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Alluvial Soil Quality Indicators As Affected By Different Land-Uses.

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ABSTRACT

Soil deterioration and yield decline are the main factors affecting the environmental sustainability of long-term irrigated sugarcane monoculture. This research was conducted to detect changes of soil physical, chemical and physicochemical quality parameters associated with intensive irrigated sugarcane monoculture with groundwater for long term. Sugarcane monoculture resulted in a severe impact on some soil physical indicators of soil quality as increased the soil bulk density and reduced soil clay content, decreased soil aggregate stability and the water content at the field capacity causing decreases in soil porosity and decline in soil fertility. Significant impacts on some soil chemical indicators of soil quality were also recorded as reduced soil organic matter content and increased soil pH and EC producing soil salinity. Fields under long-term irrigated sugarcane monoculture had low OM values ranged from 2.09 to 2.61% while areas under crop rotation had the highest OM values ranged from 2.62 to 3.39%. Fields under sugarcane monoculture system had higher pH, EC and SAR values ranged from 7.96 to 8.41, from 2.98 to 4.22 dS m^{-1} and from 7.75 to 11%, while fields under crop rotation system had the lowest pH, EC and SAR values ranged from 7.64 to 7.92, 1.41 to 2.42 dS m^{-1} and from 4.51 to 5.86%, respectively. From these results, it could be concluded that long term sugarcane monoculture has significantly deteriorated soil physical and chemical properties indicating the urgent demand for more sustainable management practices to preserve soil quality.

Keywords: Sugarcane Monoculture, Soil Deterioration, Soil Aggregate Stability.

INTRODUCTION

Soil today is well known as nonrenewable natural resource at least on a human lifespan because once soil has degraded, its rejuvenation is definitely a very slow process (Lal, 2015; Abd El-Azeim *et al*., 2020). Soil quality and productive capability can be deteriorated with long-term irrigated sugarcane monoculture (Martíni *et al*., 2020; da Silva *et al*., 2021; Taleisnik and Lavado, 2021; Marin *et al*., 2021). Sugarcane (*Saccharum hybrid* sp.) has been cultivated in Egypt since 710 and sugar manufacturing is one of the firstborn industries in Egypt (Nakhla, *et al*., 2017). In Egypt, the refined sugar industry was first discovered during the 9th century, and part of sugar products were exported to Europe (Nakhla, *et al*., 2017; Alhameid, *et al*., 2019). Production of sugar cane in Egypt increased from 408 tons in 1970 to 1,100 tons in 2019, with an average annual growth rate of 2.32% (USDA, 2020). Average of cane productivity for the year 2020 was 87.6 t sugarcane ha^{-1}, well below the peak value of 94.1 t ha^{-1} of cane documented in 2016. Certainly, over the past decade, there have been no apparent productivity gains, with average yields stagnating at around 80.0 tons sugarcane hectare despite the proffer of new improved cane cultivars and advances in agronomic practices (USDA, 2020).

Recently there has been growing evidence of decreased soil productivity as a result of long-term monoculture of irrigated sugarcane (*Saccharum officinarum* L.) combined with intensive irrigation and fertilization regimes (Umrit *et al*., 2014; Yin *et al*., 2018; Martíni *et al*., 2020; Ouda, 2020; Wu *et al*., 2020; Marin *et al*., 2021). Excessive tilth, irrigation, fertilization and management practices such as trash burning that diminish organic matter and nutrients and soil health have also been recognised as primary factors contributing to the yield decline in sugarcane monoculture systems (Umrit *et al*., 2014; Wu *et al*., 2020; Marin *et al*., 2021). With each other, these management practices give rise to dilapidation of the soil physicochemical, and microbiological properties as evidenced by less soil microbial biomass and enzymatic activity, accrual of detrimental soil organisms, increased accumulation of heavy metals, decreased amounts of SOC, lower soil CEC and pH and increased soil bulk density (Yin *et al*., 2018; Martíni *et al*., 2020).

In addition, there are growing concerns about agricultural sustainability and the environment, with recent farming systems adversely affecting long-term sugarcane productivity of soil due to the loss of soil organic matter (SOM) and increases in erosion (Alhameid, *et al*., 2019; Martíni *et al*., 2020; da Silva *et al*., 2021) accompanied by fertility loss and soil degradation in many cases. Therefore, alternative management systems that are more diverse and create less disturbance to the soil have been promoted to enhance soil properties, and consequently farm productivity. Soil management is aimed at the maintenance of optimal soil physical and hydrological quality for crop production (Wani *et al*. 2016; Alhameid, *et al*., 2019). Ecologically aware sugarcane monoculture management practices are being implemented to protect soil and water quality and enhance soil moisture preservation to meet water scarcity. The main conservation practices involve

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minimal soil disturbance, maintaining soil cover and enhancing crop productivity through crop rotations (Alhameid, *et al*., 2019).

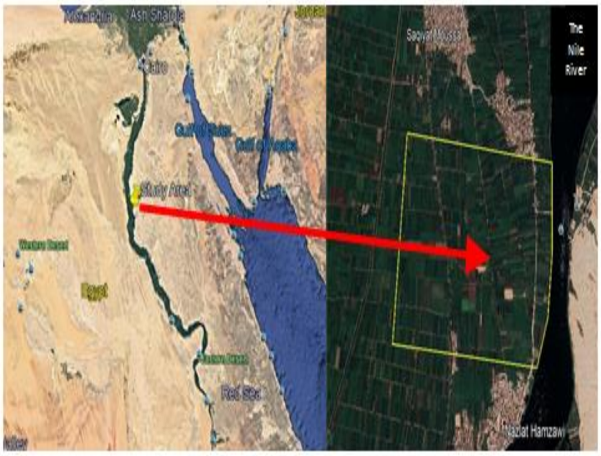
Traditional agricultural practices used for the production of sugarcane cause deterioration of soil and water quality by intensive tillage, irrigation, agrochemical additions, manual harvesting and burning of cane trash in the field (Oliver, 2004; Umrit *et al*., 2014; Wu *et al*., 2020). Common practices of burning residues rather than incorporation into soils as green manures has resulted in losses of around 11 kg ha^{-1} of N affecting crop yields and causing yields to drop by as much as 23% (Omran and Negm, 2020). In Egypt, nearly 25 million tons of rice straw and sugarcane trashes are being yearly burned in the open fields, making a strong contribution to climate change (Omran and Negm, 2020). Studies have indicated that conventional soil tillage practices for the monoculture of sugarcane may cause a loss equal to 80% of the organic carbon that can be accumulated in the soil rhizosphere within one year of motorized harvesting during a period of only 44 days (Martini *et al*., 2020; Omran and Negm, 2020; da Silva *et al*., 2021).

