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Assessment of the Quality of Salt-Affected Soils After Irrigation and Cultivation in Semi-arid Condition

Salar Rezapour[1] · E. Kalashypour[1] · F. Asadzadeh[1]

Abstract This study investigates morphological, physicochemical properties and clay mineralogy of four soil types belonging to salt-affected soils after converting into cropland. The data showed that strong platy to the medium prismatic structure of salt-affected soils was replaced by the fine angular blocky structure in cropland mainly as a result of the improvement in organic matter caused by agricultural practices and wetting–drying cycle accelerated by irrigation. After cultivation, two decreasing and increasing trends were observed in clay content (a drop of 17–51%) and sand (a rise of 8–96%), respectively. There was a remarked depletion in the values of soil pH (0.17–0.78 unit), calcium carbonate equivalent (8–30%), EC (50–82%), SAR (60–85%), exchangeable Na (53–77%), and ESP (46–65%) with cultivation, whereas the amounts of organic carbon (13–130%), total N (27–157%), and exchangeable Ca and Mg (20–60%) were increased after cultivation, indicating the improvement in the soil chemical indicators when converting salt-affected soils to cropland. Soil erodibility factor (K-factor), evaluated based on some physicochemical properties, revealed that 75% of the soils had a decreasing pattern in the K-factor and 25% had an increasing pattern after cultivation. The significant change was not observed in the XRD patterns of the clay fraction by cultivation. Overall, it can

conclude that continuous tillage and irrigation-cropping can be a useful method for quality restoration of salt-affected soils in the region.

Keywords Salt-affected soil · Soil quality · Soil improvement · Irrigation and cultivation · Semi-arid condition

Introduction

Soil is the most important resource in the earth system that contributes to the functioning of the planet as control and manages the cycles of water, biota, and minerals. Human abuse of the soil resources resulted in the land degradation due to the soil erosion, soil organic matter depletion, soil structure degradation, pollution, forest fires or deforestations (Brady and Weil 1999; Rezapour and Samadi 2012; Ahmad et al. 2016). Among these causes, salinization and alkalization are one of the worse problems that is reducing the soil productivity and needs more research and attention.

Salt-affected soils are characterized either by (i) the presence of excess levels of soluble salts(saline soils) and/or (ii) high values of sodium (Na^+) in the soil solution or on the cation exchange site (sodic soils) and/or (iii) high amounts of both soluble salts and sodium ions (saline-sodic soils). These soils exist in more than 100 countries and cover about 10^9 ha (approximately 10% of the total land surface of the globe), of which nearly 62% are saline-sodic or sodic (FAO 2000; Meena et al. 2017). Salt-affected soils in Iran, located in an arid and semi-arid region, are characterized by various degrees of salinity and alkalinity on a range of landscape, involving irrigated lands, dry farming areas and rangeland (Qadir et al. 2008b). Such soils are categorized as saline soils, sodic soils, saline alluvial soils,

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salt marsh soils, desert soils and their various combinations (Moghaddam and Koocheki 2004) and are found mainly in the central plateau, the southern coastal plains and in the northwestern parts of the country. The estimated of salt-affected soils vary widely from Iran due to (1) the different classification criteria and survey models used by various agencies and (2) the changes in the area under salt-affected soils within the irrigation commands. However, according to the data extracted from the soil map of Iran, slightly and moderately salt-affected soil cover about 25.5 million ha (a value that is almost 15.5% of the surface area of Iran) while soils having high salinity levels occupy 8.5 million ha [(a value that is almost 5.2% of the surface area of Iran) (FAO 2000)].

Recent trends suggest that the use of salt-affected soils for crop production systems, as a result of worlds expanding population, will increase to the foreseeable future (Qadir and Oster 2002; Qadir et al. 2008a) that may result in some unwanted effects on soil quality. Consistent with this, depending on external stimuli and internal change in soil processes or the internal physicochemical response to environmental forcing factors and anthropogenic activities, both positive and negative effects can highlight in some soil attributes. Such changes, in turn, have a direct impact on the activities of plant roots and soil microorganisms, and ultimately on crop growth and yield (Mengel and Kirkby 2001; Chakraborty et al. 2016). Slaking, swelling, dispersion of clay, removal of organic carbon, changes into soil pH and in the proportion of certain cations and anions present in the soil solution and on the exchange sites can be as the major aspects faced by soil after the conversion of salt-affected lands into cropland. In India, Srivastava et al. (2016) found that agricultural practices improve bulk density, total organic C, alkaline phosphatase, β-glucosidase, dehydrogenase and cellulase activities of salt-affected soils. Acosta et al. (2011) advocated that the practices of cultivation are sustainable over the time for salt-affected soils regarding the content of organic carbon, nitrate, and CEC; however, the system of irrigation with low-quality water creates an increased salinity load to the soil and consequently leads to land degradation.

Worldwide, some good work (mainly under laboratory conditions) has been done on the effects of agrochemicals, organic manures, elemental sulfur, calcite, gypsum, and organic matter content on the response of soil chemical attributes to salinity and sodicity (Rezapour 2014a, b; Singh et al. 2016; Srivastava et al. 2016). However, research work on salinity and sodicity-related soil quality issues have received less attention particular in the different soil types under long-term irrigation- cultivation practices. On the other land, salt-affected soils cover a large proportion of the world's arable land which varies from one region to another; therefore, there is a need to design studies to specifically address research related to such aspects (Qadir et al. 2008a). Therefore, the present study was carried out with the following objectives: (i) to assess changes in the combination of morphological, mineralogical, and physicochemical characteristics of salt-affected lands as affected by farming operations (ii) to highlight the most sensitive the quality attributes of salt-affected soils after converting to irrigated cropland, and (iii) analyses the impacts of irrigation and cultivation on the soil erodibility factor (K-factor) of salt-affected soils.

Materials and Methods

Site Characterization and Soil Sampling

The study was conducted in the Urmia region, the catchment of the Urmia lake, located in the eastern part of the Urmia city from $37°23'8°$ to $37°32'26°$N and $45°15'44°$ to $45°15'59°$E in the western-Azerbaijan province, northwest of Iran (Fig. 1). It has a level to nearly level topography (slope of 0–2%), where the groundwater table is greater than in adjacent areas. The geology of the region is mainly occupied by the alluvium and recent deposits belonging to the late Quaternary period (10000 BP). The mean annual precipitation of the region is less than 350 mm, leading to the existence of a semi-arid climate. The soil moisture regime is xeric and the temperature regime is mesic.

