TEST Engineering & Management

May – June 2020
ISSN: 0193-4120 Page No. 1344 - 1350

Salinity, Sodicity, and Exchangeable Cations of Soils from an Arid Region at Misurata Libya: Treated Wastewater Irrigation Impacts

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Article Info
Volume 83
Page Number: 1344 - 1350
Publication Issue:
May - June 2020

Article History
***Article Received**: 11August 2019*
***Revised**: 18November 2019*
***Accepted**: 23January 2020*
***Publication**:10 May2020*

Abstract:

This study explores the effects of treated wastewater (TWW) irrigation on soil salinity, sodicity, and cation composition. The research also included the association of some soil parameters. Soil samples taken from three horizons (Ap, B, and C) of six TWW-irrigated profiles (29 years of TWW-irrigation) and six other profiles (A, B, and C) from adjacent non-irrigated areas (dry-control). The characterization of the soil has shown that soils are slightly alkaline and sandy textured. The results also demonstrate a significantly higher sodium adsorption ratio (SAR), salinity (EC), and exchangeable sodium percent (ESP) of the TWW-irrigation profiles in comparison with control profiles. For exchangeable-Ca, the effect of TWW-irrigation on soil cations was most evident where exchangeable-Ca ranged 1.8 to 2.7 times the exchangeable-Ca in non-irrigated areas (dry-control). Exchangeable cations with a clay% and EC with a Cl content significantly correlated. The EC, SAR, pH, and ESP were both below the limits and had no sodicity or salinity issues in the TWW irrigation areas of Misurata.
Keywords: *Irrigation, Treated wastewater, Salinity, Sodicity.*

I. INTRODUCTION

Arid conditions prevail in most regions of Libya, where water resource and its quality are essential in agricultural development. The country is facing growing serious water inadequacy issues as a result of the quality and the amount depletion of groundwater resources, the absence of surface water, with more regular and more extended intervals of drought and demand imbalances. In this sense,Qadir & Scott[1] considered the reclaiming and reuse of wastewater as an alternate sustainable water and nutrients source for crop production. The growing need to use TWW in agriculture, cultivation has made agronomists face real problems that are difficult to avoid, including potential deterioration in the structure and stability of soils. Higher salinity and sodicity levels may lead to a likely risk of adverse changes in soil structure and hydraulic properties following TWW irrigation. However, increased soil salinity and sodicity, which occur naturally in arid climates, are significant negatives. Salinization of soil defined as the accumulation of soluble Na, Ca, and Mg in the soil to the degree that soil fertility severely degraded[2]. Therefore, the rise in salty soil amounts is primarily due to brackish water irrigation. Na^+ is highly present in wastewater[3], and the rise in soil exchangeable Na^+ contributes to irrigation problems with wastewater. The soil sodification process allows the disaggregation of the clay fraction by replacing the Na+ ions with the interlayer cation[4]. The Na^+ ion's mono-valences and large hydration spheres also promote the dispersal of clay[5]. They may cause a reduction of hydraulic conductivity[6] hence soil permeability, drainage, and aeration[7]. High levels of Na^+ also interact with Ca^{2+} and modify the soil ion-exchange characterizations[8]. This research explores the impact of TWW on cation composition, salinity, and sodicity by analyzing differences in soil profiles between irrigated soils and non-irrigated soils, in order to demonstrate the long-term effects of soil desalination and sodification and to propose suitable solutions for better soil conditions.

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II. MATERIALS AND METHODS

A. The Research Site Overview

The study area located in the southern region of Misurata Province, Libya. The agriculture field of interest has become part of the municipal Misurata scheme for the growing of feed crops (barley, sorghum, oats, alfalfa) from a 200-hectare area near the wastewater treatment facility since 1989 using TWW pivot sprinkler irrigation. (Figure II.1). The sewage network works through secondary treatment, with an estimated capacity of 24,000 m3/day. The most inflow is domestic wastewater, with a small share of business wastes. In this area, the Mediterranean climate prevails with some semi-desert elements.Annual temperature ranging from 13.51 °C to 28.22 °C and average annual precipitation of 246.9 mm/year, which classifies this region as an arid region (Figure II.2). The region's basement rock consists of Tertiary and Quaternary sediments. These two sediments are trying to separate because they are mixing and inter-grown, particularly the case with sand, which has been drifted by wind and deposited in various places.