Irrigation is a prerequisite for sugarcane production in arid regions such as Egypt characterized by low precipitation and irregularity in rainfall distribution (Omran and Negm, 2020). The environmental sustainability of irrigated sugarcane monoculture in Upper Egypt are affected mainly by the change of water presented for other uses, degradation of aquatic environments, soil degradation as well as crop yield decline. In Upper Egypt sugarcane is a crop of vital importance and one of the most important issues that must be addressed towards its sustainable production are how to take into account soil and water quality in the monoculture of sugarcane (Omran and Negm, 2020). Traditional monoculture farming systems can degrade soil health by organic matter loss, structures and texture creating soils with low microbial activity, aggregate stability and high dispersion ratios owing to consistent soil disorder from till practices (Negash *et al*., 2018). Therefore, continuous soil monitoring along with systematic testing of soil health is crucial for implementing sugarcane monoculture system in the future. Also, future global warming and climate change is likely to aggravate the water demand for irrigation with the consequence that crops will grow under more hot, dry and saline conditions (Negash *et al*., 2018; Omran and Negm, 2020). Therefore, this research was conducted to detect changes of soil physical, chemical and physicochemical quality parameters associated with intensive irrigated monoculture of sugarcane (*Saccharum officinarum* L.) in Egypt for long term period.

MATERIALS AND METHODS

Study area and gathering data.

The study area is located in Upper Egypt, covers about 400 ha as part of El-Minia Governorate, along the westside of Nile Valley and in between the Western and the Eastern deserts. El-Minia Governorate is one of the main sugars producing areas in Egypt, producing more than 20% of the country's total (Ouda *et al*., 2020). In El-Minia Governorate (latitude 28.05º, longitude 30.44º and elevation 40.00 m), a part of Abu-Qurqas district lies between three villages (Saqiet Mousa Village, Nazlet Makeen Village and Nazlet Hamzawy Village) was carefully chosen as it is one of the major sugarcane monoculture areas besides its proximity to New Abu-Qurqas Sugar Factories (Map 1). Also, Abu-Qurqas sugarcane farming belt was chosen because this region is part of the fertile alluvial soils around the Nile Valley and also, has many small farmers who have implemented monoculture practices of sugarcane for long periods. The surface topography fluctuates between flat around the Nile and relatively elevated in the western direction of the study area.



Map .1. Study area map and close-up.

The study area is considered as an arid zone and categorized by very hot and dry weather in summer and cold in winter. The climatic data average (over last 5 years) gathered from a national meteorological station (close to the study region) showed that the humidity ranged from 55 to 87% throughout the year and the maximum temperature is nearly 36.68 ºC throughout the summer months, while the minimum temperature is around 6.08 ºC all through winter season. The temperature sometimes reaches zero at night during January and February, as the cultivated plants suffer from the risk of frost. The annual precipitation is around 2.0 mm year and only during the last year 2020, annual rainfall exceeded 53 mm indicating that change might come due to the phenomenon of climate change.

Field interviews were directed using administrated questionnaire to document sugarcane farmers' farming management regimes, agricultural inputs, production costs and profits, irrigation water resources and methods, fertilization management, sugarcane varieties, tillage, postharvest treatments, land ownership and acreage, and finally reasons for adoption livelihood in the investigated sugarcane monoculture area. Furthermore, meeting the extension officers of the agricultural associations and Agrarian Reform situated in the investigated area were approached to confirm information about monocultural areas and management practices in different farms.

The monoculture of sugarcane has been adopted in this region since 1900 in 5–6-year renewal rounds. The experimental fields primarily exposed to soil tillage using a disc harrow at 0.30 m depth for sugarcane cultivation implantation. Yearly nutrient addition rates were the total amount of the nutrient applied for the first, second and sometimes third crop each year for crop rotation areas.

The main types of fertilizers used are nitrogen in the form of ammonium sulphate (20.6% N), ammonium nitrate (33.5% N), urea (46.5% N), calcium nitrate (15.5% N); phosphorus in the form of concentrated superphosphate (37% P_2O_5) or single superphosphate (15% P_2O_5); and potassium in the form of potassium chloride (50 to 60% K_2O) or potassium sulphate (48 to 50% K_2O). Some local fabricated or compound fertilizers containing macronutrients of N, P, K and micronutrients of Fe, Mn, Zn, Cu in different preparations for either soil addition or foliage spraying were also employed. The micronutrients may be in either elemental or chelate forms. In sugarcane monoculture farming systems, synthetic fertilizers, particularly nitrogen, phosphorus and potassium are applied to an increasing extent.

Yearly application rates of NPK sugarcane farming systems ranged from 700 to 850, 1250 to 1500 and 550 to 700 kg ha^{-1}, respectively. And always 20% of the N and K fertilizers were used as base fertilizers, and 80% of them were applied topdressing through the season. All P fertilizers were always applied as basal fertilizers. On the other hand, different amounts of total nitrogen (N), phosphate (P) and potash (K) fertilizers were applied to the investigated crop rotation sites depending on the crop type, which ranged from 250 to 450 kg N ha^{-1}, 180 t0 360 kg P_2O_5 and 270 to 500 kg K_2O ha^{-1}. The highest values of NPK were used in the case of potato cultivation, and the lowest in the case of wheat. Sugarcane monoculture or crop rotation farming systems in this area is based on the practice of 100% surface irrigation system using Lift tube-wells groundwater.

The crop rotation farming systems are mainly maize/berseem/wheat rotation and vegetable/medicinal plants /berseem, while the management pattern of the latter includes sometimes greenhouse or open-air planting for vegetables. The main resources of freshwater are the River Nile, and the Quaternary groundwater aquifer. In most sugarcane farms, the sugarcane variety was Giza Taiwan (G.T) 54-9. After insecticides and fungicides application, other field management practices were the same as usual used in the local sugarcane farming or crop rotation systems production. Traditionally, sugarcane in Egypt is harvested manually and during harvesting sugarcane crop leaves behind massive quantities of trash which have to be managed with state-of-the-art methods instead of burning.

Soil and plant sampling.

Prior to establishment of the experiment, coordinates for soil sampling locations were recorded using a Global Positioning System (Garmin GPS v). The soil sampling sites were selected based on a grid of 2 km × 2 km in accordance with the layout of the functional areas of sugarcane monoculture or crop rotation and irrigation system implemented. Soil samples were collected from sampling sites located along a connexion route, each 100 m from the next and 20 m from borders of roads, drains and irrigation wells. A total of 31 composite samples, 15 samples from the sugarcane monoculture fields, 15 samples from the crop rotation fields, were collected twice in summer (July) and winter (January), 2017. In parallel, soil sample of undisturbed and uncultivated soil in the original landform as a reference soil were taken as a control. Collected fresh soil samples were homogenised, air dried, pulverized and sieved using a <2.0-mm sieve, then stored in plastic bags for laboratory analyses.