Prior to 1985s, the area has been used as wildlife. The farming history of the soils was determined by interviews with local farmers and landowners. The agricultural practices, including land preparation for cropping along with the use of composted manure, started about 20 years ago. A flood-irrigation system was carried to reduce salinity levels in the root zone before any agricultural practices during this 2 years. Irrigation water has received mainly from two local rivers, named Shhrchay and Barandozchay and is classified as good quality according to the recommended criteria (Ayers and Westcot 1994). The water of acceptable quality has a pH value of 5.5–7.5; ECiw fluctuates between 0.7 and 0.9 dS m^{-1} with a sodium absorption ratio (SAR) below 1.0 (Table 1). Agricultural practices are intensified with high water, plowing at different depths to open up the hard soils, and fertilizer inputs [mainly manure, mineral N (as urea) and P (as di-ammonium phosphate and super phosphate). Cropping was started by growing forage plants such as alfalfa (Medicago sativa L.) for 5 years, followed by growing salt-tolerant plants [such as barley (Hordeum vulgare)] in rotation with follow and alfalfa. In the second phase, cropping is continued by growing salt-tolerant plants in rotation with industrial plants mainly sugar beet (Beta vulgaris subsp.)
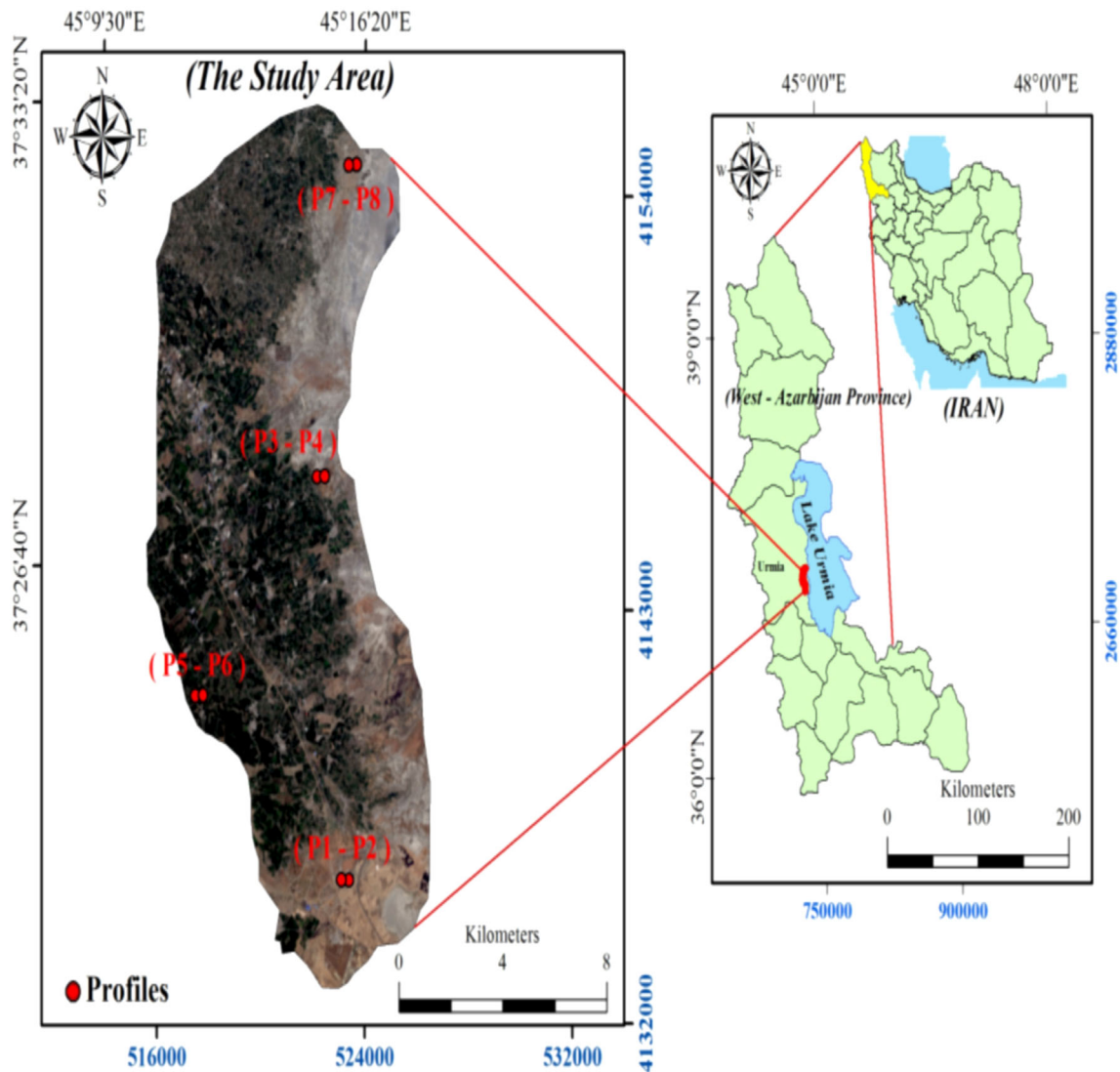
Fig. 1 Location of soil profile sites in the region (P1, P3, P5, and P7 for the cultivated soils and P2, P4, P6, and P8 for the adjacent uncultivated land)

and wheat (*Triticum aestivum* L.). In general, the main crop cultivated in the area include wheat and barley (a growing period about 232 days from October to June), alfalfa (a growing period about 240 days from April to November), and sugar beet (a growing period about 189 days from April to September). On average, the values of water applied for the irrigation of wheat and barley were about 3500 m³ ha⁻¹ and alfalfa and sugar beet were irrigated at 3900 and 4750 m³ ha⁻¹, respectively.

For the purposes of this study, two adjacent sites with relatively similar properties (soil type, parent materials, and slope) were chosen including (a) cultivated soil under rotation cropping as sugar beet, barley, maize, and (b) nearby uncultivated land as the control. The uncultivated land is covered by halophilous vegetation dominated by *Salsola kali*, *Salicornia europaea*, and *Atriplex*

verrucifera. A total of 40 composite soil samples (cultivated soil and adjacent uncultivated land) belonging to 4 series and 8 pedons (two pedons into each series soil involving 4 pedons in the cultivated soils and 4 pedons in the adjacent uncultivated soils) were taken at 0–30 cm depths. The sampling sites were selected from previous regional soil surveys. At each sampling point (0–30 cm), eight individual sub-samples were collected (using a stainless steel spade) within a radius of 10 m of a central point (surface horizon each profile). Sub-samples were mixed to achieve a composite soil sample for each sampling site and analyzed with five replications. In each soil series, cultivated and adjacent uncultivated soil was selected within a distance of 50 m. The adjacent uncultivated soil, indeed, is the initial values each soil attributes before 1985. The examined soils are developed mainly on

Table 1 Selected chemical composition of the irrigation water applied for the cropped soils

River	pH	EC dS m^{-1}	TDS mg l^{-1}	SAR	Na$^+$/Cations
Shhrchay	7.1 ± 0.21	0.3 ± 0.02	166 ± 28	0.04 ± 0.002	0.05
Barandozchay	7.6 ± 0.18	0.5 ± 0.04	320 ± 35	0.08 ± 0.005	0.07
Mean	7.4 ± 0.22	0.4 ± 0.02	243 ± 31	0.06 ± 0.003	0.06
River	Ca^{+2} meq l^{-1}	Mg^{+2}	Na$^+$	K$^+$	$\sum$Cations
Shhrchay	1.2 ± 0.08	1 ± 0.06	0.13 ± 0.02	0.01 ± 0.00	2.33
Barandozchay	2.4 ± 0.2	2 ± 0.15	0.35 ± 0.07	0.03 ± 0.001	4.78
Mean	1.8 ± 0.1	1.5 ± 0.12	0.24 ± 0.05	0.01 ± 0.00	3.55
River	CO$_3^{-2}$ meq l^{-1}	HCO$_3^-$	Cl$^-$	SO$_4^{-2}$	$\sum$Anions
Shhrchay	0	0.2 ± 0.007	2.0 ± 0.13	0.14 ± 0.01	2.34
Barandozchay	0	2.0 ± 0.17	1.0 ± 0.05	1.9 ± 0.11	4.78
Mean	0	1.1 ± 0.07	1.5 ± 0.13	0.96 ± 0.05	3.56