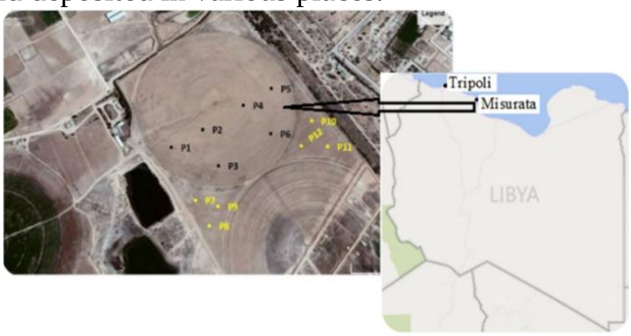

Figure II.1. Location and sampling points in the study area.

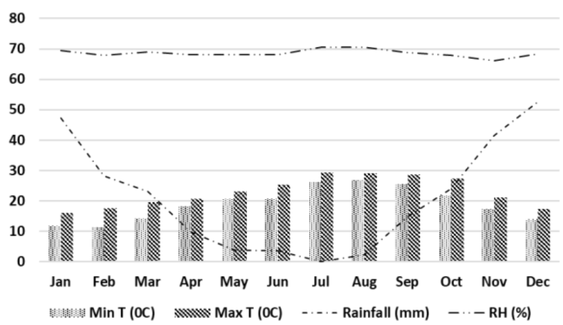

Figure II.2. The study region climatic features of the over the period 2000 -2017 recorded at Misurata Metrological station.

The Quaternary sediments consist mostly of carbonate aeolian sand, which lies over Tertiary sediments consist of limestone, sandstone, marl, and sand [9].

B. 2.2. Fieldwork and Overall Approach

Soil sampling was performed in 2017 using a free survey method covering the target sampling of TWW irrigation soils for 29 years and one adjacent site outside the irrigation boundary of the control-dry land condition where irrigation had never been undertaken. (Figure II.1). The two sites are comparable regarding parent material and topography. Accordingly, on each site, six soil profiles of about 1 m × 2 m have been excavated to a depth of 1.50 m. The soil depth investigated with an auger up to three meters, and no signs of a hardpan or water table identified. The soil profiles sampled by genetic horizons: TWW irrigated area (Ap, B, C) and control-dry area (A, B, C) after determining the dominant soil series according to the U.S. Soil Taxonomy System [12]. Three replicates were taken from each horizon to produce a representative soil sample. The soils studied developed under the Mediterranean climate, characterized by a thermic thermal regime and xeric moisture regime. Aridisols suborder was recognized in the study area, as; Calcids. Calcids suborder included great group, namely, Haplocalcids, sub-great groups, namely, xeric Haplocalcids and family, namely: Sandy, siliceous. The calcic horizons are mainly pedogenic because their dispersion is parallel to the ground surface[10]. The carbonate accumulations in the calcic horizon are different from the continuous coating in soft cemented material, which tends to be few in typical carbonate nodules.

C. Soil Analysis

The soil parameters were analyzed at the Misurata Iron and Steel Factory Laboratory, as stated by the standard method of the International Center for Agricultural Research in Dry Areas (ICARDA),[11]. Each sample was characterized for $CaCO_3$% by the volumetric calcimeter method, soil texture by the Bouyoucos hydrometer method, total organic matter calculated as OM (%) = 1. 724 x OC (%), exchangeable cations extracted by ammonium acetate and cation exchange capacity (CEC) extracted by sodium acetate. The results of the latter

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two analyses then used to calculate soil ESP using exchangeable Na and CEC values (meq/100g) (Eq. 1) [12].

$$ESP = \frac{Na}{CEC} \times 100 \qquad (1)$$

Table II.1. Statistical summary of the ionic composition of Misurata's TWW (twelve months average, standard deviation or a range; data from[13]

