

# Effect of Soil Compaction on Growth, Yield and Quality of Sugarcane (*Saccharum Officinarum* L.) Crop and Its Management: A Review

Dula Geneti

Ethiopian Institute of Agricultural Research, Jimma Agricultural Research Center,  
P.O. Box 192, Jimma, Ethiopia

## Abstract

Sugarcane is a tall growing monocotyledonous crop plant that is cultivated in the tropical and subtropical regions of the world primarily for its ability to store high concentrations of sucrose, or sugar, in the internodes of the stem. Sugar is not the only product of the cane that is used in the production of various products. Both the pulp and the outer portions of the stalk can be utilized in the creation of woven furniture, cardboard and other paper products, and disposable eating utensils. In spite of the importance of the crop there are many factors which cause the decrease in sugarcane productivity such as climate change and declining in soil fertility as an impact of conventional soil management. The use of heavy machinery during planting, harvesting and transporting operations in fine textured soils has led to the concern that subsoil compaction may decline long term productivity. Hence this leads to affects soil physical fertility, particularly storage and supply of water and nutrients, through increasing soil bulk density, decreasing porosity, increasing soil strength, decreasing soil water infiltration, and water holding capacity, and all of these processes lead to changes in plant physiology of sugarcane that leads to effect sugarcane growth, decline sugar yield and quality. Among many other management options of soil compactness; Soil Water Potential, Soil characterization before cultivation of land, Soil Tillage, passages of machine across the field and crop rotation is the major one.

**Keywords:** Sugarcane, Yield, Quality and Soil Compaction

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## 1. Introduction

Sugarcane (*Saccharum officinarum*) belongs to the Andropogonae tribe of the family Graminae. The subtribe is Sachare and the genus is Saccharum. Most of the sugarcane which is grown today is hybrids of *Saccharum officinarum* (Malavolta, 1994). Most of the sugarcane which is grown today is hybrids of *Saccharum officinarum*. Sugarcane is one of the most important field crops in the tropics. Indeed, according to (FAO 2001), world production of sugarcane was estimated to be about 1900 million t, which was grown on approximately 27.2 million hectares. Brazil was the largest producer at 737 million t (FAOSTAT, 2014). In Ethiopia the area coverage of the crop is about 31,236.81ha with annual production of 1,410,311.54 tonnes (CSA, 2017).

Sugarcane is an important agricultural commercial cash crop and also unique in the sense that a number of succeeding cane crops are raised from a single planting which is an integral component of sugarcane production system. Sugarcane is grown for its sucrose content and is mostly consumed as refined sugar or other processed products. Raw sugarcane can be squeezed or chewed to extract the juice, which is known as “caldo de cana” or “garapa” in Brazil, “chediraz” in northern India and “aseer asab” in Egypt. In some countries in which sugarcane is grown, it is bottled for local distribution or sold fresh from juice bars, cafes and restaurants.

Outside of commercial processing, artisanal processing of sugarcane occurs where sugarcane juice is boiled and cooled to make cakes of unrefined brown sugar, known as “jaggery”, “gur” and “khandsari” in India; “rapadura” in Brazil; and “panela” in Colombia. In India it is estimated that 16.5 million tonnes (t) of sugar are produced compared with 10 million t of these traditional sweeteners (Kansal, 1998).

In spite of the importance of the crop there are many factors which cause the decrease in sugarcane productivity such as climate change and declining in soil fertility as an impact of conventional soil management. Over the last 38 years, the annual cane yield has ranged from 50 to 110 Mg ha<sup>-1</sup>. The use of heavy machinery during planting, harvesting and transporting operations in fine textured soils has led to the concern that subsoil compaction may decline long term productivity. Hadas (1994) reviewed the theoretical analysis and experimental data on soil compaction under high axel load. He stated that subsoil compaction occurred under specific conditions, namely; wet, homogenous, and deep soil under high contact pressure. Axel loads exceeding 90 kN m<sup>-3</sup> increased subsoil compaction (Salire *et al.*, 1994).

