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Effect of Soil Physical Properties on Sugarcane Production: A Comparative Study in Halfa and Alguneid Sugar Factories

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Abstract

In Sudan sugarcane is a key agricultural crop which significantly contributes in economy. This study was conducted to investigate the impact of soil characteristics on sugarcane production at Halfa and Algunied areas. Soil samples were perfectly collected from different parts of each site and analyzed. Soil texture, bulk Density, sand%, clay%, moisture, pH, EC, Alkalinity $CO_3^{2-}, HCO_3^-, Cl^-, SO_4^{2-}$ and macro nutrient were determined. SAR, RSC were calculated. Some parameters showed clear variations in the two areas. Halfa soil showed mean values of pH (6.99), alkalinity (1000mg/l), chloride (520meq/l), sulfate (10.8mg/kg), bicarbonate (5.2meq/l), and SAR (3.00) indicating high potential sodicity risks. At Algunaid the mean values were pH (7.69), Alkalinity (1066mg/l), chloride (4.5meq/l), bicarbonate (6.5meq/l) and SAR (0.85).

Keywords: Sugarcane, SAR, RSC, Alkalinity.

1. INTRODUCTION

Soil quality is a key indicator of sustainable land use and management (Gong *et al.,* 2006). Soil quality was defined as its capacity of functioning to sustain plant and animal productivity, enhance water and air quality, support human health and habitation (Karlen *et al.,* 1997; Pedro Cairo-Cairo 2017). Sugarcane (*Saccharum officinarum L.*) is an important long duration industrial crop for white sugar production (Bodhinayake *et al.,* 1998, Pedro Cairo-Cairo, *et al.,* 2017). When compared with soils under native vegetation or at the first year of sugarcane cultivation, old sugarcane land may suffer physical, chemical and biological degradation (Garside *et al.,* 1997, 2005). Old lands are more compacted and have lower levels of, organic carbon, water infiltration rates, cation-exchange capacities, Cu and Zn content in addition to more exchangeable Al, higher acidity, more plant-parasitic nematodes and more root pathogens (G.R. Stirling *et al.,* 2010). The essential soil quality parameters are, structure, pore space size, aggregate stability, saturated hydraulic conductivity, retention mechanisms, exchange capacity, pH, adsorption capacity (D. L. Karien *et al.,* 1997). Soil quality evaluation can be determined by four critical functions including, accommodation of water entry, plants water supply, degradation resistance, and plant growth support (Karien *et al.,* 1994). The best traits for selection of sugarcane clones in water-limited environments are, the increase of, rooting depth, intrinsic water use efficiency, transpiration efficiency, and reduced conductance (N.G. Inman-Bamber *et al.,* 2012). Continuous sugarcane cultivation increases soil acidity, lowers total sulfur content (Pang, Z.; Tayyab, M *et al.,* 2021). The main conflict in sugar cane growing is the necessity of optimum soil conditions which may need heavy machinery use, fertilizers application, weed and cane extraction (Wakgari *et al.,* 2020; Montero-Arellano *et al.,* (2022). Long term land use may significantly affect clay texture, total porosity, bulk density, pH, organic carbon, available (P) and total (N) of sugarcane growing soils (T. Wakgari *et al;* 2018)

Machinery overuse may result in soil compaction as a serious factor which reduces rooting, water infiltration, nutrition uptake and crop yield (Barzegar *et al.,* 2000, Hamza and Anderson, 2005, Zhang and Lovdahi, 2006, T.Wakgari *et al.,* 2018). In terms of biogeochemical processes, soil compaction reduces air-filled porosity resulting in N_2O and CH_4 emissions, loss of biodiversity and ecosystem function (Benton *et al.,* 2003, Ball, 2013). To improve soil structure and water availability gypsum, organic matter and plant residues should be added (Dhan Pal and Yihenew G. Selassie 2018**).** Soil pH is an informative measurement that determines soil characteristics and lime may be required after sugarcane ploughed-out to sustain optimal soil pH levels conductive to long-term soil fertility and productivity (A.E. Harteminkr 1998). The soils maintain a neutral pH and moderate organic content, supporting microbial activity and nutrient cycling. Salinity remains a persistent issue, requiring leaching and irrigation scheduling to mitigate it's effects (Sposito, 2008, Elbashier *et al.,* 2019). In alkaine soils, basic cations stabilize pH during dilution, while salts content of soil solution represent a primary factor influencing pH. Lime addition before planting enhances Ca and Mg availability, but when alkalinity is significantly high Ca (II) form complexes with P, leading to phosphorous deficiency (Gong *et al.* 2006). To lower soil alkalinity gypsum and/or powdered sulfur can add to the soils (Forth, 1990, M. Shanmuganathan and A. Rajendran, 2018).