EC electrical conductivity, *TDS* total dissolved solids, *SA* sodium adsorption ration

alluvial deposits with the level to depression and basin type landforms (a slope 0–2%) along with slight erosion and poorly (pedons 1 and 2) to somewhat poorly (other pedons) drained condition. In all the soils, the poorly drained and somewhat poorly drained condition were characterized by: (i) the presence of gray color (chroma ≤2) and redoximorphic features below A or Ap horizon and within B horizon, and (ii) soil positive reaction to alpha, alpha dipyridyl when the soil is not being irrigated (FAO 2006). Using the WRB system (IUSS 2014), these soil shows well developed natric, salic, and cambic horizons and are classified as Solonetz, Cambisols, and Solonchaks. Typically, the following soil types occur in the study region: Salic Gleyic Solonetz (pedons 1and 2), Salic Cambisols (pedons 3 and 4), Sodic Cambisols (pedons 5 and 6), and Sodic Solonchaks (pedons 7 and 8) according to WRB system (IUSS 2014).

Soil Physical, Chemical and Mineralogical Analyses

Particle-size analysis was carried out by the modified sedimentation hydrometer procedure (Bouyoucos 1962). Soil pH was measured using 1:5 soil to 0.01 M CaCl$_2$ suspension and EC was determined in saturated paste extracts. Calcium carbonate was measured by acid dissolution of carbonate and subsequent titration of CO$_2$ with NaOH (Nelson 1982). The methods of Walkley–Black (Nelson and Sommers 1982) for soil organic carbon (OC) and Kjeldhal for nitrogen (N) were employed. The percentage of organic matter (OM) was calculated as percent organic carbon multiplied by 1.724. Cation exchange capacity (CEC) was measured using the sodium acetate

method at pH 8.2 (Chapman 1965). Soluble cations were estimated using saturation extract and exchangeable cations were estimated using 1 M NH$_4$OAc at pH 8.2 (Thomas 1982). Sodium absorption ratio (SAR) was calculated by the concentration of solution K, Ca, Mg while the exchangeable sodium percentage was calculated as ESP = (exchangeable sodium Na/CEC) × 100. For different soil properties, a relative enrichment (RE) and/or a relative depletion (RD) was calculated as the value of each property in the cultivated soil divided by the value of that property in the uncultivated land. Statistical analyses were performed using the SPSS software.

The mineralogical phases were identified by X-ray Diffraction (XRD) with a Shimadzu 6000 instrument using CuKα.

Soil Erodibility Factor (*K*-Factor)

A soil erodibility factor (*K*-factor) that refers to soil's susceptibility to erosion was used to describe the effects of irrigation-cultivation on the properties of salt-affected soils. Soil erodibility is a complicated factor resulting from the effects of some of the soil characteristics and the interaction between them mainly with soil structure, particle-size distribution, permeability, and organic matter. Soil erodibility is represented by an erodibility factor (*K*-factor) based on the universal soil loss equation (USLE) and the revised universal version (RUSLE). Although *K*-factor is a quantitative description of the inherent erodibility of a soil in its natural condition, past management or misuse of a soil by cropping can also change the erodibility index of a soil (Blanco and Lal 2008). Zhang et al. (2004)

reported that the *K*-factor for USLE/RULSE is more appropriate for agricultural soil than the erodibility index developed locally.

This index was calculated as follows (for details, see Blanco and Lal 2008):

$$K_{\left(\frac{Mg\ ha-h}{ha\ MJ-mm}\right)} = 2.8 \times 10^{-7} M^{1.14}(12-a)$$
$$+ 4.3 \times 10^{-3}(b-2) + 3.3 \times 10^{-3}(c-3)$$
$$M_{(particle-size\ parameter)} = (\%Silt + \%\ Very\ fine\ sand)$$
$$\times (100 - \%clay)$$

where *a* is % of soil organic matter content, *b* is soil structure code (1 = very fine granular; 2 = fine granular; 3 = medium or coarse granular; 4 = blocky, platy, or massive), and *c* profile permeability (saturated hydraulic conductivity) class [1 = rapid (150 mm h^{-1}); 2 = moderate to rapid (50–150 mm h^{-1}); 3 = moderate (12–50mm h^{-1}); 4 = slow to moderate (5–15 mm h^{-1}); 5 = slow (1–5 mm h^{-1}); 6 = very slow (<1 mm h^{-1})]. The size of soil particles for very fine sand fraction ranges between 0.05 and 0.10 mm, for silt content between 0.002 and 0.05, and clay <0.002 mm. The soil organic matter content is computed as the product of percent organic C and 1.72 (Blanco and Lal 2008).

Results and Discussion

Classification and Morphophysical Properties

The examined soils are assigned to Salic Gleyic Solonetz (SaG-S), Salic Cambisols (Sa-C), Sodic Cambisols (So-C) and Sodic Solonchaks (So-S)] according to WRB system (2014). Soils having, also, pH <8.5, electrical conductivity (EC) >4 dS m^{-1}, exchangeable sodium percentage (ESP) >15, and Sodium absorption ratio (SAR) >13 are referred to as saline-sodic soils (Fig. 2).

The cultivation of salt-affected soils led to some changes in soil structure and particle-size distribution (Table 2). Consistent with this, strong platy to the medium prismatic structure of salt-affected soils was replaced by the fine angular blocky structure in cropland soils as a result of the improvement of organic matter caused by agricultural practices (as will see after) and wetting–drying cycle accelerated by irrigation-cultivation (Rezapour and Samadi 2012). Compared to the uncultivated soils, cultivation has produced a decreasing trend in the clay content [a drop of 17% (RD of 0.83) to 51% (RD of 0.49)] whereas the value of the sand fraction was increased [a rise of 8% (RE of 1.08) to 96% (RE of 1.96)] in the majority of the examined soils. This could be attributed to the combination of clay movement towards the subsoil and soil erosion caused by

the tillage-irrigation operation (Rezapour and Samadi 2012). In Fig. 3, the value of RE and RD for the fraction of sand and clay in different soil types is illustrated.