Subsoil compaction can cause serious root restriction (Tardieu, 1994; Westermann and Sojka, 1996; Håkansson *et al.*, 1996) and the loss of both transmission and water storage pores. These changes result in lower water infiltration due to the loss of transmission pores and higher soil water caused by the loss of storage pores (Soane *et al.*, 1982; Gupta *et al.*, 1987; Hadas, 1994; Lipiec *et al.*, 1998), that may consequently reduce nutrition

uptake and crop yield (Hammel, 1994; Westermann and Sojka, 1996; Håkansson *et al.*, 1996; Grath and Arvids son, 1997). Torres *et al.* (1990) reported a decrease in sugarcane rooting depth and crop yield as a result of subsoil compaction.

Different parameters and methods are used to characterize soil compatibility, such as dry bulk density, vane shear strength, pore size distribution, gas and water diffusion, and morphological analysis (Hadas, 1994). Micro morphological studies were extensively used to characterize soil deformation (Jager *et al.*, 1983; Koppi *et al.*, 1992). Jager *et al.* (1983) indicated that macro pores and meso pores were less frequent in plough pans as compared with other soil layers, whereas micro pores were more common. However, little information is available on the micro morphology of compacted subsoil layers, particularly under sugarcane cultivation. Therefore, this review was initiated to conduct systematic investigations by concentrating on different research conducted on effect of soil compaction for sugarcane productivity and quality in the long term with the objectives of 1. To provide an overview of effect of soil compaction on growth and yield of sugarcane. 2. To summarize the cause and management option of soil compaction for sugarcane production and quality. 3. To identifying future research areas to solve production problems with in adequate knowledge of soil compaction.

## 2. Discussion

### 2.1 Origin and Domestication of Sugarcane

The origins of *S. officinarum* are intimately associated with the activities of humans, as *S. officinarum* is a purely cultivated or garden species which is not found in the wild (Sreenivasan *et al.*, 1987). The centre of origin of *S. officinarum* is thought to be in the Indonesia/New Guinea area (Daniels and Roach, 1987), where it has been grown as a garden crop since 8000 B.C. (Fauconnier, 1993). It has been proposed that *S. officinarum* evolved from the selection of sweet forms of *S. robustum*. The canes may have previously been used for house building, fencing and archery (Daniels and Roach, 1987) and may have been selected with the aid of animals such as pigs or rats that would have a preference for sweeter individual plants (Daniels and Roach, 1987). Its cultivation spread along the human migration routes to South East Asia, India and the Pacific, hybridizing with wild canes. It reached the Mediterranean around 500 B.C. (Fauconnier, 1993). From there it spread to Morocco, Egypt, the Syrian Arab Republic, Crete, Greece and Sicily, the main producers until the 15<sup>th</sup> century, followed by introduction to West Africa and subsequently Central and South America and the West Indies (Fauconnier, 1993). It is thought to have reached Australia in 1788 on the First Fleet, but did not become established until after it was reintroduced in 1817 from Tahiti (Bull and Glasziou, 1979).

*S. spontaneum* is believed to have evolved in southern Asia (Daniels and Roach, 1987). It accumulates little sucrose content and has thinner stalks and higher fibre content than *S. officinarum* (Jackson, 2005). *Saccharum spontaneum* is an adaptable species and grows in a wide range of habitats and at various altitudes in the tropics through to temperate regions, from latitude 8°S to 40°N extending across three geographical zones. These are: 1) the east zone which is Burma, China, Japan, Malaysia, the Philippines, Chinese Taipei, Thailand Viet Nam and the South Pacific Islands; 2) the central zone, which includes Afghanistan, Bangladesh, India, the Islamic Republic of Iran, Nepal, Pakistan, Sri Lanka and the Middle East; and 3) the west zone which includes Egypt, Kenya, Sudan, the United Republic of Tanzania, Uganda and other countries in the Mediterranean (Panje and Babu, 1960; Tai and Miller, 2001).

Commercial sugarcane hybrid cultivars have arisen through intensive selective breeding of species within the *Saccharum* genus, primarily involving crosses between *S. officinarum* and *S. spontaneum*. *Saccharum officinarum* accumulates very high levels of sucrose in the stem but is highly susceptible to diseases (Cox, Hogarth and Smith, 2000; Lakshmann *et al.*, 2005), whereas *S. spontaneum* accumulates little sucrose, has thinner stalks and higher fibre content but is a highly polymorphic species with resistance or tolerance to many pests and diseases (Bull and Glasziou, 1979; Jackson, 2005).