Soil Physicochemical Analysis

Soil samples collected from both sugarcane monoculture and crop rotation farming systems were mixed thoroughly and strange materials were removed and then 500 grams of soil was prepared for the analysis of selected physicochemical properties. Undisturbed soil samples using core ring samples were also obtained from each experimental site for the analysis of particle-size fractions (sand, silt and clay), bulk density (BD) and field capacity (FC) at the corresponding soil depth of 30 cm following the procedures suggested by Jimenez *et al*., (2020). Soil samples were analyzed for pH (1: 2.5 water) by Jetway pH-meter, model 3305, electrical conductivity (EC) by Jenway conductivity meter model 4310, cation exchange capacity (CEC), soil organic matter (OM), soil organic carbon (SOC) and labile carbon (LC) in accordance with Page *et al*., (1982) and Avery and Bascomb, (1982).

Estimation of soil aggregate stability (SAS) as functions of PAR and CROSS

Calcium, magnesium, potassium and sodium cations in the samples of soil aggregates were separately analyzed to determine sodium adsorption ratio (SAR), potassium adsorption ratio (PAR) and cation ratio of soil structural stability (CROSS).

Determination of soil aggregate stability.

Undisturbed soil samples were sieved to the size diameter of 1–2 mm before determining soil aggregate stability according to Phocharoen *et al*., (2018). Sieved soil samples were moisturized gradually for 48 h to avoid slaking effects, causing soil aggregate collapse when dried soils are moistened suddenly. Soil aggregate stability was evaluated by wet sieving procedure according to Kemper and Rosenau (1986) with three replications for each soil sample. Soil aggregated particles remaining on the sieve are considered soil stable portion, while the fragmented fractions of the soil aggregates passed across the sieve are considered unstable aggregate portions. Divided stable and unstable portions detached from the soil aggregates were then placed in a furnace at 105°C until the water vanished, and the sample weight was constant. The soil aggregate stability was calculated as described by this equation.

$$\textbf{Soil Aggregate Stability(SAS) \%} = \frac{\mathbf{SP}}{\mathbf{(SP + UP)}} * \mathbf{100}$$

where SP is the stable portions dry weight, and UP is the dry weight of unstable portions.

Determination of Soil PAR and CROSS

To assemble the soil liquid phase, size of soil aggregates with a diameter of 1–2 mm was soaked to make a soil paste followed by the extraction of soil solution using suction technique and a Buchner funnel (CH-9230, Switzerland). The leachates were then inspected for the concentrations of exchangeable Mg^{2+}, Ca^{2+} K^{+}, and Na^{+} using atomic absorption spectrophotometer (AA 240, A. Technologies, US). The extracted soil solution from the soil saturated paste was examined for K^{+} together with Ca^{2+}, Mg^{2+}, and Na^{+} to execute SAR, PAR, CROSS and MCAR indicating the impacts of Na^+, K^+, Mg^{2+}, and Ca^{2+} on the soil aggregate stability. The potassium adsorption ratio (PAR (mmolc $L^{-1})^{0.5}$), cation ratio of structural stability (CROSS (mmolc $L^{-1})^{0.5}$) (Marchuk and Rengasamy 2010), monovalent cations adsorption ratio (MCAR) and SAR were then determined according to the following equations.

$$PAR = \frac{K}{(Ca^{2+} + Mg^{2+})^{0.5}} \qquad CROSS = \frac{Na^{1+} + 0.56K^{1+}}{\left(\frac{(Ca^{2+} + 0.6Mg^{2+})}{2}\right)^{0.5}}$$

$$MCAR = \frac{(Na^{+} + K^{+})}{\left(\frac{(Ca^{2+} + Mg^{2+})}{2}\right)^{0.5}} \qquad SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{++} + Mg^{++}}{2}}}$$

The amounts of K^+, Na^+, Mg^{2+}, and Ca^{2+} are expressed in mmolc L^{-1}.

Statistical Analysis.

Research data were calculated as a mean of three replicates. Analysis of variance was carried out using (SPSS, Inc., Chicago, USA), and means were separated by the least significant difference ($P \leq 0.05$) according to Duncan's test. Descriptive statistics of minimum and maximum values, means, standard deviation and coefficient of variance for raw soil data were established and Pearson's correlation was used to relate soil aggregate stability and CROSS, MCAR, PAR and SAR.

RESULTS AND DISCUSSIONS

Soil physical, chemical and physicochemical characteristics were considerably impacted by the monoculture of sugarcane and the implementation of intensive agricultural practices. Results included physical, chemical and finally some soil physicochemical properties.

Effects of long-term sugarcane monoculture on some soil physical properties.

Percentage of sand, silt, and clay representing soil texture, soil bulk density, and soil moisture content at field capacity were significantly different under different land use management practices. The average values of sand, silt, and clay contents for sugarcane monoculture fields were 31.72% sand, 32.20% silt and 35.87% clay and for crop rotation fields were 29.46% sand, 37.32% silt and 33.20% clay, while the average values of sand, silt, and clay contents for reference soils were 32.40% sand, 22.20% silt and 45.40% clay (Table 1). Average values of soil bulk density (BD) and water retention at soil field capacity (FC) for fields of sugarcane monoculture, crop rotation and refence uncultivated soil are given in Table 1. Bulk density (BD) values in the sugarcane monoculture fields were significantly higher than those of crop rotation fields and uncultivated soil.

Bulk density of the soil superficial layers (0-30 cm) in the reference soil was a mean of 1.21 Mg m^{-3}, while for fields of crop rotation and sugarcane, it reached 1.36 Mg m^{-3} and 1.59 Mg m^{-3}, respectively. Water contents at the field capacity were decreased in sugarcane monoculture soils or crop rotation in relation to the uncultivated soil. The average value of FC to the reference control soil was 0.41 m^3 m^{-3} while, values were observed in the crop rotation fields ranged from 0.27–0.34 m^3 m^{-3}. Lower values of field capacity (FC) were observed in the sugarcane soils ranged from 0.24 to 0.31 m^3 m^{-3} in a soil depth of 30 cm. Comparable findings were detected by Cherubin *et al.* (2016), who confirmed reductions in soil porosity as a result of sugarcane cultivation compared to native forest soils. Cavalcanti *et al.* (2020) and Jimenez *et al.*, (2020) disclosed that continuous sugarcane plantation enlarged the soil bulk densities and reduced water contents at the field capacity.

Table 1. Some soil physical properties as affected by sugarcane monoculture.