Table 1: The recommended levels of pH and SO_4^{2-} in sugarcane soils (Rodrigues *et al.,* 2013)

Level	pH	SO_4^{2-}
Very High	<4.3	
High	4.4-5.0	>10
Medium	5.1-5.5	5-10
Low	5.6-6.0	0-4
Very Low	>6.0	

Algunied and Halfa schemes

The oldest sugarcane growing scheme in Sudan are Algunied (1962) and Halfa (1966). They may be good examples for long-term used lands which need scientific evaluation of soil suitability for cane sugar production. Alguneid scheme is located in Gezira State at the Eastern bank Blue Nile on a dark brown alkaline heavy clay (Ali, 1969; Ibrahim, 1970). It is requires adequate amounts of moisture, sunlight and nutrients and use of new technologies to reduce production costs and increase sugar yield and quality (Gopalasundaram *et al.,* 2012). New technologies for sugarcane should be used to increase the yield, quality, and to reduce production costs. Halfa sugar project is located in kassala state and irrigated from Atbara River. It covers a vast area of farmland and contributes to both local livelihood and national sugar production. This project has also been studied for its sustainability and agricultural planning in post-resettlement contexts (Ali *et al.,* 2021). New Halfa soils are predominantly study loam mixed with clay that makes them moderately fertile and well-drained. Irrigation from Atbara River plays a vital role in maintaining soil moisture and crop productivity. The soils tend to have low organic matter and elevated pH, which restrict nutrient bioavailability, especially iron and phosphorous. Organic amendments and pH-neutralizing agents are recommended to counter these deficiencies (Ali *et al.,* 2021; FAO Soil Bulletin, 2021).

2. METHODOLOGY

Ten soil samples were collected at depth of 50cm from the soils surface at different parts of each site. Composite samples were prepared for each site. Soil texture, bulk density, saturation, pH, EC, alkalinity, mineral content, specific anions and sodium adsorption ratio (SAR) were determined.

3. RESULTS AND DISCUSSION

Halfa soils were determined by silty clay loam (SiCL) with clay percentages range of 25.60% to 31.60% and mean (28.6%), whereas Alguneid soils showed a mixture of clay (C) and silty clay (SiC) textures. Montero-Arellano, *et al.,* (2022), reported Clay loam Texture for sugarcane soils in Mexico, whereas M. Shanmuganathan and A. Rajendran, (2018) reported, silty clay loam and clay loam textures. The bulk density of Halfa samples, range from (1.279 to 1.310 g/m^3), while, Algunied Samples were ranged from (1.25 to 1.27 g/m^3), tables (2, 3).

Table 2: Some properties of Halfa soil samples

Samples/ Halfa	Soil Class	Sand %	Silt %	Clay %	Bulk Density *(g/cm³)*	Saturation%	Moisture %
1	SiCL	8.10	60.30	31.60	1.279	.55322	6.210
2	SiCL	8.10	63.30	28.60	1.293	.50101	5.364
3	SiL	8.10	66.30	25.60	1.310	.50467	5.010