### 2.2 Current Status of Sugarcane in Ethiopia

Commercial sugarcane production has a history of six decades, sugarcane had been cultivated in Ethiopia since century. According to the report by central statistics agency (CSA) currently sugarcane is produced in about 31,236.81 ha with 1,565,060.00 holdings in different parts of the country (CSA, 2017). But the production is not usually used for industrial purposes. It is noticeably used for making confectioneries, household consumption (chewing), selling for immediate cash, and feeding livestock. In some areas, sugarcane is used to prepare local beverage called “Karibo” mainly preferred by Muslim communities, while in others the leaves are used for thatching and as firewood (Esayas, 2014). However, the potential of this sector is not well explored and has not been given due consideration. Furthermore no exploration and germplasm collection have been done to represent and preserve local landraces.

Sugarcane plays a significant role in the Ethiopian socio-economy. Sugar and its byproduct are used for local consumption and export. The industry created job opportunity for a large number of people. Today in the country sugar consumption outstrips its production. The per capita sugar consumption in Ethiopia is very low (5-

6 kg) which is even below the African standard (15 kg) while the world average per capita consumption is 21 kg in 2016. The commercial sugarcane sector in Ethiopia commenced since 1951. Sugar Corporation of Ethiopia currently administers six sugar factories, namely, Wonji-Shoa, Metahara, Finchaa, Tendaho, Arjo-dedessa, and Kessem, and nine sugar development projects at Kuraz, Tana Beles, and Welkayit. Sugarcane plantations are expanding with current area coverage of 98,986 hectares and production of 400,000 tons of sugar and 25,388 m<sup>3</sup> of ethanol per annum.

In spite of the great importance of Ethiopian sugarcane, analysis of soil compactness to increase sugarcane production and quality across the country is lacking. No efforts have been made so far to assess and document the effect of soil compactness. Furthermore, study of the variation and assessment of extent and geographical pattern of distribution of soil compactness is lacking in Ethiopia when compare with other parts of the world.

### 2.3 Causes and Effect of soil compaction

#### a. Causes of soil compaction

The use of heavy machinery during planting, harvesting and transporting operations in fine textured soils has led to the concern that subsoil compaction may decline long term productivity. Soil compaction caused by agricultural traffic is commonly accepted as one of the causes of reduced crop productivity. This was attributed to increased spatial variability in crop stand, water, nutrient and root distribution (Hadas *et al.*, 1986). Soil compaction due to machinery traffic causes substantial losses at the farm level but the extent of it depends on the tractor size used, machinery use intensity, weather conditions, and the type of crop grown (Lavoie *et al.*, 1991). Harris and Pearce (1990) presented a design for a large capacity, high flotation haulout bin that would be compatible for cane harvesting areas throughout Australia. No assessment of a reduction in soil compaction compared with conventional equipment was made.

Soil water content is the most important factor influencing soil compaction processes (Soane and Van Ouwkerk, 1994). In sugarcane harvesting systems, harvesters or transshipment machines with total weight ranging from 20 to 30 t are commonly used, and their traffic occurs during several crop cycles at varying conditions of water content in soil with high compaction potential, causing physical and structural degradation of the soil (Cavaliere *et al.*, 2011). Root penetration resistance (RPR) and Bulk density (BD) have been used to define the levels of soil compaction so that corrective measures could be implemented. Sene *et al.*, (1985) recorded values between 6.0 and 7.0 MPa as critical for the growing of plant roots in sandy soils, and a value of 2.5 MPa for clayey soils. Regarding bulk density, the critical values are 1.65 Mg (sandy soils) and 1.45 Mg (clayey soils) (Araujo *et al.*, 2004).

