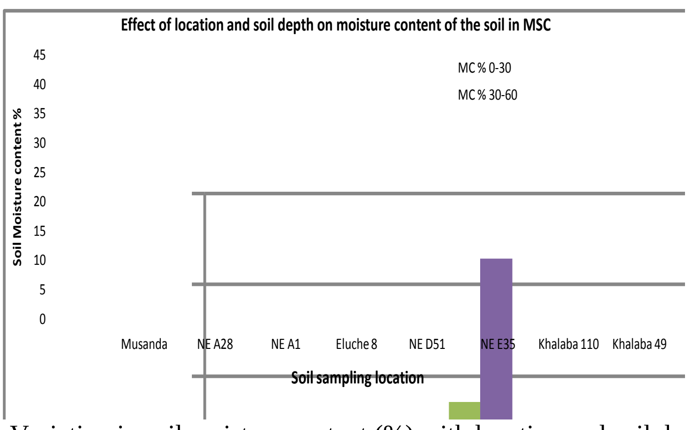

Figure 3: Variation in soil moisture content (%) with location and soil depth (cm)

4.3 Soil porosity (%)

Average porosity ranged from a low of 31.9% in NE D51 to a high of 44.5% in Musanda 22 (Figure 4a). Porosity, being inversely related to BD was highest in areas with least BD. Porosity was generally higher in the top soil than in the lower soil for reasons that top soil is always exposed to air and disturbance (ploughing, weeding, intensive root activity etc.). Soil porosity is an indicator of the amount of air available in the soil for plant growth and so the higher it is the better. Porosity can be reduced in soil by compaction induced by movement of machinery and equipment say during land preparation or cane loading and haulage operations especially on wet soil.

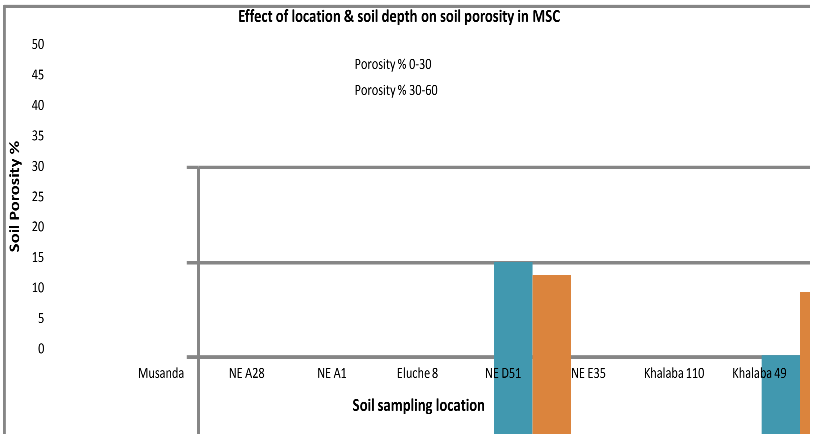

Figure 4a: Variation of soil porosity (%) with location and soil depth (cm)

As in the case of BD, there was significant difference (p=0.023) in soil porosity between top soil and sub soil as shown in Figure 4 (b) below:

Figure 4 (b): Overall variation of porosity with soil depth (cm)

V. Discussion

The general definition of soil quality is the degree of fitness of a soil for specific use (Marta et al., 2009). Soil quality requires the integration of three major components: sustainable biological productivity, environmental quality and plant and animal health (McGarry and Bristow 2001). The main indicators of biological productivity include: organic matter, organic Carbon (C), total Nitrogen (N), C/N ratio, microbial biomass, biomass-C, biomass-N and biomass C/N ratio. Chemical parameters include pH, cation exchange capacity (CEC), exchangeable bases K, Ca, Mg and base saturation (BS). Physical parameters encompass particle size distribution, aggregate size distribution, water stability of aggregates, bulk density (BD), water holding capacity and stabilized infiltration rate. Regular monitoring of these parameters can be used to check the health status of the soil, detect problems early and recommend best management practices (BMPs) which ensures continuous good soil health.

According to sugar websites http://sugarcane@hmtl.com, http://wilkes.edu/.boram/soilwatr.htm, and USDA Natural resource conservation services (1998), sugarcane ideally requires a well-drained, deep loamy soil with a bulk density of 1.1 to 1.2 g/cm^3 (1.3-1.4 g/cm^3 in sandy soils) and total porosity, with an adequate balance between pores of various sizes, higher than 50%. Soils with bulk density in the range of 1.1-1.4 g/cm^3 are recommended for sugarcane growing in Kenya (KESREF, 2002).

The BD and P measurements confirmed that the soils in MSZ had values far and above the desirable threshold described above. This result corroborated that of an earlier study on Mumias soils which established that dry bulk densities ranging from 1.40 - 1.76 g/cm^3 restricted sugarcane root growth (Kanabi, 1990). This study also established an inverse relationship between sugarcane yields and BD from historical data in three sites (Figure 5 and Table 2). This finding was corroborated by that of a different study to determine the effect of BD on cane yields (Yang, 1977), which found that yields and BD had a linear but inverse relationship where cane yields reduced by as much as 26.5 tons/ha for every increment of 0.1 g/cm^3 in BD.