Constituents	Units	Mean	Max	Min	St.Dev.
EC	µS/cm	1297.04	1576.21	980	147.66
pH	-	7.7	8.14	7.25	0.31
Ca2+	mg/L	101.11	125.13	71.32	15.63
Mg2+	mg/L	24.95	33.45	12.3	5.95
Na+	mg/L	74.71	97.29	52.54	14.19
K+	mg/L	24.54	40.26	10.91	9.29
HCO3-	mg/L	427.02	499.52	229.98	71.12
CO32-	mg/L	1.6	3.7	0.25	1.29
SO42-	mg/L	104.19	152.15	48.38	30.01
Cl-	mg/L	142.32	183.91	110.5	22.45
BOD	mg/L	39.71	53.5	24.48	8.19
COD	mg/L	9.11	12.55	6.02	1.92
SAR	meq/L	1.72	2.08	1.27	0.25
SSP	%	35.34	41.26	29.45	3.85
RSC	meq/L	-0.04	1.14	-1.52	0.96
MAR	%	28.69	39.1	22.14	4.45

Soil reaction (pH), salinity (EC), water-soluble bases cations, and anions determined in the soil saturated paste extract of each soil sample. The results then used to calculate the SAR based on [Na^+], [Ca^{2+}], and [Mg^{2+}] in meq/L (Eq. 2) [12].

$$SAR = \frac{Na}{\frac{\sqrt{Ca+Mg}}{2}} \qquad (2)$$

The concentration measured is considered as the concentration of the corresponding layer for each sample obtained in different soil depths by calculating the weighted average concentration.

A. Irrigation water (TWW) characteristics

Evidence from Khalifa A. & Aydin[13]suggests that the TWW used for irrigation had a slightly alkaline quality. The EC values suggested a marginally to moderate (permissible) limit for the irrigation of this TWW. The SAR values ranged from 1.27 to 2.08 meq / L with a mean value of 1.72 meq / L. Both TWW samples fell within the "excellent SAR" water level. EC and SAR plotted on the salinity diagram revealed that all TWW samples had a high salinity and low sodium exchange risk (C3-S1). While the Piper chart revealed that most of the TWW samples (about 83.3 percent) fell into the diamond-framed calcium bicarbonate region, suggesting the Prevalence of the Calcium Bicarbonate Water Type (Table II.1).

B. Statistical analysis

Mean values obtained from replicates of measurements comparedusing One-way ANOVA with Tukey HSD post hoc test (IBM SPSS Statistics 23 Program). Data sets were first analyzed for normality by applying Shapiro-Wilk's test and the homogeneity of the variance (Levene's tests) $p > 0.05$. In the case of failure to comply with the terms of the normal distribution, we used the Games-Howell post hoc test.

III. RESULTS AND DISCUSSION

A. Vertical patterns in soil salinity (EC) and sodicity

The salinity of the saturated extract, as measured by electrical conductivity for the different soil horizons of the two areas, is given in Table III.2. There was a substantial increase in EC in the TWW-irrigated area over the non-irrigated area in the present study. The highest EC has obtained in the C-horizon and Ap (plow-layer) horizon followed by B horizon with an average of 0.72, 0.60, and 0.49ds/m, respectively, in the TWW-irrigated area. Continued long-term TWW-irrigation can result in excessive salinization of the soil. According to [14], when precipitation is less than 250 mm, there is a high risk of soil salinization. Nevertheless, EC values remained much below the salinity threshold of 4000 µs/cm [12]after 29 years of TWW-irrigation.Studied soil looks unlikely to maintain adequate amounts of salts to prove harmful to soil and poisonous to crops after 29 years of irrigation using TWW. Most likely, it is the coarse texture of the soil and the in-depth soil profile (> 2.5 meters), which have made it possible to pour a bunch of salt beyond the sampling depth during irrigation seasons.The values and distribution pattern of electrical conductivity between the horizons of non-irrigated pedons indicate little leaching, eluviation, and illuviation have taken place. The texture of the soil influences the movement of soil water, water retention capacity soil hydraulic properties, and the ability of soil particles to adsorb or desorb chemical ions [15], [16]. As a result, under standard irrigation practices, low CEC sandy textured soils, such as the examined soil (Table II.1), can naturally flush dissolved salts through the root zone and can withstand higher salinity irrigation water. Differently, the major problem in arid and semi-arid zones as the evaporation rate would be higher, and accumulated salt is not flushed regularly from the soil profile by rainfall [19]. In the current case, as crops only abstract small quantities of salt [20], the irregular vertical distribution of dissolved salts and exchanged cations in soil profiles may be directly linked to the water movements, which are directly ruled by the frequency of irrigation, rainfalls, and evaporation.