Soil property	control	Sugarcane Monoculture					Crop Rotation				
		Descriptive Statistics					Descriptive Statistics				
		Average	Max	Min	SD	C.V%	Average	Max	Min	SD	C.V%
Sand %	32.40	31.72	35.26	28.33	1.90	5.99	29.46	31.93	26.42	1.75	5.95
Silt %	22.20	32.20	36.24	29.05	2.16	6.73	37.32	40.93	34.76	1.97	5.29
Clay %	45.40	35.87	38.96	31.48	2.38	6.64	33.20	34.23	32.08	0.67	2.03
Texture	Clay	Clay loam					Clay loam				
B.D Mg/m^3	1.21	1.59	1.65	1.53	0.03	2.25	1.36	1.46	1.33	0.03	2.44
F.C m^3/m^3	0.41	0.27	0.31	0.24	0.02	8.77	0.30	0.34	0.27	0.02	7.12

These results indicated that soil texture is affected by the degree of agriculture intensification owing to the significant large differences in particle size distribution between soil shallow horizons of sugarcane monoculture soils, crop rotation soils and uncultivated reference soil. The overall mean values of soil texture particles of sand, silt, and clay, in the uncultivated soil compared to soils under intensive sugarcane monoculture clearly showed the decreasing tendency of soil clay content. On the contrary, soils silt content showed a steady increase for sugarcane and crop rotation land-uses. In general, there was a slight but significant variation of sand, silt, and clay fractions between soils of both sugarcane and crop rotation land uses. In accordance, texture of the Nile alluvial soils under crop rotation or sugarcane monoculture is classified as a clay loam soil albeit that the soil particle size distribution was significantly different, while soil texture for the Nile alluvial uncultivated soil is classified as clay texture. Reference soil (control) is characterized by a significant higher clay content but lower silt than sugarcane and crop rotation land uses. This indicated that long term cultivated alluvial soils with sugarcane or crop rotation in Abo-Qurqas district, El-Minia Governorate, Egypt was characterized with a decline in soil fertility because clay soil contents were decreased.

Long-term monoculture of irrigated sugarcane farming system has transformed the soil texture and hence soil structure resulting in major changes in these soil functions and services. This signifies that the espousal of more sustainable management practices is essential for long-term preservation of soil texture and soil quality in Upper Egypt under the intensive monoculture systems of sugarcane. The intensive mechanized tillage and heavy mechanical harvesting used in sugarcane fields lead to degradation of soil structure and texture, which affect manifold of soil processes and functions (Negash *et al.*, 2018; Rabot, *et al*, 2018). The structure of a soil reflects the arrangement of soil aggregates and pores into soil structural units of different shapes and sizes, which manipulate soil biochemical and physical services such as soil CEC, soil organic matter turnover, nutrient availability, soil water retention and percolation, soil ventilation, soil consistency, and plant growth (Barthes and Roose, 2002; Six, *et al*., 2004). Therefore, soil functionalities related to soil structure or associated with soil texture are considered major indicators of soil quality (Bunemann *et al*., 2018).

Previous studies indicated that changes in soil uses from native plants to pasture to sugarcane plantation degraded soil microstructure, decreased soil porosity and negatively affected soil pores and particle size distribution, regardless of soil texture and the environmental conditions of the investigated regions (Canisares, *et al*., 2020). It is well confirmed that land use changes (LUC) alter soil structure and texture and accordingly, soil functionalities and services (Canisares, *et al*., 2020; Jimenez *et al*., 2020). The shift from extensive pasture to sugarcane production is one of the largest land-based shifts in Brazil because of the growth of the global and national needs of biofuels. Hence, largescale land use changes (LUC) to expand sugarcane production in Brazil have reduced soil micro-porosity, regardless of the site-specific conditions and soil type, signifying that implementation of more reliable management practices is imperious to preserve soil structure and sustain soil health in sugarcane fields (Canisares, *et al*., 2020; Jimenez *et al*., 2020; Cavalcanti *et al*., 2020).

Soil water conservation at field capacity and soil bulk density as physical indicators of soil quality in the uncultivated soil specified that monoculture of sugarcane for long term resulted in a severe impact on these soil physical indicators as reduced the water content at the field capacity and increased the soil bulk density causing decreases in soil porosity and decline in soil fertility. Sugarcane monoculture increased the degree of compaction, causing pore size distribution changes and hence an increase in the water capacity and reduction in the air capacity (de Lima *et al*. 2020; Jimenez *et al*., 2020; Singh *et al*., 2021). Changes in soil bulk density, water content at the field capacity and soil texture and structure may affected these soil physical functionalities. Furthermore, loss of soil structure and changes in soil texture due to intensive tillage for sugarcane monoculture systems and successive mechanized harvesting with heavy machinery (Silva *et al*. 2018; Cavalcanti *et al*. 2019) during long crop growth cycle seems to have induced consequent changes in pore architecture, soil particle size distribution which caused changes in soil water retention and negatively impacted field capacity.

It is expected that in the long term, consecutive mechanized harvests and tillage for sugarcane replanting will lead to induce the formation of plough pans, with significant reductions in soil pore spaces and water availability leading to deterioration of soil physical functions for plant growth (Cavalcanti *et al*. 2019, 2020; de Lima *et al*. 2020; Jimenez *et al*., 2020). Cherubin *et al*. (2016), observed that physical quality of the soil reduced by 90–56% of its full capacity from native vegetation soils to sugarcane as the consecutive monoculture of sugarcane deteriorated the soil physical quality for plant growth. Results displayed that the decline of soil physical quality occurs principally in the plow depth layer which is vulnerable to the formation of plow pans underneath the tillage depth (Jimenez *et al*., 2020). Augmentation in soil compaction, damage of soil ventilation capacity and soil consistency are the key source of the decrease in the soil physical quality. Mitigation of soil compaction with subsequent testing of field traffic impacts could help avert the decline of soil physical quality in sugarcane fields (Jimenez *et al*., 2020).

Effects of long-term monoculture of sugarcane on some soil chemical properties.

Soils under sugarcane monoculture systems had significant lower contents of OM, SOC, and CEC values than the soils under crop rotation systems and significantly higher contents of labile C, soluble salts (EC) and pH values at the soil depth of 0.0-30 cm layer (Table 2).

Table 2. Some soil chemical properties as affected by sugarcane monoculture.