Soil Chemical and Fertility Attributes

Mean (±SD) values of selected soil chemical and fertility characteristics are presented in Table 3. The pH values of both the cultivated (min = 7.3, max = 8.7, mean = 7.8) and uncultivated soils (min = 7.7, max = 8.55, min = 8.17) were classified into slightly and moderately basic category. Except the soil types of SaG-S, the values of pH appeared a slight decline by cropping with a drop of 2.2% (RD of 0.98) to 9% (RD of 0.9), on average. Referring to literature, any decrease in soil pH can be viewed as a positive change and any increase in soil pH, in contrast, can be viewed as a negative change in the alkaline and calcareous soils (Smith and Doran 1996). In the light of this, 75% of soil samples had positive changes in pH and 25% had native changes. Nevertheless, pH values can be considered to be optimal (7–8) for many plant species in most of the tilled soil (Brady and Weil 1999). The principal mechanisms associated with the reduction of pH in the cultivated soils can be categorized as: (i) the movement of salts into and out of different soil zones as soil moisture moves down through the soil profiles following tillage-irrigation practices (Rezapour 2014a, b), and (ii) the uptake of basic cations by the roots of growing plants with frequent release of H$^+$ ions, the product of organic acids and CO$_2$ by organic matter oxidation, and amplified CO$_2$ levels related to root respiration and nitrification (Yao et al. 2010; Rezapour 2014a, b). Results found by some researchers (Ponnamperuma 1972) showed that the pH of alkaline soils was highly sensitive to changes in the partial pressure of CO$_2$.

A considerable positive change in soil quality was observed through cultivation with respect to soil organic carbon except SaG-S. In this context, the content of organic carbon increased by 13–130% in the cultivated soils as compared to the control (uncultivated soils) which is comparable with the results of other authors (Singh et al. 2016). However, the value of organic matter of the cultivated soils (mean = 1.22%, min = 0.5%, max = 1.82%) could be classified into diverse categories from very poor (0.4–0.59%) to high (1.6–1.8%) (Hazleton and Murphy 2007) due probably to the diversity of in soil type and crop residue distribution. Similarly, the total N was build-up by cultivation in parallel with organic C ranging from 27 to 157%, suggesting that the distribution of total N was in matching with the pattern of organic carbon as evidenced by linear correlation between two the attributes (r = 0.82, P ≤ 0.01). The increase in soil organic C and total N may be associated with the combination of decomposition and
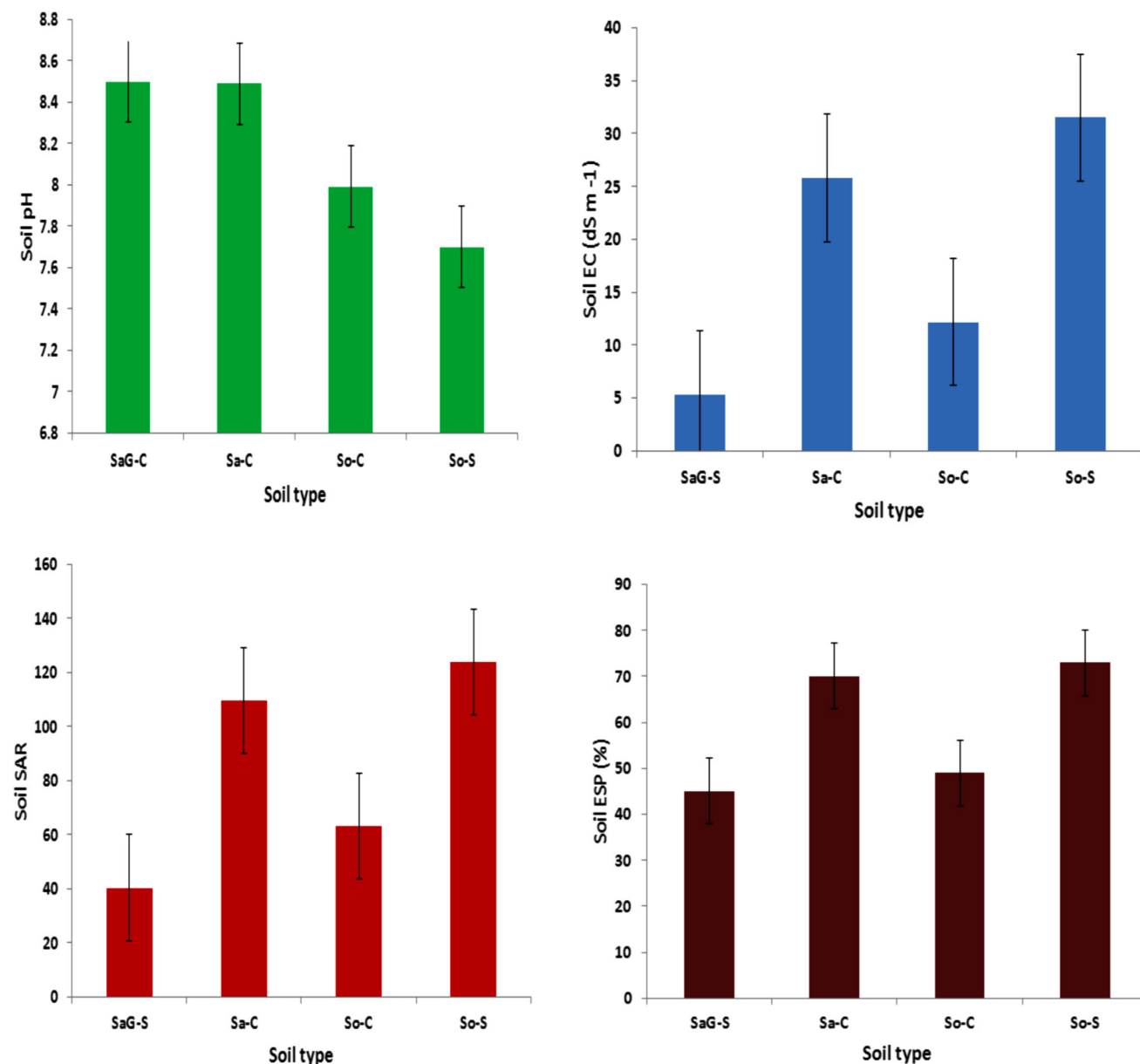
Fig. 2 The mean values of soil pH, EC, SAR, and ESP for the different soil types (the uncultivated soils). *SaG-S* Salic Gleyic Solonetz, *Sa-C* Salic Cambisols, *So-C* Sodic Cambisols, *So-S* Sodic Solonchaks

turnover of root residues, the additional of crop residues after harvest, and the application of manure by farmers. Rezapour et al. (2013) and Rezapour (2014a, b) also showed that cultivation improves the organic C and total N contents of alkaline-calcareous soils.

Exchangeable Ca^{+2} and Mg^{+2} were found to accumulate in the cultivated soils ranging from 20% (RE of 1.2) to 58% (RE of 1.5) and from 20% (RE of 1.2) to 60% (RE of 1.6), respectively, as compared to before cropping. This could be ascribed to rhizosphere chemical effects and organic matter decomposition during tillage and cropping, resulted in an increase in CO_2 (P_{CO_2}), or the formation of organic acids (Wong et al. 2009) and consequently, caused

more dissolution of calcite and dolomite, thereby enhanced soil Ca^{+2} and Mg^{+2}. Compared to the uncultivated soils, cultivation caused an effective drop in exchangeable K in all soil types, ranging from 8% (RD of 0.92) to 53% (RD of 0.46) which can be explained by plant uptake and erosion. These findings are consistent with the results reported by other research about the decline in soil Ex-K through K removal by the crops (Rezapour and Samadi 2012; Rezapour et al. 2013).