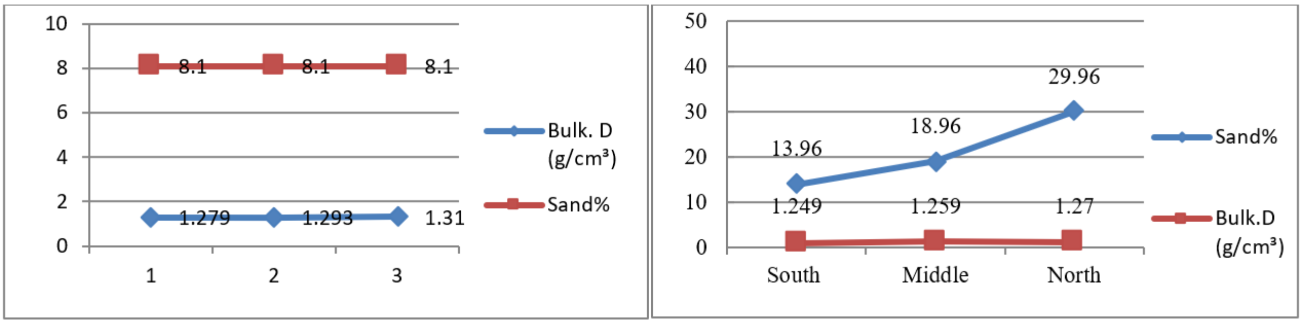
S= Sand, C= Clay, L = Loam, Si= Silt.

Table 3: Some properties of Algunied soil samples

Samples/ Algunaid	Soil Class	Sand %	Silt %	Clay %	Bulk Density *(g/cm³)*	Saturation%	Moisture %
South	SiC	13.96	44.28	41.76	1.249	59.568	4.577
Middle	SiC	18.96	39.28	41.76	1.259	59.969	4.971
North	C	29.96	25.28	44.76	1.270	57.912	2.920

S= Sand, C= Clay, L = Loam, Si= Silt.

According to John Rey N. Labajo *et al.,* (2022) the soils bulk densities increases with high sand percentage compared to fine silts and clays. This relationship was shown in Algunied samples (Fig. 1). Keniya, *et al.,* (2024) reported bulk density range of (1.10 to1.68g/cm³). M. Shanmuganathan and A. Rajendran, (2018) reported bulk density range of (1.12 to 1.14 g/cm³).



(a) (b)

Fig. 1: Bulk density and sand percentage in (a) Halfa, (b) Algunied

Tullberg and Freebrain., (2001), Zhang and Lovdahi., (2006), Wakgari, *et al.,* (2020) reported that, the change of soil properties increases bulk densities and lead to low nutrition uptake and crop yield reduction. Bulk density depends on soil texture representing an indicator of soil health (M. Shanmuganathan and A. Rajendran 2018).

Halfa soils showed lower saturation levels (50.01-55.32%) compared to Alguneid (57.91-59.96%), indicating better water retention in Alguneid soils. Moisture content range of (5.01 to 6.21%) and mean (5.53%) is considered moderate to relatively high depending on clay and sand concentrations, this may indicate direct proportionally between moisture content and saturation percentage. Algunaid soils are slightly high saturated (57.9-59.9%), whereas moisture content was lower (2.9-4.97%). This may be due to high sand percentage or soil compaction (Tables 2, 3 and Figure 2).