Soil property	Control	Sugarcane Monoculture					Crop Rotation				
		Descriptive Statistics					Descriptive Statistics				
		Average	Max	Min	SD	C.V%	Average	Max	Min	SD	C.V%
SOC (g kg^{-1})	12.18	13.53	15.66	12.14	1.30	9.62	16.74	18.56	15.27	1.11	6.67
Labile C (g kg^{-1})	1.02	3.50	5.31	1.12	1.21	34.75	3.21	3.77	2.34	0.53	16.77
CEC cmolc kg^{-1})	31.22	32.93	38.96	30.28	2.51	7.63	36.96	41.17	30.27	2.76	7.47
OM %	2.15	2.31	2.61	2.09	0.18	7.85	2.90	3.39	2.62	0.21	7.39
pH (1:2.5)	7.45	8.18	8.41	7.96	0.15	1.87	7.85	7.92	7.64	0.07	0.91
EC (dS m^{-1})	1.15	3.53	4.22	2.98	0.31	8.84	2.02	2.42	1.41	0.34	16.93
SAR %	3.73	8.98	11.00	7.75	1.19	13.33	5.06	5.86	4.51	0.36	7.11

Fields under long-term irrigated sugarcane monoculture had low OM values ranged from 2.09 to 2.61% while areas under crop rotation had the highest OM values ranged from 2.62 to 3.39%. In the same direction, fields under crop rotations had significantly the higher average of CEC value (36.96 cmol$_c$ kg^{-1}) than fields with sugarcane monoculture (32.93 cmol$_c$ kg^{-1}) (Table 2). Whereas, soil reaction (pH), soil EC and SAR values showed a significant increase from sugarcane > crop rotation > uncultivated land. Fields under sugarcane monoculture system had higher pH, EC and SAR values ranged from 7.96 to 8.41, from 2.98 to 4.22 dS m^{-1} and from 7.75 to 11% while fields under crop rotation system had the lowest pH, EC and SAR values ranged from 7.64

to 7.92, 1.41 to 2.42 dS m^{-1} and from 4.51 to 5.86%, respectively (Table 2). Soil reaction (pH) and electrical conductivity (EC) are among the soil chemical properties that are highly affected by sugarcane monoculture management practice where they both tend to increase significantly with monoculture years and the intensity of agriculture. The electrical conductivity (soil EC) of the monocultured sugarcane fields at 0-30 cm soil depth was nearly fourfold (4.22 dS m^{-1}) higher than the reference virgin uncultivated soil (1.15 dS m^{-1} control) and twofold of crop rotation fields (2.42 dS m^{-1}).

From the chemical characteristics of the soil samples, it was observed that soil samples pH values were alkaline in nature with an average value of 7.85 at crop rotation and 8.18 at sugarcane fields, while the average values of pH at control soil samples were 7.45. In this study, sugarcane monoculture was found to affect soil EC and the exchangeable cations of Ca^{2+}, Mg^{2+}, K^{+}, and Na^{+} showing a general significant increase for sugarcane than from crop rotation fields. This implies that the sugarcane monoculture cropping practices resulted in augmentation of the soil salt contents increasing soil salinity. These results were anticipated as the adopted long-term surface irrigation practices with saline groundwater without drainage, intensive organic and inorganic fertilization and ash accrual from cane burning led to the development of soil salinity. In fact, the practice of irrigation in agriculture increases food production, but water quality used for irrigation, particularly saline waters, exposes soil and crop growth to potential ecological risks (da silva *et al*., 2013).

Sugarcane plants have a salinity threshold of 1.7 dS m^{-1} and are therefore a crop of moderate sensitivity for soil salts according to Maas and Hoffmam (1977). Lira, *et al*., (2018), stated that irrigation with saline water negatively predisposed all sugarcane growth quality parameters: leaf area, stem diameter, stem height, number of tillers and number of leaves, more significantly leaf area and stem diameter. In addition, irrigation with saline water linearly declined sugarcane yield and dry weight. In arid regions, excess sodium (Na^{+}) of irrigation water and soil is often a problem and usually leads to sodicity upsurges along with salinity. Sodium hazard is generally designated as sodium adsorption ratio (SAR%), which in specific refers to the exchangeable Na^{+} activity occurred in soil or water relative to the activities of the exchangeable Mg^{2+} and Ca^{2+}. Both Mg^{2+} and Ca^{2+} are common ions found in soils and water of arid regions and they have a greater charge density than Na^{+} and they usually incline to aggregate clay particles maintaining soil structure. As exchangeable sodium increases compared to Mg^{2+} and Ca^{2+}, clay dispersion can occur and disorder the physicochemical functions of the soil (Sparks, 2003).

Results of this research indicated that long-term sugarcane production not only had negative decline effects on OM, SOC and CEC but also has increased soil pH, soil EC and soil SAR with a gradual increase over years in these parameters reflecting an increase in soil salinity and a decline in soil fertility compared to soils under crop rotation cultivation systems. It was certainly due to the continuity of further intensification by farmers of all agronomical practices for sugarcane monoculture, specifically inorganic fertilization, excessive irrigation and tillage, with the objective of increasing yields regardless of soil quality decline. In the sugarcane monoculture system, intensive surface irrigation using groundwater is the major method of irrigation, this irrigation regime usually give rise to water logging and salinity problems under arid conditions. According to Sun *et al*., (2007) water logging can increase soil pH level through quick depletion of O_2 that leads to anaerobic conditions with concurrent reduction in Eh (redox potential). Dissimilar to these results, there was a decrease in the soil reaction (pH) in other sugarcane producing countries, for instance, Hartemink (1998), reported an 11% decline during 18 years monoculture of sugarcane in Papua New Guinea.

The average of soil organic matter (SOM) content of the sugarcane monocultured soils was 2.31% lower than the crop-rotation soils at 0 cm-30 cm depth. Thus, the SOM of the monoculture sugarcane fields was exhausted considerably suggesting that long-term sugarcane traditional monoculture practices have deteriorated the soil. Numerous findings from other long-term farming systems also showed a decrease in SOM and degradation of soil quality under monoculture system as compared to crop rotation or fallow sugarcane farming systems (Garside *et al*., 2005; Mohamed *et al*., 2019). In China, Liu *et al*., (2014), conveyed that during different cultivation periods of sugarcane (5-, 14- and 50-year), SOC losses were 17%, 28% and 55%, respectively. By contrast, Bramley *et al*., (2014) reported insignificant differences in SOC contents after 20 and 30 years of sugarcane monoculture. This in the latter case could be attributed to the adoption of recommended agronomic practices involving integrated management of nutrients and sugarcane trash canopy retention which have the potential to maintain and increase SOM contents and sugarcane yield and quality.