The mean values of cation exchange capacity (CEC) were medium, ranging from 13 to 23 $cmol_c$ kg^{-1} in both cultivated and uncultivated soils, making those in the range of the saline-sodic soils under semi-arid condition. After

Table 2 Selected morphophysical properties for the cultivated and uncultivated soils

Characteristics	Salic Gleyic Solonetz		Salic Cambisols		Sodic Cambisols		Sodic Solonchaks	
	Cultivated soil	Uncultivated soil	Cultivated soil	Uncultivated soil	Cultivated soil	Uncultivated soil	Cultivated soil	Uncultivated soil
Structure	f_1abk	c_2pl	f_1abk	c_2pl	f_1abk	c_2pl	f_1abk	m_2pr
Color (moist)	10YR5/4	10YR 3/2	10YR3/4	10YR4/3	10YR3/2	10YR4/2	10YR3/2	10YR4/2
Consistence (moist)	fi	fi	fi	fi	vfi	vfi	sfi	fi
Sand (%)[a]	31.25 ± 0	32.91 ± 1.44	30.25 ± 3.75	16 ± 3.3	34.58 ± 1.44	32.08 ± 5.2	61.25 ± 3.3	31.25 ± 2.5
Silt (%)	29.58 ± 5.77	31.25 ± 2.1	42.66 ± 2.88	28.58 ± 1.4	30.4 ± 2.5	25.4 ± 5.2	21.25 ± 0	36.66 ± 3.6
Clay (%)	39.16 ± 5.77	35.83 ± 1.44	27.08 ± 6.4	55.4 ± 4.01	35 ± 2.5	42 ± 3.6	17.5 ± 1.1	32.08 ± 1.9
Texture	CL	CL	CL	C	CL	C	SL	CL
SP (%)[b]	46.68 ± 3.9	47.99 ± 6.1	39.77 ± 1.4	62.86 ± 0	45.33 ± 4.9	46.41 ± 0.72	28.33 ± 2.5	45 ± 9.84

Symbols applied according to abbreviation given in guidelines for descriptions (FAO 2006)

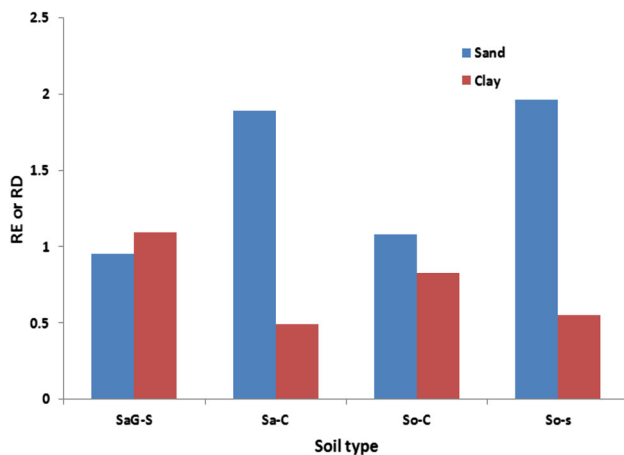[a] Mean ± standard deviation

[b] Saturation percentage

Fig. 3 Relative enrichment (RE) or relative depletion (RD) for the mean values of sand and clay fraction for the different soil types. *SaG-S* Salic Gleyic Solonetz, *Sa-C* Salic Cambisols, *So-C* Sodic Cambisols, *So-S* Sodic Solonchaks

cultivation, the CEC amount of salt-affected soils decreased from 0.6% (RD of 0.99) to 29% (RD of 0.71). Typically, this pattern was in matching to the distributive trend of the clay fraction, suggesting the significant contribution of clay to CEC. Contributions by clay to CEC, also, are evidenced by the recorded significant correlation between the content of clay and CEC ($r = 0.82$, $P \leq 0.01$) which is in accordance with the results of Rezapour and Samadi (2012).

A loss of 8% (RD of 0.92) to 30% (RD of 0.70) was occurring in the values of calcium carbonate equivalent (CCE) in all soil types. The possible explanation could be attributed to the dissolution/translocation of native carbonates under ambient moisture (by irrigation) and relatively high soil CO2 partial pressure (by the biological activity of roots and microorganisms) which can lead to CCE leaching to subsurface horizons (Rezapour 2014a, b).

Soil Salinity and Alkalinity Attributes

Mean (±SD) values of soil salinity and alkalinity characteristics are illustrated in Table 4. There was a pronounced significant decrease in the values of EC and SAR with cultivation except the soil types of SaG-S. The content of EC dropped from 69% (RD of 0.31) to 82% (RD of 0.18) in the cultivated soils as compared to the uncultivated soils. Such pattern might have been due to tillage practices (mainly moldboard tillage) and the extent of the root system that improved the soil contains plow layer for the percolating soil solution, causing the salt on the soil surface was accelerated to move downwards through leaching caused by flooding irrigation. These results are uniform to field studies elsewhere (Mishara and Sharma 2003; Qadir et al. 2008b). The values of Cl^-, SO_4^{-2}, and HCO_3^- followed the same pattern as EC and decreased after cultivation in the range of 75–90%, 31–89%, and 35–62%, respectively. This shows that the distribution of salinity (EC) tends to be associated with the salt concentration of soil as is evidenced by linear correlation recorded between EC with Cl^- ($r = 0.95$ $P \leq 0.001$) and SO_4^{-2} ($r = 0.8$, 5 $P \leq 0.01$). A rise of 62% (RE of 1.62) to 118% (RE of 2.18) and 33% (RE of 1.33) to 52% (RE of 1.52) was observed in the amount of soluble Ca^{+2} and Mg^{+2} with cropping, whereas the quantity of soluble Na^+ declined by 51% (RD of 0.48) to 83% (RD of 0.17) in the majority of soil types. The case of the increase in Ca^{+2} and Mg^{+2}

Table 3 Mean ± standard deviation values of selected chemical and fertility properties for the cultivated and uncultivated soils