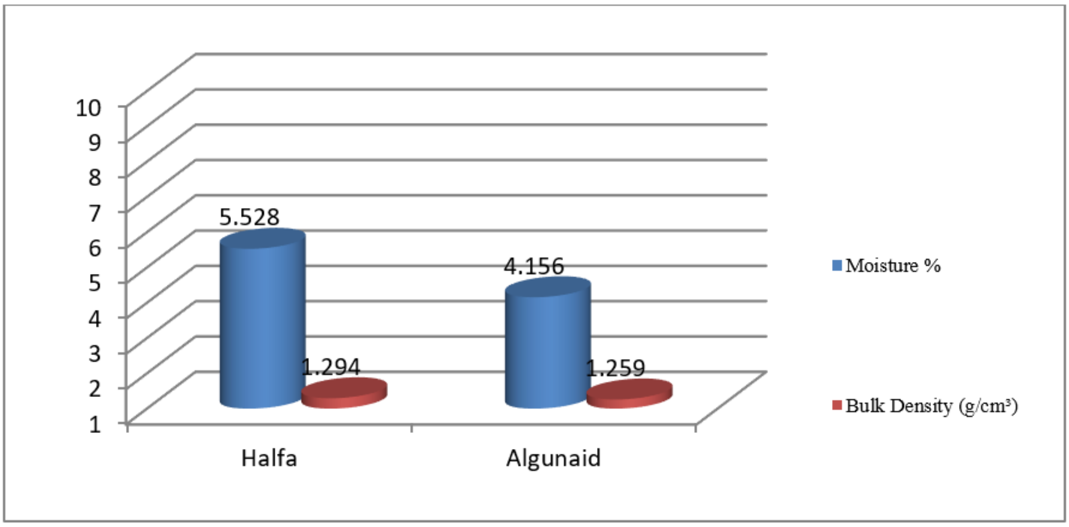


Fig. 2: Moisture and Bulk density relation in two fields

pH values and salinity

pH of Halfa soils were range from slightly alkaline to slightly acidic, (6.30-7.40), with a mean value (6.99), whereas, Alguneid soils were alkaline pH range of (7.58 to 7.81) with a mean as (7.70). Wakgari *et al.,* 2020 reported pH range of (5.35 to 6.63), whereas, Montero-Arellano *et al.,* (2022), reported pH mean value as (7.06±0.03). M. Shanmuganathan and A. Rajendran, (2018) reported slightly acidic to moderately alkaline soil pH ranged from (6.9 to 8.3). H. S. Ibrahim, (1978) showed pH range from (8.5 to 9.2) in Algunied soils. Ibrahim, G. *et al.,* (2022) reported alkaline pH for sugarcane soils as (7.14 to 8.18) with a mean (7.70). Dhan Pal and Yihenew G.Selassie, (*2018*) also described alkaline soil (pH) ranged from (7.7 to 8.2). Halfa samples showed high salinity, with EC range of (0.465- 6.590 mS/cm) and mean as (2.835). On the other hand Algunied samples showed EC range of (0.322 to 0.393mS/cm). High EC of Halfa soil may negatively influence sugarcane growth. Mean EC was reported by Montero-Arellano *et al.,* (2022) as (0.435±0.040dS/m) and by Ibrahim G. *et al.,* (2022) as (2.43 dS/m).

Relatively low EC ranges were described by M. Shanmuganathan and A. Rajendran, (2018) as (0.03 to 0.27 mmho/cm), compared with that reported by H. S. Ibrahim, (1978) as (2.11- 3.90 mmho/cm) and Dhan Pal and Yihenew G.Selassie, (2018) as (0.9 to 8.0dS/m). Long term land use may significantly affect and and clay content, bulk density, total porosity, salinity and pH of soil (T. Wakgari *et al;* 2018).

Sodium Adsorption Ratio (SAR)

For Halfa samples (SAR) was ranged from (1.667-5.603) indicating potential sodium risk. In Algunied (SAR) range was (0.418-1.182) (Fig.3). Sodium adsorption ratio (SAR) of the two fields may be considered as moderate and below the threshold for sodic soils (SAR > 13). Ibrahim, G. *et al.,* (2022) reported relatively high SAR mean value as (6.53).