In sugarcane monoculture, soil deterioration was found to be one of the major contributors to low yields (Garside *et al*., 2005; Awe *et al*., 2020; Verma *et al*., 2020; Chandra *et al*., 2021). The diminutions in soil production capacity of a sugarcane field could be mainly attributed to long-term monoculture itself, uncontrolled heavy machineries, excessive tillage, pre- and post-harvest cane burning, intensive irrigation with inadequate drainage and excessive utilization of agrochemicals (Garside *et al*., 2005; Awe *et al*., 2020; Verma *et al*., 2020; Chandra *et al*., 2021; Marin *et al*., 2021). Likewise, the aforementioned practices have been adopted over the last fifty years in Abu-Qurqas district, El-Minia Governorate, Egypt which may lead to soil degradation and sugarcane yield decline. Results of this research confirmed that excessive tillage, intensive irrigation with insufficient drainage, excessive fertilization, lacking fallowing and burning of cane trashes are the major reasons for SOM deterioration during long-term conventional sugarcane monoculture practices under arid conditions. These traditional farming practices resulted in significant changes in soil physical, chemical and physicochemical characteristics with concurrent decline in sugarcane yield. Implementation of inappropriate agricultural practices in the production of the sugarcane belt area of Abu Qurqas played an important role in the intrinsic differences observed in the SOM contents under different crop production systems. For example, due to pre-and post-harvest burning of sugarcane residues, about 10 ton/ha of soil organic matter has been lost up at harvest versus 120 ton/ha sugarcane. In addition, excessive tillage might result in 10% decrease in SOC content in a four-month period (Gmach *et al*., 2020).

Effects of long-term sugarcane monoculture on some soil physicochemical properties.

Soil aggregate stability as functions of PAR and CROSS.

Effects of sugarcane monoculture on soil aggregate stability (SAS%) as a function of cation ratio of soil structural stability (CROSS) and potassium adsorption ratio (PAR) are shown in Table (3).

Table 3. Some soil physicochemical properties as affected by sugarcane monoculture.

Soil property	**control**	**Sugarcane Monoculture**					**Crop Rotation**				
		Descriptive Statistics					**Descriptive Statistics**				
		Average	**Max**	**Min**	**SD**	**C.V%**	**Average**	**Max**	**Min**	**SD**	**C.V%**
PAR	0.52	1.44	1.90	0.92	0.32	22.65	1.52	2.24	0.89	0.37	27.62
CROSS	8.21	9.91	11.90	8.60	1.15	11.66	7.04	8.21	6.10	0.55	7.81
MCRA	7.73	10.43	12.75	8.69	1.45	17.85	4.97	5.72	4.25	0.47	9.50
SAS %	92	81.6	88	68	5.56	6.82	90.4	92	88	1.24	1.37
SDR %	8	18.4	32	12	5.56	30.24	9.6	12	8	1.24	12.93
Na^+	16.6	22.06	30.1	18.1	3.93	28.00	13.7	17	11.6	1.41	10.31
Ca^{++}	6.2	6.77	8.2	6.2	0.51	7.55	8.02	10.1	7.1	0.82	10.26
Mg^{++}	4.4	5.18	7.2	4.4	0.69	13.45	6.63	9.3	5.8	0.90	13.67
K^+ (cmol$_c$ kg^{-1})	1.2	3.54	5.3	2.2	0.91	25.90	4.12	5.9	2.4	0.98	23.92
HCO_3	2.5	4.33	6	2.0	1.27	29.47	7.44	9.3	6.1	1.00	13.48
Cl^-	9.5	17.19	20.1	15.6	1.54	13.72	11.22	15.6	9.5	1.53	8.90
$So_4^=$	9.4	9.66	16.9	6.8	2.39	24.82	15.98	26.2	11.8	3.93	24.58

Compared to the uncultivated soil, these results showed that decreases in soil aggregate stability (SAS%) of sugarcane monoculture system was the most pronounced followed by that of crop rotation system. It is noticeable that soil aggregate stability (SAS%) significantly and sharply dropped from 92% in uncultivated soils to 68% at some sugarcane fields. Soil aggregate stability of sugarcane monoculture fields significantly decreased over years within a range of 88–68%, but gradually decreased from 92 to 88% in the case of rotational crops fields compared to the reference soil (92%). Cation ratio of structural stability (CROSS (mmolc L^{-1})$^{0.5}$) was applied to clarify whether increasing K^+ and Na^+ against Ca^{2+} and Mg^{2+} due to sugarcane monoculture agricultural practices will cause decreases or increases of soil aggregate stability (SAS%). Whereas, potassium adsorption ratio (PAR (mmolc L^{-1})$^{0.5}$) was used to denote K^+ existed in the soil aggregates due to sugarcane monoculture agricultural practices considering influence of Ca^{2+} and Mg^{2+}.

Potassium adsorption ratio (PAR) values of soils under sugarcane monoculture decreased significantly with a range of 0.92–1.90 (mmolc L^{-1})$^{0.5}$, followed by crop rotation values of 0.89–2.24 (mmolc L^{-1})$^{0.5}$, and for uncultivated soils of 0.52 (mmolc L^{-1})$^{0.5}$, (Table 3). The same trend was also found with CROSS, but the data range was higher because Na^+ and K^+ are included for calculating CROSS. Results of correlations between percentage of soil aggregate stability (SAS%) or soil dispersion ratio (SDR% = 100 - SAS) and PAR, SAR, CROSS or MCAR under sugarcane monoculture system or crop rotation are illustrated in figures (1) and (2) accompanied by the coefficient of determination (r^2). The correlations were significant in all events but negative in the case of soil dispersion ratio and positive in the case of soil aggregate stability. Under sugarcane monoculture system, the (r^2) values for correlation of SAS% or SDR% with PAR, SAR, CROSS, and MCAR were significantly higher than values under crop rotation system, indicating higher impacts of sugarcane monoculture system on soil aggregate stability and soil dispersion ratio. Rengasamy and Marchuk (2011) suggested a new index of soil structural and aggregate stability termed CROSS (Cation Ratio of Soil Structural Stability), to denote the effects of Na^+, K^+, Mg^{2+}, and Ca^{2+} on soil structural stability. In addition, CROSS is also used to demonstrate the dispersive powers of Na^+ and K^+ versus the aggregating powers of $Ca^{2+}$and Mg^{2+}, but its influence on different soils under different agricultural practices and climate and relevant soil structural properties needs to be also validated (Canisares *et al*., 2020).

Results showed that sugarcane agricultural practices decreased significantly soil aggregate stability, by decreasing PAR and increasing MCAR, CROSS and sodium adsorption ratio SAR compared to soils under crop rotation system. Soil aggregate stability decreased significantly with increasing Na^+ in soil solution compared to Ca and K in all sugarcane monoculture fields due to intensive irrigation with saline groundwater indicating that sugarcane monoculture had a negative influence on soil aggregate stability. Compared to sugarcane monoculture system, increasing PAR under crop rotation system caused higher soil aggregate stability due to double addition of potassium fertilizer and gypsum under crop rotation system implying that Ca^{2+} and K^+ are considered as flocculating catalytic agents for arid soils. These results revealed that sodium (Na^+) increased significantly in sugarcane monoculture fields compared to rotational crop fields, while significant decreases has occurred in Ca^{2+}, Mg^{2+}, and K^+.