Characteristics[a]	Salic Gleyic Solonetz			
	Cultivated soil	Uncultivated soil	% Change	RD or RE[b]
pH	8.66 ± 0.19	8.48 ± 0.46	1.88	1.02
OC (%)	0.59 ± 0.04	0.86 ± 0.07	−31.4*	0.69
Total N (%)	0.31 ± 0.07	0.34 ± 0.04	−8.8	0.91
Exchangeable Ca (cmol$_c$ kg^{-1})	12.58 ± 2.3	8.61 ± 1.3	21.3	1.21
Exchangeable Mg (cmol$_c$ kg^{-1})	4.58 ± 1.09	2.56 ± 1.18	89.5**	1.9
Exchangeable K (cmol$_c$ kg^{-1})	0.45 ± 0.19	0.7 ± 0.14	−35.7*	0.64
CEC (cmol$_c$ kg^{-1})	20.59 ± 0.52	21.35 ± 0.29	−3.55	0.96
CCE (%)	17.0 ± 1.32	18.5 ± 0.86	−8.11	0.92
Characteristics	Salic Cambisols			
	Cultivated soil	Uncultivated soil	% Change	RD or RE
pH	7.71 ± 0.22	8.49 ± 0.36	−9.19	0.91
OC (%)	1.77 ± 0.05	0.77 ± 0.08	129.89***	2.3
Total N (%)	0.9 ± 0.17	0.35 ± 0.023	157.14***	2.57
Exchangeable Ca (cmol$_c$ kg^{-1})	11.19 ± 1.2	6.5 ± 2.32	25.35*	1.25
Exchangeable Mg (cmol$_c$ kg^{-1})	6.61 ± 2.3	2.24 ± 1.18	83.4**	1.83
Exchangeable K (cmol$_c$ kg^{-1})	1.37 ± 0.21	1.49 ± 0.23	−8.1	0.92
CEC (cmol$_c$ kg^{-1})	22.4 ± 3.05	25.23 ± 0.23	−12	0.89
CCE (%)	21.5 ± 1.80	24.0 ± 1.0	−10.41	0.89
Characteristics	Sodic Cambisols			
	Cultivated soil	Uncultivated soil	% Change	RD or RE
pH	7.3 ± 0.17	7.99 ± 0.24	−8.63	0.91
OC (%)	1.52 ± 0.41	1.32 ± 0.45	15.15	1.15
Total N (%)	0.74 ± 0.27	0.54 ± 0.187	37.03*	1.37
Exchangeable Ca (cmol$_c$ kg^{-1})	11.9 ± 1.98	6.6 ± 4.94	80.3**	1.8
Exchangeable Mg (cmol$_c$ kg^{-1})	4.5 ± 1.14	2.35 ± 1.4	91**	1.91
Exchangeable K (cmol$_c$ kg^{-1})	0.73 ± 0.61	1.57 ± 0.49	−53.5*	0.46
CEC (cmol$_c$ kg^{-1})	20.7 ± 0.72	20.82 ± 0.26	−0.58	0.99
CCE (%)	12.83 ± 4.0	18.2 ± 2.1.1	29.7*	0.70
Characteristics	Sodic Solonchaks			
	Cultivated soil	Uncultivated soil	% Change	RD or RE
pH	7.53 ± 0.2	7.7 ± 0.39	−2.2	0.98
OC (%)	1.0 ± 0.29	0.57 ± 0.22	75.4**	1.75
Total N (%)	0.78 ± 0.065	0.51 ± 0.15	52.9*	1.53
Exchangeable Ca (cmol$_c$ kg^{-1})	22.24 ± 3.3	18.2 ± 2.2	22.2	1.22
Exchangeable Mg (cmol$_c$ kg^{-1})	9.88 ± 2.8	7.0 ± 1.52	41.1*	1.41
Exchangeable K (cmol$_c$ kg^{-1})	0.61 ± 0.06	1.09 ± 0.15	−44.03*	0.56
CEC (cmol$_c$ kg^{-1})	15.52 ± 0	21.79 ± 0.91	−29.0*	0.71
CCE (%)	14.5 ± 4.4	17.6 ± 6.29	−18.0	0.82

OC organic carbon, *CCE* calcium carbonate equivalent, *CEC* cation exchangeable capacity, *RD* relative depletion, *RE* relative enrichment

* $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$ based on paired t test results

Table 4 Mean ± standard deviation values of selected salinity and alkalinity attributes for the cultivated and uncultivated soils

Characteristics	Salic Gleyic Solonetz			
	Cultivated soil	Uncultivated soil	% Change	RD or RE[b]
EC (dS m^{-1})	8.33 ± 3.7	5.3 ± 0.40	57**	1.57
Cl^{-1} (me l^{-1})	68 ± 32.12	21.33 ± 2.4	218.8***	3.19
SO$_4^{-2}$ (me l^{-1})	36.63 ± 16.13	10.29 ± 6.88	255.97***	3.56
HCO$_3^{-1}$ (me l^{-1})	12.33 ± 7.09	17.33 ± 8.08	−28.85*	0.71
CO^{-2} (me l^{-1})	Nil	Nil	–	–
S-Ca (me l^{-1})	1.96 ± 0.57	1.5 ± 0.03	31	1.31
S-Mg (me l^{-1})	1.66 ± 0.33	1.4 ± 0.15	18.6	1.19
S-Na (me l^{-1})	145.7 ± 45	47.8 ± 4.1	204.68***	3.05
S-K (me l^{-1})	0.3 ± 0.18	0.13 ± 0.05	130.76***	2.31
SAR	108.84 ± 40.15	40.4 ± 5.2	169.0***	2.69
Exchangeable Na (cmol$_c$ kg^{-1})	13.84 ± 4.86	9.65 ± 5.09	43.4*	1.43
ESP (%)	64.41 ± 7.05	44.9 ± 3.2	84.52**	1.84

Characteristics	Salic Cambisols			
	Cultivated soil	Uncultivated soil	% Change	DF or EF
EC (dS m^{-1})	6.03 ± 4.6	25.8 ± 3.59	−76.7**	0.23
Cl^{-1} (me l^{-1})	41.7 ± 13.1	168.3 ± 32.53	−75.0**	0.0.25
SO$_4^{-2}$ (me l^{-1})	30.62 ± 18.59	44.4 ± 21.2	−31.04*	0.69
HCO$_3^{-1}$ (me l^{-1})	3.66 ± 0.57	9.66 ± 0.57	−62.11**	0.38
CO^{-2} (me l^{-1})	Nil	Nil	–	–
S-Ca (me l^{-1})	5.96 ± 0.57	3.7 ± 0.04	61**	1.61
S-Mg (me l^{-1})	4.6 ± 0.82	3.33 ± 0.57	38.0*	1.38
S-Na (me l^{-1})	48.4 ± 18.5	206.2 ± 51.7	−51.53*	0.48
S-K (me l^{-1})	1.12 ± 0.02	1.63 ± 0.42	−31.3*	0.69
SAR	27.39 ± 57.92	109.42 ± 75.76	−62.03*	0.48
Exchangeable Na (cmol$_c$ kg^{-1})	5.92 ± 5.88	17.02 ± 9.15	−65.0*	0.35
ESP (%)	28.45 ± 94.58	70.40 ± 4.4	−52.17*	0.48

Characteristics	Sodic Cambisols			
	Cultivated soil	Uncultivated soil	% Change	RD or RE
EC (dS m^{-1})	2.23 ± 1.87	12.2 ± 18.7	−81.72**	0.18
Cl^{-1} (me l^{-1})	11.66 ± 6.54	113.3 ± 27.67	−89.7**	0.103
SO$_4^{-2}$ (me l^{-1})	12.11 ± 6.06	114.2 ± 17.9	−89.39**	0.106
HCO$_3^{-1}$ (me l^{-1})	2.7 ± 1	7.2 ± 3.6	−62**	0.38
CO^{-2} (me l^{-1})	Nil	Nil	–	–
S-Ca (me l^{-1})	7.2 ± 0.57	5.5 ± 0.56	118.2***	2.18
S-Mg (me l^{-1})	4.66 ± 2.30	3.5 ± 1.02	33.14*	1.33
S-Na (me l^{-1})	23.5 ± 19.7	138.3 ± 17.8	−83*	0.17
S-K (me l^{-1})	0.25 ± 0.29	1.85 ± 1.43	−86.48*	0.14
SAR	10.78 ± 10.5	62.73 ± 9.35	−73.25*	0.27
Exchangeable Na (cmol$_c$ kg^{-1})	3.52 ± 0.18	11.05 ± 6.28	−90.53*	0.66
ESP (%)	15.5 ± 16.09	48.5 ± 6.15	−68**	0.32