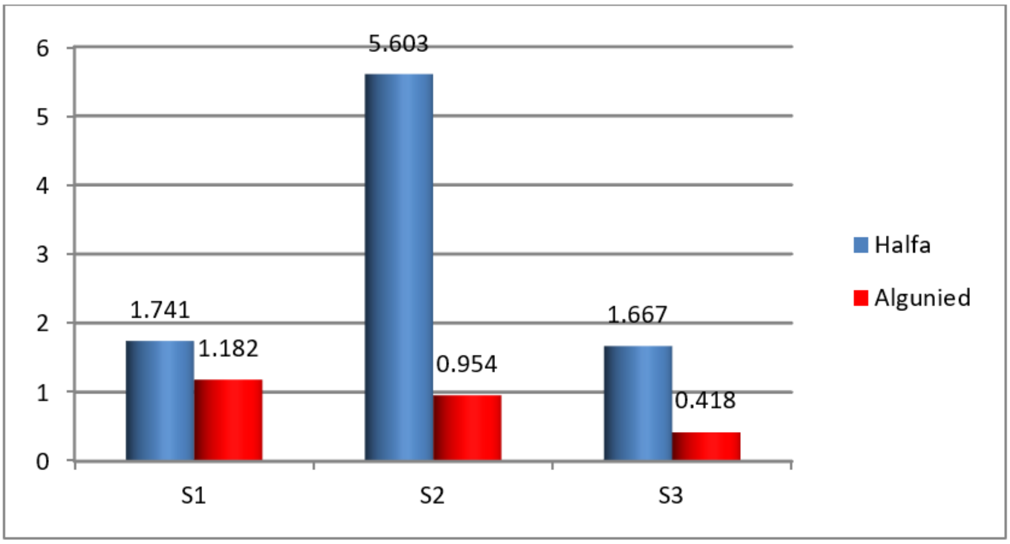


Fig. 3: SAR for Halfa and Algunaid fields

Alkalinity mean was more pronounced in Alguneid samples (1800 mg/l) compared with that of Halfa (1500mg/l). This may strongly reflect the high availability of bicarbonate, although it was suggested to be due to both carbonate and bicarbonate (Braddy and Weil, 1999, Daquiado and Pabiona, (2017). As shown by (Fig. 4, table 4), two samples of Halfa soil positive values of residual sodium carbonate (RSC) as (5.7) and (0.14) whereas one sample showed high negative RSC value (-39.056meq/l). This may suggest high availability of the divalent cations Ca^{2+} and Mg^{2+}, over CO_3^{2-} and HCO_3^- anions.

Table 4: pH, EC, Alkalnity, RSC and SAR parameters of Halfa samples.

Samples/ Halfa	pH Paste	EC. mS/cm	Alkalinity mg/l	RSC meq/l	SAR
1	7.26	0.465	1000.00	5.703	1.741
2	6.30	6.590	1500.00	-39.056	5.603
3	7.40	1.450	500	0.141	1.667

SAR = Sodium Adsorption Ratio.

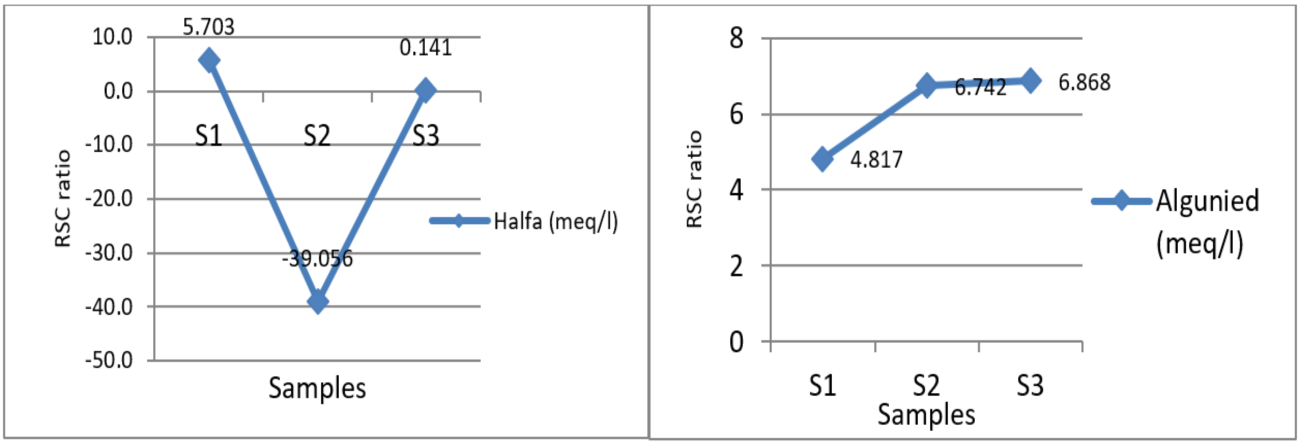
Algunied samples showed (4.8), (6.74), (6.87) and (Table 5 and figure 4).

Table 5: pH, EC, Alkalnity, RSC and SAR parameters of Algunied samples

Sample / Algunied	pH Paste	EC. mS/cm	Alkalinity mg/l	RSC meq/l	SAR
South	7.58	0.393	800	4.817	1.182
Middle	7.81	0.387	1800.00	6.742	0.954
North	7.72	0.322	600	6.868	0.418

SAR = Sodium Adsorption Ratio.

Halfa soils showed signs of salinity and sodium-related challenges which can potentially limit sugarcane productivity whereas; the lower salinity of Alguneid soils may indicate better overall growth conditions. In the two fields (CO_3^{2-}) ions were not detected. Relatively high (HCO_3^-) content was shown by Algunied samples as (5.2, 7.3 and 7.3meq/l) compared with Halfa samples (4.40 and 4.8 meq/l). This may explain the high alkalinity values in the two fields and may agree with (Braddy and Weil 1999), and (Daquiado and Pabiona, 2017).