On the other hand, when we consider manual harvesting system, the burning of straw aims to facilitate the process, however, it is a harmful practice to the maintenance of organic matter (OM) levels, because it reduces the supply of total organic matter and favors its mineralization (Ceddia *et al.*, 1999). The remaining straw deposited on the soil under this type of system is of 3.0 Mg/ha/year, on the average estimate (Souza *et al.*, 2005), so soil coverage will be lower and the loss of soil and nutrients will be greater, in addition to having a negative influence on the physical quality of soils (Garbiate *et al.*, 2011).

Torres *et al* (1990) also compared the effect of row and inter-row compaction under wet harvest conditions on soil properties and subsequent ratoon yield. Passage of machinery resulted in an increase in bulk density and soil strength. Correspondingly porosity and infiltration rate decreased. However, direct damage to the stool by equipment was thought to be the largest cause of yield decline.

#### b. Effect of soil compaction on Growth of Sugarcane

For sugarcane, adverse soil properties associated with compacted soils negatively affect root growth rates (Torres and Rodrigues, 1995). The physiological cost of recovering the functions of fine roots may be as high as 70% of the accessible carbon flow (Vogt *et al.*, 1996). Kozlowski (1999) found that the increased carbon flow due to soil compaction leads to an overall decrease in photosynthesis. This is a result of reduced foliage surface, which is an outcome of reduced water intake caused by changes in the soil structure and moisture conditions (Arvidsson & Jokela, 1995). Therefore, a plant might not have enough energy to reconstruct its root system, and the growth of roots as well as the above-ground parts stagnate or even die. Reduced foliage surface is a reaction to a water deficit in the leaves, which is brought about by soil compaction and may lead to the closing of pores and further loss of photosynthesis (Masle & Passioura, 1987).

Often, extreme soil compaction leads to reduced absorption of mineral nutrients by the roots, especially nitrogen, phosphorus and potassium. Nutrient uptake is reduced as a result of the loss of minerals from soil, reduction of root access to nutrients and decreased root capacity for nutrient intake (Kozlowski & Pallardy, 1997). A reduction of nutrient uptake caused by soil compaction in the upper as well as deeper soil layers (Kozlowski, 1999) might be the reason for different reactions to the compaction among species, as some have higher nutrient demands than others.

Potassium deficiency results in depressed growth, thin stalks and yellowing of the older leaves with chlorotic spots and ultimately death of the leaf (Bakker, 1999). Potassium may also play a role in the ability of

sugarcane to withstand dry conditions (Wood and Schroeder, 2004). Since absorption of potassium is declined by effect of soil compactness the tolerance sugarcane plants are become susceptible to peculiar adverse environmental effect.

Magnesium is important for photosynthesis, being required for chlorophyll function, and is responsible for the green colour in the leaves (it absorbs the blue and red light spectrum). Deficiencies result in leaf chlorosis and stalks of reduced diameter with internal browning (Bakker, 1999).

#### c. Effect of soil compaction on yield and Quality of Sugarcane

Soil compaction is the reduction in the volume of the pores due to an external force. In such conditions, the distribution and the size of the pores are altered, reducing the permeability and hydraulic conductivity. As a result of this, bad ventilation of soil, increase of bulk density and yield reduction is resulted. The yield reduction occurs due to limitation of root growth and so declining their efficiency to absorb nutrients.

It has been estimated that a crop of 74 tonnes of cane per ha removes 107 kg nitrogen, 60 kg phosphorus oxide and 300 kg potassium oxide per ha (Purseglove, 1972). The sugarcane plant requires nitrogen for optimum development for yield and sugar content of the canes. Symptoms of nitrogen deficiency are thin, stunted stalks; yellowing leaves with necrosis at the edge and tips; and reduced root mass (Calcino, Kingston and Haysom, 2000). However, excess nitrogen can prolong the crop maturation, resulting in a plant with an excessive leafy canopy, which in turn can make the plant more susceptible to leaf diseases and attack by pests (Bakker, 1999). It can also cause excess growth with little storage of sucrose (Irvine, 2004). This clearly showed that the effect of soil compactness in quality of sugarcane.