Moncada *et al.* (2013), stated that a soil was considered unstable having less than 50% soil aggregate stability (SAS), intermediate from 50 to 70% SAS and stable more than 70% SAS. Therefore, the SAS of some soil samples under sugarcane monoculture were unstable, while the SAS of rotational crops fields were stable. Results of this research agreed with previous studies that sugarcane monoculture practices degraded soil structure, affecting multiples of soil processes and functions (Bunemann *et al*., 2018; Canisares *et al*., 2020). Soil aggregate stability serves as a central soil physical quality indicator for soils to function properly in an agroecosystem and the environment. One of the most widely used soil physical properties to determine soil structural stability and consistency to resist degradation through natural or agricultural activities is the soil aggregate stability (Phocharoen, *et al*., 2018).

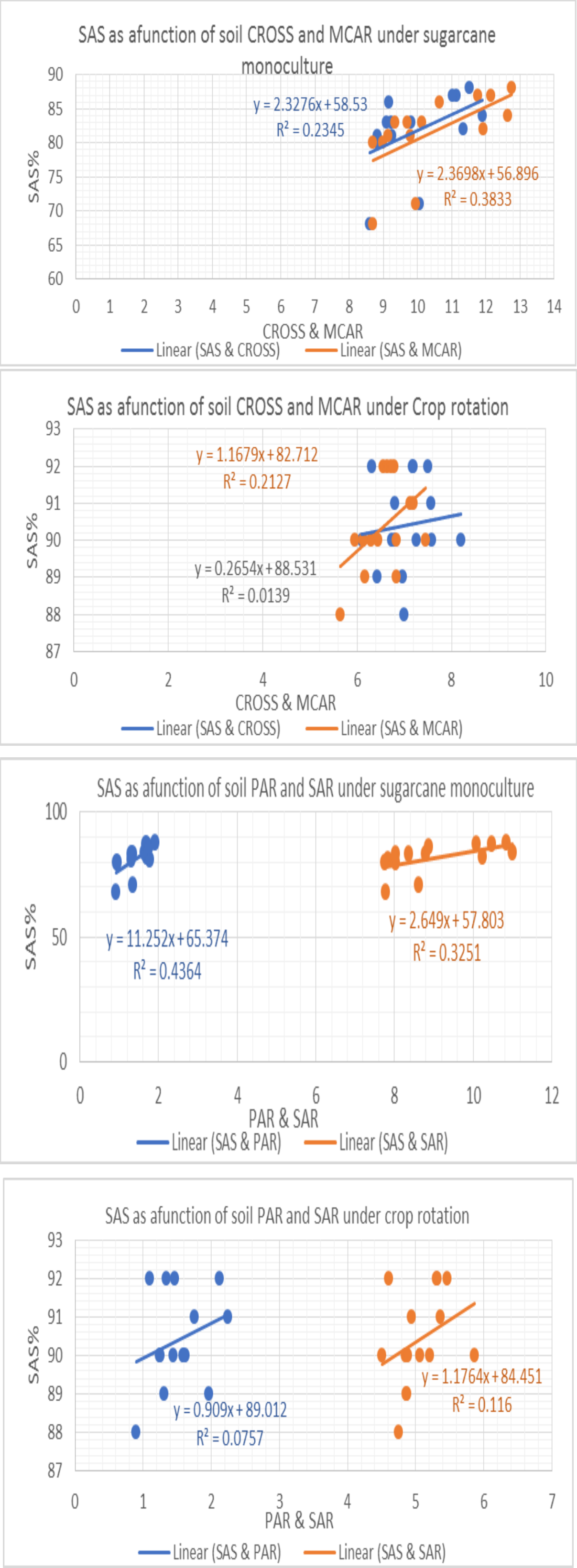


Figure 1. Soil aggregate stability (SAS %) as a function of CROSS, MCAR, PAR and SAR under sugarcane monoculture and crop rotation systems.

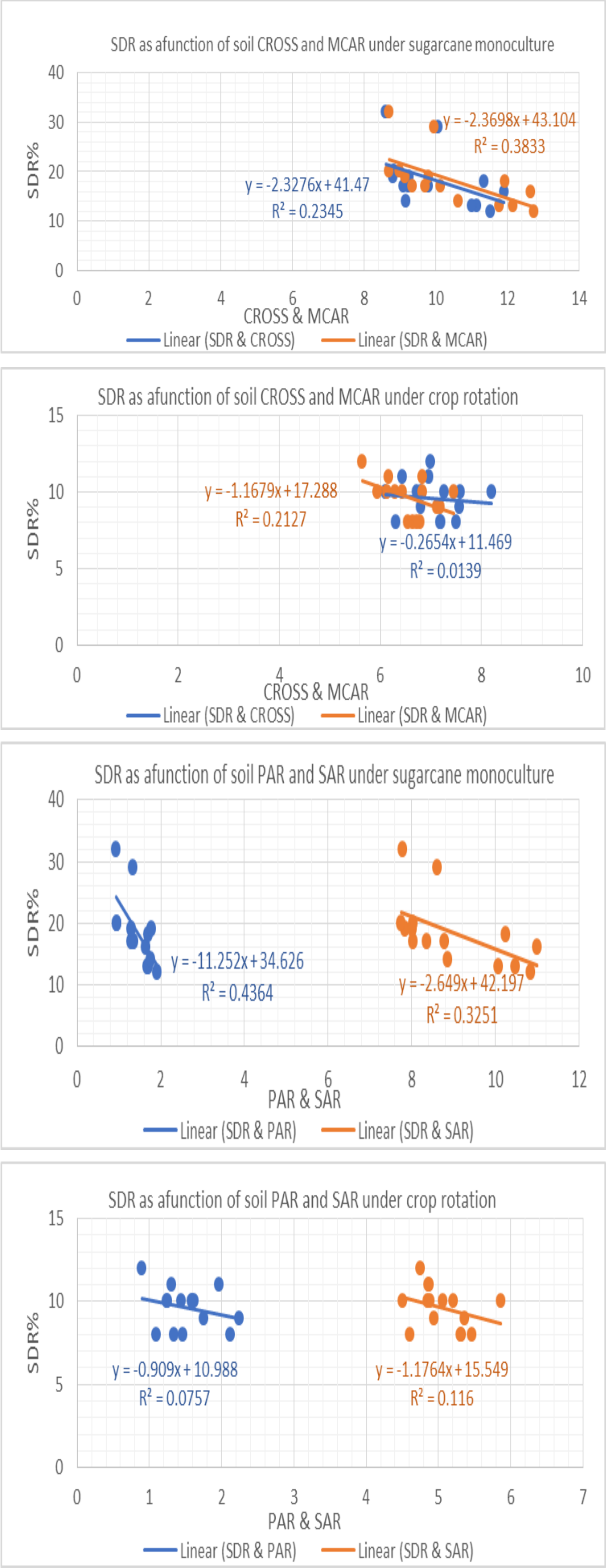


Figure 2. Soil dispersion ratio stability (SDR %) as a function of CROSS, MCAR, PAR and SAR under sugarcane monoculture and crop rotation systems.