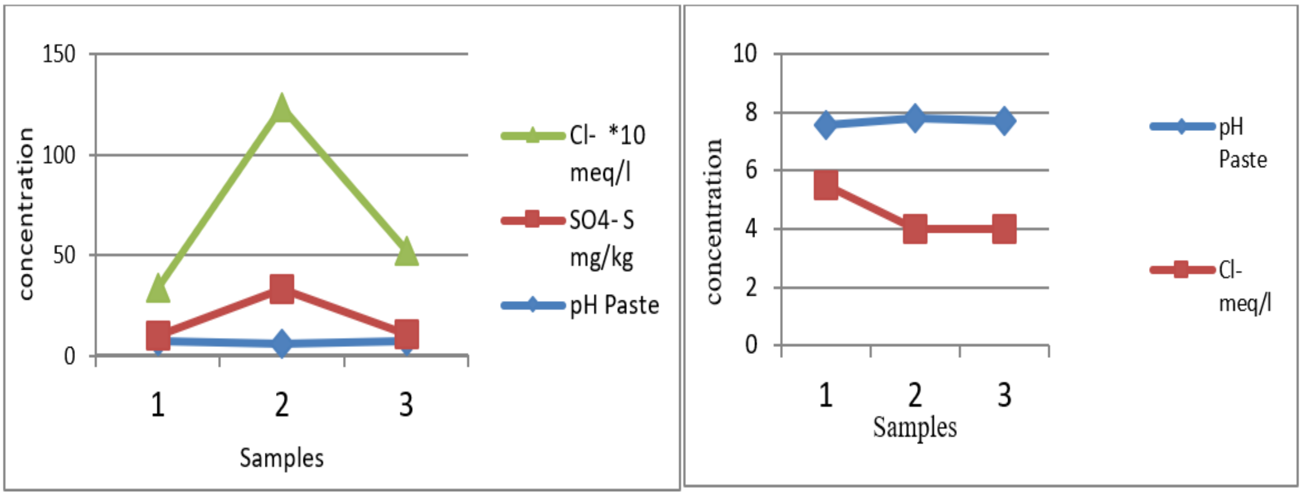
(a) (b)

Fig. 4: RSC of Halfa (a) and Algunaid samples (b)

Chloride and sulfate

Halfa samples showed high Chloride range (220 to 900meq/l) compared with that of Algunied (4.0 to 5.5meq/l). The suitable chloride for sugarcane cultivation was described by M. Shanmuganathan and A. Rajendran (2018) as (<4mg/L). High chloride may affect the hydration degree of plant cells and cations balance in the plant.

The composite samples No.2 of Halfa soil indicated clear soil quality variations as (pH=6.59) sulfate (26.93meq/l), chloride (900meq/l), bicarbonate concentration (4.40meq/l) in addition to high SAR (5.6) and alkalinity (1500 mg/l). The high alkalinity may be due to a presence of some alkaline metal oxides like (K_2O, Na_2O, MgO or even FeO in addition to HCO_3^-, Cl^- 6.22meq/l and SO_4^{2-} (4.13meq/l) (Tables 6 and 7).



(a) (b)

Fig. 5: Relation of pH, chloride and sulfate, (a) Halfa and (b) Algunaid

Table 6: Anions concentrations of Halfa samples

Sample / Halfa	CO_3^{-2} meq/l	HCO_3^- meq/l	Cl^- meq/l	SO_4^- S mg/kg
1	ND	6.40	240.00	2.534
2	ND	4.40	900.00	26.928
3	ND	4.80	420.00	3.062

Table 7: Anions of Algunied samples

Sample / Algunied	CO_3^{-2} meq/l	HCO_3^- meq/l	Cl^- meq/l	SO_4^-S mg/kg
South	ND	5.20	5.50	ND
Middle	ND	7.20	4.00	ND
North	ND	7.20	4.00	ND

4. CONCLUSION AND RECOMMENDATIONS

- Significant physicochemical variations were observed between Halfa and Algunied soils.
- The high salinity and sodium levels could negatively affect sugarcane production in Halfa soils.
- The physical and chemical properties of Algunied soils may be more suitable for sugarcane cultivation.

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