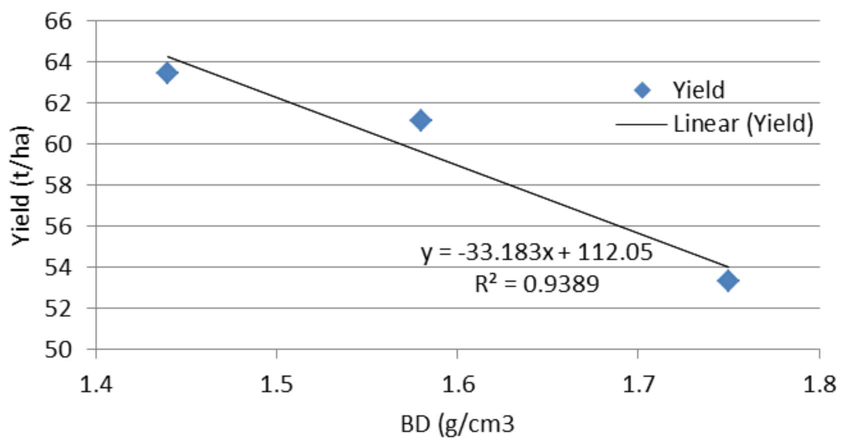

Fig. 5: Relationship between yield and BD at selected study sites

Table 2: Historical yield and BD at selected sites

Site	n	BD (g/cm^3)	Yield (t/ha)
Musanda 22	3	1.44	63.4
Khalaba 49	6	1.58	61.4
NE D 51	13	1.75	53.3

In-field mechanized cane loading and haulage are the major mechanisms by which bulk density is increased. Since mechanized cane loading and haulage are indispensable at Mumias, the deleterious effect of soil compaction is inevitable. However, excessive soil compaction caused by mechanization could be reduced or improved by proper soil management so as to obtain desirable yield in the ratoon crop. A study by Torres and Pantoja (2005) found that semi-mechanized harvesting operations could reduce ratoon yields by up to 50% in Colombia. The introduction of super trailers and mobile weigh bridges may bring the much needed reprieve in the fields as lighter less compacting machinery and equipment may be used in transporting cane from the fields to the weigh bridges.

There is a strong linkage between BD and porosity on sugarcane yields. This is because the yield is the final effect of combined adverse effects such as poor aeration status, lower water utilization, root impediment and restricted nutrient uptake. High BD coupled with low porosity negatively affects water and nutrient use efficiency and restricts root development ending up with a shallow root zone that cannot supply enough water and nutrients for the requirements of plant growth. A common symptom of restricted root zone is the unmistakable water stress signs occurring just few days after a heavy rainfall event. Some of the effects of high bulk density which is mainly caused by heavy machineries include decrease in infiltration rate, water logging, poor root penetration, low storage capacity, decrease in yields, poor movement of air in the soil, reduction in vegetation cover and yield.

Some of the recommended soil management practices include:

(a) Adoption of minimum/conservation tillage with occasional subsoiling to break hard pans developed over time. Minimum tillage is not difficult to implement as most factories especially MSC have been doing it but on a small scale. According to (Lal, 1989; Havlin *et al*. 1990), conservation tillage often shows higher efficiency than conventional tillage in improving soil properties and crop yields. In a study to compare the effect of conventional and minimum tillage on tillage cost and cane yields, no significant difference in cane yield was observed but there was a marked difference of 75% in tillage cost in favour of minimum tillage (Muturi *et al.*, 2007).

(b) Adoption of green cane harvesting and trash blanketing on farms. At the
present time, most trash is either burnt during re-establishment of fields or removed from the to serve as fuel in the rural homes.

(c) Introduction of intercropping of sugarcane with N-fixing legume crops like soybean.

(d) Improvement of soil and water conservation practices among smallholder farmers.

(e) Avoidance of heavy machinery and equipment in the field under conditions which are
conducive to soil compaction e.g. during wet season.

(f) Use of floatation tires in the field to minimize soil compaction and stool damage.

(g) Adoption of dual row planting with controlled traffic. In this approach, cane is planted in dual rows in wide rows of 1.8 m which coincides with track width of the farm tractors and equipment. The traffic is confined in the interows thus avoiding compaction along the rows.

VI. Conclusions & Recommendations

This study clearly demonstrated that the sugarcane production practices in the Mumias sugar zone had led to serious deterioration of two soil physical quality parameters the bulk density (BD) and porosity which may have contributed to sharp yield decline over the last 15 years. The current practices include intensive mechanized (conventional) tillage and in-field cane loading and haulage operations in wet soil using heavy field equipment which cause severe soil compaction and stool damage.