Limited studies have engrossed in the effects of sugarcane monoculture on soil aggregate stability or collapse and relevant other soil physical properties. Since soil aggregates are established, soil provides organized pores matrix, these pores influence the fate and movement of air, water and essential nutrients for plant growth, and soil organic carbon retention, as well as soil degradation (Wang *et al*. 2016; Zhao *et al*. 2017; Phocharoen, *et al*., 2018). Electrolytes separated into cations and anions in soil solution are one of the most important inner factors that affect soil structural stability via aggregation of soil particles and anchoring individual sand, silt and clay soil particles into stabilized aggregates (De Lira *et al*., 2018; Phocharoen, *et al*.,2018; Singh *et al*., 2018). Sodium Na^+ had negative effects dissimilar to calcium Ca^{2+}, magnesium Mg^{2+} and potassium K^+ on soil penetrability by boosting clay dispersion, deforming soil structure, and ultimately decreasing soil hydraulic conductivity (Phocharoen, *et al*.,2018; Singh *et al*., 2018). The role of potassium (K^+) in the formation of soil aggregates and aggregate stability was studied compared to Ca^{2+} and Mg^{2+}, as the results indicated that K^+ boosted the formation and stabilization of soil macro-aggregates in the corresponding order of K > Ca > Mg and/or Ca > Mg > K (Phocharoen *et al*., 2018; Taleisnik and R. S. Lavado, 2021).

These results imply that decreasing CROSS by increased Na^+ compared to decreased K^+, Ca^{2+} and Mg^{2+} in soil solution due to long term sugarcane monoculture resulted in degrading soil aggregate stability. By contrast, these results indicate that increasing CROSS by increased K, Ca and Mg in soil solution due to crop rotation agricultural practices resulted in improving soil aggregate stability SAS and reducing clay dispersion. In addition, increased K^+ in a soil solution can overcome the influence of Ca^{2+} and Mg^{2+}, indicating a progressive PAR increase of soil aggregates, then eventually stimulated improvements in soil aggregate stability SAS (Canisares *et al*., 2020). Based on these results, soil aggregate stability as a function of PAR and CROSS indicating that increased K^+ in soil solution due to different agricultural systems is deemed as a clay flocculating agent like Ca^{2+} and Mg^{2+}, not a disbanding agent as Na^+, especially under arid conditions. Canisares *et al*., (2020), reported that K^+ can be considered as either an aggregation or dispersion promoter for clay behavior related to soil structural properties depending on soil pedological and chemical properties.

It has been recognized broadly that maintaining soil aggregates is crucial, particularly in arid regions where organic matter is scarce spoused with economic intensive crop production such as sugarcane monoculture. Appropriate management strategies for soil aggregate stability conservation must then count on handling the limiting factors controlling soil aggregate formation and stability. Finally, soil properties in the sugarcane monoculture production system were more affected from the viewpoint of crop production, compared with crop rotation system. Characteristics of the studied soils indicate a high risk of physical, chemical and physicochemical deterioration. Without implementing measures that control the decrease of soil organic matter, aggregate stability and the increase in soil pH and soil salinity for instance, the future degradation will increase.

CONCLUSIONS

The long-term traditional farming practices of sugarcane monoculture substantially degraded the major soil physical and chemical quality indicators i.e., decreased SOM, SOC, CEC, field capacity, aggregate stability and increased soil pH and soil salinity of the Egyptian sugarcane production belt along the Nile Valley in Upper Egypt. Accordingly, sugarcane monoculture induced to soil alkalinization and salinity, indicating that alluvial soils are presently of poor soil physical and chemical quality in the prime sugarcane producing region of Egypt. As the soils of the sugarcane production belt is mainly fertile alluvial soils, particularly, the decline in SOM content along with the increase in soil salinity and the excessive irrigation and fertilization in the sugarcane belt fields might play a role for the observed soil degradation and sugarcane yield decline. Therefore, the adoption of more sustainable sugarcane management practices is critical to preserve soil quality on the long run and to sustain sugarcane yield and quality in Upper Egypt. Finally, an extensive multidisciplinary recovery ecosystem should be further implemented in order to handle the problem of soil quality under sugarcane monoculture systems.

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مؤشرات جودة التربة الطمييه تحت تأثير الاستخدامات المختلفة للأراضي.

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يعد تدهور التربة وانخفاض إنتاجيه المحاصيل من العوامل الرئيسية التي تؤثر على الاستدامة البيئية للزراعة الأحادية لقصب السكر. تم إجراء هذا البحث للكشف عن التغيرات في مؤشرات جودة التربة الفيزيائية والكيميائية الفيزوكيميائية المرتبطة بالزراعة الأحادية لقصب السكر على المدى الطويل والمروي بالغمر بالمياه الجوفية. أدى الاستزراع الأحادي لقصب السكر إلى تأثير شديد على بعض المؤشرات الفيزيائية لجودة التربة حيث أدت إلى زيادة الكثافة الظاهرية للتربة وانخفاض محتوى الطين، وانخفاض التجمعات الأرضية الثابتة والمحتوى المائي عند السعة الحقلية، مما تسبب في انخفاض مسامية التربة وانخفاض خصوبة التربة. كما تم تسجيل تأثيرات كبيرة على بعض المؤشرات الكيميائية الخاصة بجودة التربة، مثل انخفاض محتوى المادة العضوية في التربة وزيادة درجة حموضة التربة وزيادة ملوحة التربة. الأراضي تحت الزراعة الأحادية لقصب السكر المروى بالغمر على المدى الطويل كانت لها قيم OM منخفضة تتراوح من 2.09 إلى 2.61٪ بينما المناطق تحت نظام الدورة الزراعية لديها أعلى قيم OM تراوحت من 2.62 إلى 3.39٪. كانت الأراضي الخاضعة لنظام الزراعة الأحادية لقصب السكر ذات قيم pH وEC وSAR تتراوح من 7.96 إلى 8.41، من 2.98 إلى 4.22 d Sm^{-1} ومن 7.75 إلى 11٪، بينما كانت الحقول الخاضعة لنظام تناوب المحاصيل لديها أدنى قيم pH وEC وSAR تراوحت من 7.64 إلى 7.92 ومن 1.41 إلى 2.42 d Sm^{-1} ومن 4.51 إلى 5.86٪ على التوالي. ومن هذه النتائج يمكن استنتاج أن الزراعة الأحادية لقصب السكر على المدى الطويل قد أدت إلى تدهور كبير في الخصائص الفيزيائية والكيميائية للتربة مما يشير إلى الحاجة الملحة إلى ممارسات أكثر استدامة للحفاظ على جودة التربة.