Characteristics	Sodic Solonchaks			
	Cultivated soil	Uncultivated soil	% Change	RD or RE
EC (dS m^{-1})	5.8 ± 4.34	31.5 ± 34.9	−81.6**	0.18
Cl^{-1} (me l^{-1})	28.2 ± 19.68	198 ± 86.6	−85.7**	0.14

Table 4 continued

Characteristics	Sodic Solonchaks			
	Cultivated soil	Uncultivated soil	% Change	RD or RE
SO_4^{-2} (me l^{-1})	20.26 ± 12.35	179.1 ± 58.3	−88.7**	0.11
HCO_3^{-1} (me l^{-1})	2.66 ± 1.52	4.1 ± 1.1	−35.0*	0.65
CO^{-2} (me l^{-1})	Nil	Nil	–	–
S-Ca (me l^{-1})	6.6 ± 3.08	3.5 ± 2.5	88.6**	1.89
S-Mg (me l^{-1})	5.0 ± 2.29	3.3 ± 1.53	51.5*	1.52
S-Na (me l^{-1})	86.47 ± 24.1	231.2 ± 465	−58.0*	0.42
S-K (me l^{-1})	0.42 ± 0.13	5.21 ± 3.27	−91.9*	0.08
SAR	35.8 ± 8.27	124.2 ± 12.79	−69**	0.29
Exchangeable Na (cmol$_c$ kg^{-1})	3.52 ± 3.27	15.92 ± 19.84	−77.89**	0.22
ESP (%)	22.52 ± 5.4	72.4 ± 2.4	−69.0**	0.31

EC electrical conductivity, *S* soluble, *SAR* sodium adsorption ratio, *ESP* exchangeable sodium percentage, *RD* relative depletion, *RE* relative enrichment

* $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$ based on paired t test results)

Fig. 4 Histogram of soil erodibility (*K*-factor) in the different soil types. *SaG-S* Salic Gleyic Solonetz, *Sa-C* Salic Cambisols, *So-C* Sodic Cambisols, *So-S* Sodic Solonchaks
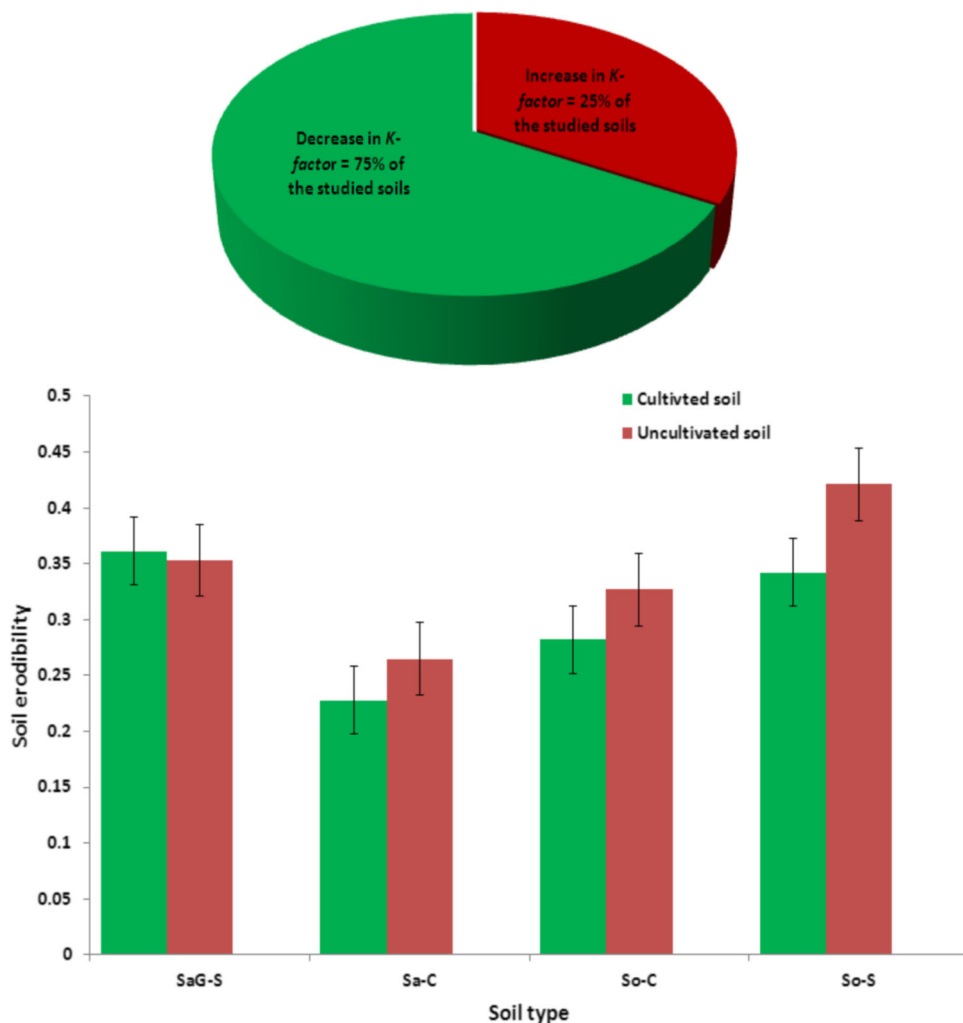
content and decline in Na^+ content led to a decreasing trend in SAR that reduced in the range of 62% (RD of 0.38) to 73% (RD of 0.17). The decrease in SAR could be attributed to a series of processes, involving: (1) increase to soil atmosphere CO_2 concentration as a result of rhizosphere respiration (both root and microbial respiration) during crop growth, (2) dissolution of CO_2 in water to form carbonic acid (H_2CO_3), (3) dissociation of H_2CO_3 resulting in proton (H^+) and bicarbonate (HCO_3^-), (4) reaction of H^+ with soil $CaCO_3$ or $CaMg (CO_3)_2$ to produce Ca^{+2}, Mg^{+2}, and HCO_3^-, (5) $Na^+–Ca^{+2}$ or $Na^+–Mg^{+2}$ exchange at the soil's cation exchange sites as a consequence of increased Ca^{+2} and Mg^{+2} concentration in soil solution, (6) leaching of the exchanged Na^+ in percolating water and (7) subsequent reduction in soil SAR (Qadir and Schubert 2002; Qadir et al. 2008a, b). In Salic Gleyic Solonetz, in contrast to other soil types, an increasing trend was observed in the amounts of Cl^-, SO_4^{-2}, Na^+, EC, and SAR with cultivation. In view of the fact that the drainage condition was weaker in the soil types than those in other soils, this trend might be attributed to the effect of soluble salt movements towards the surface due to evaporation and capillary rise and subsequent salts precipitation. On the other hand, the value of organic matter (as mulching) decreased by 31% after cultivation in Salic Gleyic Solonetz which in turn could have increased the rate of surface soils evaporation.