Phosphorus is required for optimum growth. Deficiencies may manifest as plants with short, thin stalks and stools with a low number of primary stalks, a poorly developed root system and sometimes leaves that are green-blue in colour. Conversely, an excess of phosphorus can lead to a deficiency of other trace elements such as zinc and iron, thus reducing sugar yields (Bakker, 1999). Potassium is required for many physiological processes. It helps to promote the formation and translocation of sugars, and thus may improve the extraction and purity of the cane juice. Supplementing sugarcane plants that are exposed to excessive nitrogen with potassium can alleviate the symptoms of over-supply of nitrogen.

Calcium is an important element for plant growth and also a regulator of soil acidity. A deficiency in calcium results in leaf chlorosis and reduced stem diameter. Increasing soil acidity, which can be ameliorated by lime application, can result in an increased fixation of phosphorus, aluminum, iron, manganese and nickel, which may lead to toxicity (Bakker, 1999). Thus, these will be contributed reducing sugar yields and quality.

Generally soil compaction is the reduction in the volume of the pores due to an external force. In such conditions, the distribution and the size of the pores are altered, reducing the permeability and hydraulic conductivity. As a result of this, bad ventilation of soil, increase of bulk density and yield reduction is resulted. The yield reduction occurs due to limitation of root growth and so declining their efficiency to absorb nutrients.

Table 1. Yield response and proportion of deformed roots of sugarcane in clay soil

Location of compacted layer (cm)	Decrease of yield (%)	Deformed roots (%)
Non-compacted	100% = 32.54 Mg/ha	2.1
< 28	10–13	5.6
< 22	21–25	13.4
6–10 and below 28	29–32	18.8
0–30 (compacted after sowing)	55–59	53.2

Source; (Birkás M. and Gyuricza C, 2001)

## 2.4 Management options of Soil Compaction in Sugarcane production

### A. Soil Water Potential

At all compaction levels, the penetration resistance increases with decreasing soil water potential (Lipiec *et al.*, 2002). In other words, increasing soil moisture content causes a reduction in the load support capacity of the soil, thus decreasing the permissible ground pressure (Medvedev and Cybulko, 1995). Knowing the changes in soil compaction with changes in water content helps to schedule farm trafficking and cultivation operations at the appropriate moisture content (Ohu *et al.*, 1989). Soil deformation increases with moisture content and the number of passes and timing of tillage in relation to soil water moisture content and soil texture (Hakansson and Lipiec, 2000). For any compaction energy level it is thus necessary to define the moisture content of the soil corresponding to the liquid, plastic and solid limits (Quiroga *et al.*, 1999). Soil water infiltration rate also can be used to monitor soil compaction status, especially of the topsoil. Water infiltrates un-compacted soils that have well-aggregated soil particles much faster than massive, structure-less soils (Hamza and Anderson, 2002a, 2003).

### B. Soil characterization before cultivation of land

Batey, (1990), reported that the effects of soil compaction on crops and soil properties are complex and since the state of compactness is an important soil structural attribute, there is a need to find a parameter for its characterization, such as relative bulk density, that gives directly comparable values for all soils (Hakansson and

Lipiec, 2000). Since soil bulk density is the mass of dry soil per unit volume, then the relationship between soil compaction and its capacity to store and transport water or air is obvious. For this reason the dry soil bulk density is the most frequently used parameter to characterize the state of soil compactness (Panayiotopoulos *et al.*, 1994). Hence, before cultivation of land soil characterization is must by using afro mentioned parameters to identify weather it is compactness or not.

#### C. Soil Tillage system

The current management techniques of sugarcane cultivation are based on vigorous soil tillage during preparation and planting, which together with to the harvest system used (manual or mechanized), cause alterations in the physicochemical properties and levels of organic matter (OM) of the soil (Vasconcelos *et al.*, 2010). The following main changes have been observed in the physical properties of soils: reduction in macro porosity, change in aggregate size, reduction in water infiltration rate, increase in bulk density (BD), and increase in root penetration resistance (Rpr) (Camargo; Marques Júnior; Pereira, 2010), which may eventually cause decrease in crop yield. Therefore, soil depending harvesting system choice of appropriate tillage system is paramount important to avoid soil compaction.

#### D. Passage of machinery

In sugarcane harvesting systems, harvesters or transshipment machines with total weight ranging from 20 to 30 t are commonly used, and their traffic occurs during several crop cycles at varying conditions of water content in soil with high compaction potential, causing physical and structural degradation of the soil (Cavaliere *et al.*, 2011).