A suit of recommendations has been made to improve soil physical quality which includes full adoption of minimum tillage practices, full embrace of green cane harvesting and trash blanketing, improvement of soil and conservation practices among smallholder farmers, introducing intercropping in sugarcane, avoidance of heavy machinery in the field when wet and adoption of dual row planting with controlled traffic among others.

While some recommendations such as minimum tillage and green cane harvesting with trash blanketing can be implemented without delay, other practices require refinement through research. Research is required to improve techniques in the area of dual row planting with controlled traffic, modalities and methods for using floatation tires, soil and water conservation and selection of rotation crops. Research is also required to find out the long term effect of minimum tillage on cane production.

Acknowledgements

The authors wish thank Dr. Chrispine O. Omondi, then Director Kenya Sugar Research Foundation (KESREF) for funding the project. The Management of Mumias Sugar Company for logistical support in soil sampling, laboratory analyses and final report preparation.

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Appendices

Appendix 1

1.0 Description of the Soils of the study site

Acrisols: the soils are acidic with low base status; they are strongly leached but less weathered than Ferralsols. They develop mainly on basement rocks like granite, but also on colluviums from quartzite. The base saturation (BS) of the B horizon is < 50% thus indicating low fertility. Acrisols are dark shallow soils, rich in Aluminum and Iron Oxide elements, but have less Phosphorus (P) fixation. They are dominant in the Northern and eastern sub-zones.

Ferralsols: they are strongly weathered soils (Murram) of the humid tropics with oxic horizons. Soil fertility is low to very low due to low mineral contents, kaolinites (as clay minerals) and low CEC of less the 16 m.e/100g of clay. They are slightly coarse, murram with a higher level of sand and low water retention capacity. They are mainly found in Western and Busia sub-zones.

Nitosols: they are soils with normally high fertility due to high content of montmorillonites (as dominating clay minerals), minerals and available soil water as well as a high CEC. Nitosols are deep and red soils, very low in organic matter, and are found mainly in the Southern sub-zone.

Cambisols: they are brown soils with cambic B horizons as the major feature; layers are differentiated and changing characteristically due to their relatively young age. The Cambisols found in unit UmG7 and UIGC1 are highly fertile. The rest of the soils are poor in fertility levels since most of them are highly leached or murram soils.

Planosols: these are soils with albic E horizon, hydromorphic properties and a slowly permeable B horizon, developing on different parent materials of the bottomlands.

Appendix 2

Table 2: Soil physical characteristics

Site	*n*	BD (g/cm^3)			M.C (%)			Porosity (%)		
		0-30 cm	30-60 cm	Mean	0-30 cm	30-60 cm	Mean	0-30 cm	30-60 cm	Mean
Musanda 22	4	1.39	1.48	1.44	33.6	41.4	37.5	45.0	44.4	44.7
NE A28	3	1.59	1.50	1.55	31.6	40.6	36.1	40.1	43.4	41.8
NE A1	2	1.67	1.71	1.69	26.9	35.6	31.3	37.0	35.7	36.4
Eluche 8	2	1.75	1.76	1.76	25.7	32.9	29.3	34.0	33.5	33.8
NED51	5	1.69	1.81	1.75	31.1	28.2	29.7	36.2	31.9	34.1
NE E35	6	1.57	1.58	1.58	26.6	30.4	28.5	41.0	40.5	40.8
Khalaba 110	4	1.51	1.65	1.58	16.9	18.7	17.8	43.0	37.6	40.3
Khalaba 49	4	1.49	1.67	1.58	13.2	17.1	15.2	44.0	37.1	40.6
n μ ±	30	30 1.57 0.15	30 1.64 0.14		30 25.7 7.87	30 29.7 9.03		30 40.6 4.86	30 38.2 5.27	

Table 3: Soil chemical characteristics

F/No.	pH	P ppm	K me	Ca me	Mg me	Ca/Mg ratio	CEC	% B sat.	% Ca sat.	% K sat.
Musanda 22	4.7	25.5	0.3	1.0	1.07	0.9	10.1	23	10	3
NE A28	5.1	18.1	0.3	6.6	3.01	2.19	12.5	79	53	2
NE A1	5.6	19.8	0.4	19.8	1.83	1.91	10.4	55	53	2
Eluche 8	5.3	12.2	0.5	2.5	1.58	1.58	10.6	43	24	5
NE D 51	5.5	8.8	0.2	5.5	2.27	2.42	11.3	71	49	2
NE E 35	4.9	13.3	0.4	6.1	2.58	2.36	15.8	57	39	3
Khalaba 110	4.8	17.8	0.1	1.7	0.74	2.3	7.2	35	24	1
Khalaba 49	5.2	27.9	0.3	2.1	1.01	2.08	8.5	40	25	4
Recommended range	6-8	>20	>0.7	>4.0	>2.0	N/A	>12.0	>65.0	>45.0	>8.0

Mutonyi J. " What do data on dry bulk density (BD) and porosity (P) tell about the quality of soils in the Mumias Sugar Zone, Western Kenya?. "IOSR Journal of Agriculture and Veterinary Science (IOSR-JAVS) 12.3 (2019): PP- 12-20.