Table III.2. Soil texture, salinity (EC), CaCO3%, and exchange capacity (CEC) in the soil samples studied.

	Soil horizon	EC dS/m	Clay %	Sand	CaCO3	CEC meq/100mg
Control-Dry area	A	0.17	1.49	92.57	19.53	2.54
	B	0.29	0.83	91.30	29.06	1.66
	C	0.31	0.42	93.04	22.45	0.64
TWW-Irrigated area	Ap	0.60	2.64	94.07	6.56	4.45
	B	0.49	3.87	89.59	13.16	4.58
	C	0.72	1.67	88.53	28.06	1.65

The rate of irrigation during the crop season (700 mm/year) combined with a precipitation rate of 246.9 mm/year (Figure II.2) seems to be not regular enough to prevent the rise of salt from the deeper layers. Thus, the overall trend was not unexpected.

B. Vertical patterns in soil SAR soluble base cations and anions

The concentration ofsoluble cations except potassium follows the trend of EC allocation along with the soil pedon depth in both irrigated and non-irrigated fields (Figure III.2). With the introduction of TWW-irrigation, trends of the cation concentration have undergone a marked change. Sodium maintained its most plentiful cation in the three horizons of the TWW-irrigated area followed by Ca^{2+}, Mg^{2+} and K^+ were the least abundant cation. Na increased quite substantially with nearly 6.50-fold in the A-horizons, decreased by 0.98-fold in B and increased by 1.49-fold in the C horizons, of the irrigated area, over the non-irrigated equivalents. The source of such a high sodium level can be attributed to its displacement by excess Ca^{2+} from the TWW used in irrigation (Table II.1) and weathering of Na-plagioclase feldspar (albite) [21]. Within the profile, the concentration of Na, Ca^{2+}, and Mg^{2+}maximized at the surface (Ap) and (C). K^+ alone concentrated markedly at the surface A-horizon after that declined with depth. However,TWW-irrigation reflects the relative amounts of the cation added with TWW-irrigation.The dominant salt types in the irrigated and non-irrigated areas were not comparable. The dominant anions in soil from the irrigated area were Cl- followed by HCO_3^-, and SO_4^{2-} while the dominant anions in soil from the non-irrigated areas were HCO_3^- followed by Cl^-, and SO_4^{2-} in decreasing order (Figure III.2). Thus, it was possible to suggest that there was more sodium chloride (NaCl) salt concentration and calcium bicarbonate ($CaHCO_3$) with the least expected salt type of potassium sulfate (K_2SO_4)TWW-irrigated area.Sodium containing salt dominance in the irrigated area can be due to the relatively high concentration of Na^+, Ca^{2+}, and HCO_3^- ions in irrigation water, and the concentration of HCO_3^- ions was high enough to cause precipitation of Ca^{2+} and Mg^{2+} to facilitate Na^+ dominance in the soil.According to the correlation coefficient, EC showed a significantpositive-

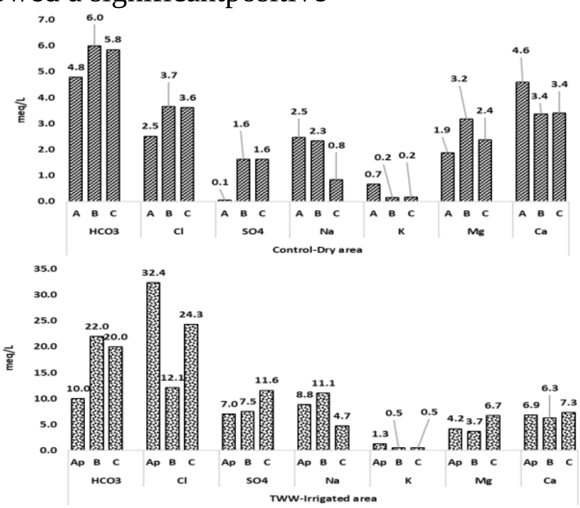

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Figure III.1. Changes in soil soluble base cations and anions with depth in dry-control or TWW- irrigated areas.