The values of ESP were found to decrease with cropping and the rate of decrease was from 52% (RD of 0.48) to 69% (RD of 0.31). Similarly, the exchangeable Na^+ also dropped from 65% (RD of 0.35) to 90% (RD of 0.11) after cropping that is in agreement with past researches (Mishra and Sharma 2003). The only exception is SaG-S that did not show such trend. The significant reduction in the amount of ESP and exchangeable Na^+ may be due to the mobilizes insoluble carbonates (mainly calcite) by the biological activity of roots and microorganisms within the root zone, leading to increase Ca^{+2} to replace excess Na^+ from the cation exchange sites. Another explanation is the release of organic acids from the decomposition of organic matter, promoted dissolution of soil $CaCO_3$, resulted in becoming more available of Ca^{+2} to replace excess exchangeable sodium on the ion exchange complex of the soil, decreasing exchangeable Na^+ absorption and ESP by soil. Such interpretation and evaluation are in line with the results of other researchers (Qadir and Oster 2002; Singh et al. 2016). As a result, effects of tillage and intensive irrigation promoted the processes of desalinization and desodification in the soil types of Sa-C, So-C, and So-S, whereas the processes of re-salinization and re-sodification occurred in the SaG-S type regarding to soil pH, EC, SAR, exchangeable Na^+, ESP, and soluble salts.

Fig. 5 Comparison of the XRD patterns (Mg-plus ethylene glycol-solvated) of the clay fraction in the uncultivated (Unculti) and the cultivated soils (Culti) in the soil types of Salic Gleyic Solonetz (**a**) and Sodic Solonchaks (**b**). *Ch* chlorite, *Il* illite, *Ka* kaolinite, *Q* quartz
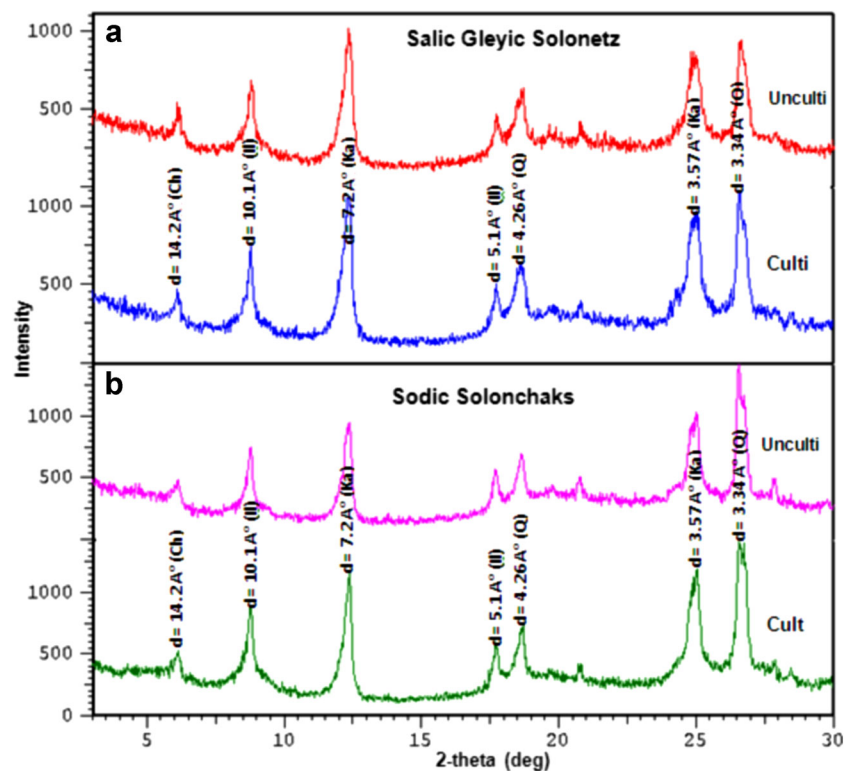
Soil Erodibility Factor (*K*-Factor)

To better highlight the effects of the conversion of salt-affected soils to cropland, soil erodibility factor was investigated. The results revealed that the soil types of Sa-C, So-C, and So-S tend to decrease the *K*-factor (a drop of 14–19%) whereas Salic Gleyic Solonetz reflected an increasing pattern (a rise of 3%) with cultivation. Indeed, 75% of the soils had positive changes in the *K*-factor and 25% had negative changes during farming practices (Fig. 4). The lowest *K*-factor value was observed in the salic cambisols where the highest content of organic matter was occurring, indicating the importance of organic matter to protect soil from degradation.

Clay Minerals

The XRD patterns of the clay fraction of both the cultivated and adjoining uncultivated soils (Fig. 5) exhibited a similar composition of phyllosilicate minerals, involving illite, chlorite, and kaolinite. In some clay samples, K-saturation treatment with 25 and 550 °C showed that the 14 Å XRD peak shifted to lower d-spacing and the intensity of the 10 Å peak increased by the treatment of K-saturated and K-heated at 550 °C, indicating the presence of vermiculite. There is not any significant change in the XRD patterns of the <2-pm fractions, either in the intensity and figure or in the position of peaks for the clay minerals following the conversion of salt-affected soil to cropland. This trend is not surprising for the kaolinite and chlorite because of the two minerals are very stable against the weathering process in calcareous and alkaline soils (Rezapour 2014a, b). Nevertheless, some authors report changes in the illite composition, as observed using X-ray diffraction, after long-term cropping or fertilisation (Velde and Peck 2002; Rezapour and Samadi 2012; Rezapour 2014a, b), although other authors have reported no change (Singh and Goulding 1997). In general, the no occurrence of changes in the illite composition may be caused by (1) XRD-technique is not likely to detect small changes resulting from cultivation (Singh and Goulding 1997) and (2) the time length of cultivation practices was not favorable (short) to make changes in illite because of clay minerals are examples of soil properties that change slowly [(100–1000 years) (Chadwick and Chorover 2001)].

Conclusion

Positive effects of irrigation-cultivation of salt-affected soils have appeared on soil quality indicators monitored in the majority of the soils. With the exception of Sodic Gleyic Solonetz, the significant decrease in the values of soil pH,

EC, SAR, exchangeable Na, and ESP and increase in soluble Ca^{+2} and Mg^{+2} content showed that the processes of desalinization and desodification occurred after converting salt-affected soils to cropland. Such pattern was in matching with the decreasing pattern of soil erodibility, calculated based on *K*-factor, and the increasing trend of soil organic matter, total N, and exchangeable Ca^{+2} and Mg^{+2}, revealing the improvement in salt-affected soils with cultivation. The combined effects of leaching caused by irrigation, organic matter, and the biological activity of roots and microorganisms within the root zone were known to be the most indicators effective in improving the properties of the studied soils. Overall, we conclude that continuous irrigation and cropping can lead to two aspects in soil quality involving negative (the soil type of Sodic Gleyic Solonetz) and positive changes (other soil types) as a result of management strategies applied in the region. On the other hand, since a vast area of Iran is under the influence of saline and sodic attributes with low precipitation and very low organic matter, such activities (tillage-irrigation-cropping) can be useful for increasing soil quality in this region.

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