Torres *et al* (1990) also compared the effect of row and inter-row compaction under wet harvest conditions on soil properties and subsequent ratoon yield. Passage of machinery resulted in an increase in bulk density and soil strength. Therefore, making passage of machinery across the farm is paramount important to reduce the effect of soil compactness come-up with heavy machinery.

#### E. Crop rotation

The effect of roots on soil structure depends on the species grown, soil constitution and environmental factors (Monroe and Kladvko, 1987). The effect is also influenced by soil micro-flora associated with plant roots (Tisdall, 1991). Plants grown in compacted soil have shown a smaller number of lateral roots with less dry matter than plants grown under controlled conditions at both low and high soil water contents (Panayiotopoulos *et al.*, 1994). Roots grown in more compact soil had smaller ratios of fresh to dry mass. Soil compaction can have adverse effects upon plants growing in the soil by: increasing the mechanical impedance to the growth of roots, altering the extent and configuration of the pore space (Tardieu, 1994).

Roots of different crop species, as well as of cultivars within species, differ considerably in their ability to penetrate through hard soil layers (Singh and Sainju, 1998). Their response is related to the ability of the root system to overcome the soil strength limitations of compacted soil (Kirkegaard *et al.*, 1992). Plant species that have the ability to penetrate soils with high strength usually possess a deep tap root system. Incorporating such species in the rotation is desirable to minimize the risks of subsoil compaction (Ishaq *et al.*, 2001b). If there is enough topsoil for root growth, roots will concentrate themselves there and increases in density of the subsoil may not result in significant decreases in yield. Sugarcane continuous cropping, together with inadequate management practices, as intense traffic of machinery and the absence of crop rotation, can result in soil degradation and reduce productivity (Masilaca *et al.*, 1986).

### 3. Conclusion

Now a day's sugarcane production has many advantages due to its products and byproducts. Products such as, the sugar juice is used for making sugar, and several byproducts are produced from crushing sugarcane at the sugar mill. This includes alcohol, molasses, bagasses, and syrup. In spite of the importance of the crop there are many factors which cause the decrease in sugarcane productivity such as climate change and declining in soil fertility as an impact of conventional soil management. Among many conventional soil management soil compaction adversely affects soil physical fertility, particularly storage and supply of water and nutrients, through increasing soil bulk density, decreasing porosity, increasing soil strength, decreasing soil water infiltration, and water holding capacity, and all of these processes lead to changes in plant physiology of sugarcane that leads to effect sugarcane growth, decline sugar yield and quality. The current management techniques of sugarcane cultivation should be based on vigorous soil tillage during preparation and planting, which together with to the harvest system used (manual or mechanized), cause alterations in the physicochemical properties and levels of organic matter (OM) of the soil. Among many management options of soil compactness Soil Water Potential, Soil characterization before cultivation of land, Soil Tillage, passages of machine across the field and crop rotation is the major one.

#### Recommendations and future prospective

✓ Effect of soil compaction on growth, yield and production of sugarcane should be considered as measure.

- ✓ Sugarcane harvesting, planting and fertilizer application in the field at wet time can cause soil compaction due to mechanized method, so as much as possible doing all this works should be practiced at fully dry time, if it's impossible manual work is better.
- ✓ Soil compaction also causes disorder in plant physiological processes by reducing amount of water in the soil, limiting movement of nutrients in the soil, closing soil pore spaces, diminishing water and soil air balance, reduction in aeration and also limits growth and water uptake of roots, so as much as possible subsoiling, early earthing up, continuous following up the field after doing works mechanically.
- ✓ Accordingly it is important to till the soil at the right soil moisture if compaction is to be minimized and measuring the bulk density of the soil before using machines in the field should be done to minimize the effects of soil compaction on soil and to have better production of sugarcane in the future.
- ✓ Giving awareness and teaching society about the impact of soil compaction on the growth, yield and quality of sugarcane will be paramount importance
- ✓ Assessment of soil compactness for Ethiopian like countries is paramount important, because of to know current yield also occurred by this problem and to design strategies for the problem that leads to increase overall economy of the country

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