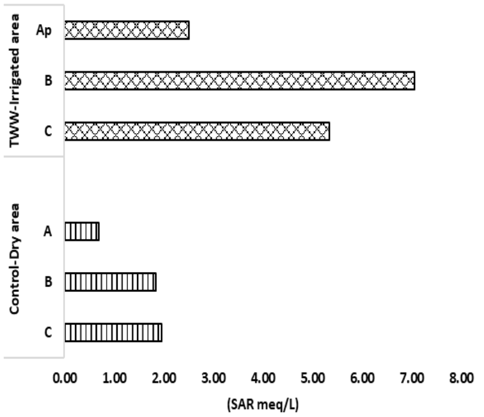

Figure III.2. Changes in soil SAR (meq/L) with depth in dry-control or TWW- irrigated areas.

correlation with Cl^- (R^2 = 0.64). Weak positive correlations also obtained for EC versus clay% (R^2 = 0.16), which clearly shows that an increase in fine soil fraction does not correspond to an increase in soil salinity (Figure III.3).The SAR values were significantly higher in all TWW-irrigated pedons, compared with the control. Individual pedons irrigated with TWW show the highest SAR values in the B-horizon, (mean value = 7.05meq/L), followed by Ap-horizon (mean value = 5.34meq/L) and the lowest values in the C-horizon (mean value = 3.841meq/L). The SAR distribution with depth reflected the relative concentration of soluble Na^+, Ca^{2+}, and Mg^{2+} in the soils (Figure III.2) as the TWW added to the soil from the surface, sodium expected to be higher in the Ap-horizon as it replaces other cations. However, the distribution pattern of the SAR could be due to the SAR of the Ap-horizon will increase until it reaches that of the irrigation water. With further water addition, the SAR of the B-horizon will increase to that of the A-horizon, and at the same time, the SAR of the lower horizons will increase.

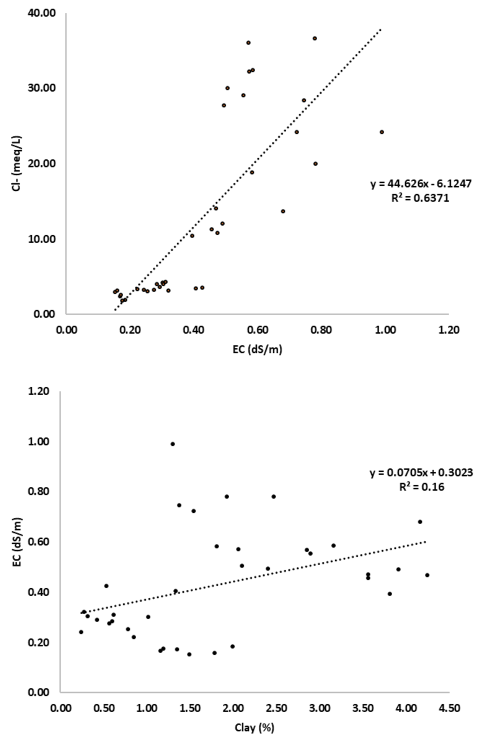

Figure III.3. Soil clay% vs. soil EC and soil EC vs. Cl (meq/L).

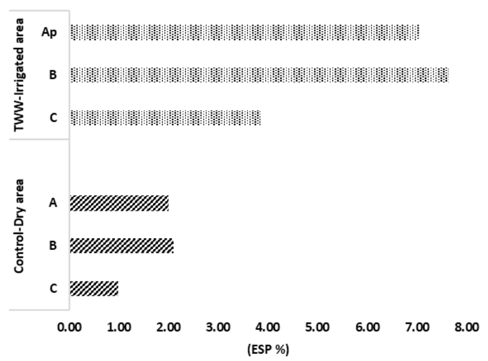

Figure III.6. Changes in soil ESP% with depth in dry-control or TWW- irrigated areas.

The equilibrium can be reached when the SAR of the soil is equal to the SAR of irrigation-water. However, when irrigation water is high in bicarbonates, precipitation of $CaCO_3$ may result in a higher soil SAR than that of irrigation water. Moreover, organic matter present in the wastewater tends to form a complex fraction with soluble Ca^{2+} and Mg^{2+} ions, thereby causing an increase in the SAR value of the water and subsequently the SAR of the soil solution [22].

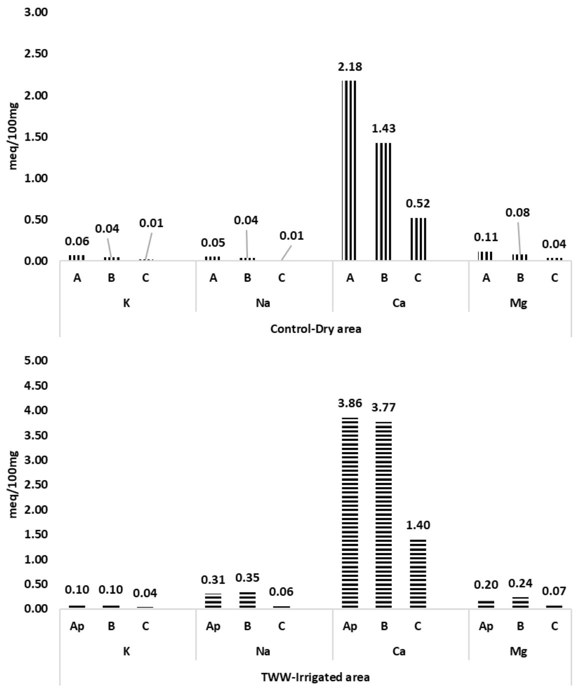

Figure III.7. Changes in exchangeable soil cations with depth in dry-control or TWW- irrigated areas.

According to the limit set by the U.S. Salinity Laboratory Staff [12], if the electrical conductivity of the saturation extract (EC) at 25°C is >4 dS/m, the soil is saline. If the ESP >15 (or SAR >13), the soil is sodic. Though, these soils fall within the soil class grade non-saline non-sodic soils (pH < 8.5, SAR < 13, ESP< 15 and EC < 4 dS/m). SAR values remained below the sodicity and salinity threshold and did not have serious problems after 29 years of TWW-irrigation, perhaps as a result of their coarse texture.

C. Vertical patterns in soil ESP and exchangeable cations

Figure III.4 highlights the results of soil ESP changes as a function of TWW-irrigation. The ESP profiles differed between the soils studied. The ESP of the soil samples taken from the TWW-irrigated area was significantly higher than that of the ESP of the samples from the non-irrigated control area. The impact of TWW-irrigation on the ESP relied on the clay% of both the TWW-irrigated and non-irrigated (Table III.2). The TWW-irrigated area had higher concentrations of all exchangeable cations compared with the non-irrigated control area (Figure III.5). Exchangeable Mg2+, Ca2+, Na+, and K+ correlated strongly with the soil clay fraction (R^2 = 0.76), (R^2 = 0.77), (R^2 = 0.73), and (R^2 = 0.72) respectively suggesting that their concentrations on soil exchange sites primarily controlled by the presence of containing clays that mainly originated from TWW-irrigation add and cultivation practices (Figure III.8). Eventually, due to the accumulation of organic matter and cation retention at exchange sites, soil EC can extend over time.

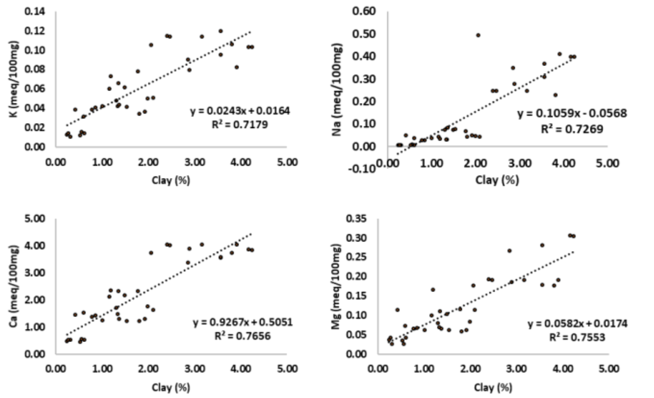

Figure III.9. Soil clay content vs.exchangeable soil cations (meq/100mg of soil)

The use of the TWW from Misurata for irrigation ultimately calls for control and surveillance action plans to avoid soil salination and/or sodification.

ACKNOWLEDGMENTS

The authors are very much thankful to the Libyan Ministry of Higher Education and Scientific Research for financial help in the form of academic scholarship. We also appreciate the help and facilities received by employees of the Misurata Iron and Steel Factory Laboratory.

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