Available online at www.sciencedirect.com
ScienceDirect
Geoderma 144 (2008) 361 – 369
GEODERMA
www.elsevier.com/locate/geoderma

Assessment of different soil to water ratios (1:1, 1:2.5, 1:5) in soil salinity studies

Sahriye Sonmez[a], Dursun Buyuktas[b,*], Filiz Okturen[a], Sedat Citak[a]

[a] Akdeniz University, Faculty of Agriculture, Department of Soil Science, 07059, Antalya, Turkey
[b] Akdeniz University, Faculty of Agriculture, Department of Farm Structures and Irrigation, 07059, Antalya, Turkey

Received 13 December 2006; received in revised form 23 November 2007; accepted 5 December 2007
Available online 14 January 2008

Abstract

Soil salinity is one of the limiting factors of agricultural productivity. It is essential to determine the soil salinity in a reliable and yet relatively easy method. This experimental study was carried out to assess the possibilities of measuring electrical conductivity as well as ion concentrations in the extracts of different soil to water ratios, (1:1, 1:2.5, 1:5), and to compare them with those measured in saturated paste extract. Sandy, loamy, and clay textured soils were artificially salinized for one month by capillarity with different saline water of 0.02 (de-ionized water), 0. 4 (tap water), 2, 4, 8 and 16 dS/m. The saline waters were prepared by adding various amounts of NaCl, KCl, and $CaCl_2$ into tap water for each level of salinity to obtain desired salinity level. Having measured electrical conductivity, the extracts were analyzed for Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, CO_3^{2-}, and HCO_3^-. The results showed that highly significant correlation exists between values measured in saturated paste extracts and in extracts of different soil to water ratios for electrical conductivity and ion concentrations. Based on the results obtained, it was concluded that extracts of (1:1), (1:2.5) or (1:5) soil to water ratios can be used to estimate saturated paste electrical conductivity and ion concentrations of soils.

Keywords: Salinity; Electrical conductivity; Ion concentration; Soil texture; Soil to water ratios; Extracts

1. Introduction

Salinity, defined as the concentration of dissolved mineral salts present in the soil or water, is one of the most severe environmental factors limiting the productivity of agricultural crops. Most crops are sensitive to salinity caused by high concentrations of salts in the soil. Salinization commonly occurs as an outcome of agricultural practices. Salinization associated with agriculture occurs when salts build up in the root zone, either because the soil is intrinsically saline or because the drainage of water from the sub-soil is not sufficient to prevent saline waters rising into the root zone (Pitman and Lauchli, 2002).

Saline soils exist mostly under arid and semi-arid regions. Although the data regarding the extent and severity of salinized areas are observational, estimates show that about 955 million ha of the world are under different categories of salt affected soils (Qadir et al., 2000).

Until the 1950's, the salt contents of soils were estimated from the electrical conductivity of saturated soil pastes. As a result of progresses made in the understanding of saline soils, it was found that the plant responds to the salt concentration of soil solution rather than the total salt content of the soil. Therefore, the conductivity of the saturation extract is recommended as a general method for estimating soil salinity in relation to plant growth (USDA, 1954; Rhoades et al., 1989). The use of saturation extracts as a method of measuring and referencing salinity provides a direct relationship with the field moisture range for most soils. However, soil water suspensions of different ratios such as 1:1, 1:2, 1:5 and 1:10 can be more easily made and extracted than obtaining saturation extracts.

* Corresponding author. Tel.: +90 242 3102473; fax: +90 242 2274564.
E-mail address: dbuyuktas@akdeniz.edu.tr (D. Buyuktas).

0016-7061/$ - see front matter © 2007 Elsevier B.V. All rights reserved.
doi:10.1016/j.geoderma.2007.12.005

Table 1
Correlation equations established by different studies to convert different soil water ratios to saturated paste (SP) equivalents (Zhang et al., 2005)

Parameter	USDA (1954)	Hogg and Henry (1984)	Franzen (2003)	Zhang et al. (2005)	Ozcan et al. (2006)[a]
EC dS m^{-1}	SP=3.00 (1:1)	SP=1.56 (1:1)−0.06	SP=3.01 (1:1)−0.06[b] SP=3.01 (1:1)−0.77[c] SP=2.96 (1:1)−0.95[d]	SP=1.85 (1:1) SP=1.79(1:1)+1.46	SP=1.93 (1:1)−0.57 SP=3.30 (1:2.5)−0.20 SP=5.97 (1:5)−1.17
Cl^- mg kg^{-1}	SP=2.78 (1:1)	SP=0.95 (1:1)+5.31		SP=2.04 (1:1) SP=2.03(1:1)+174	SP=2.41 (1:1)−60.84 SP=3.97 (1:2.5)−7.35 SP=7.42 (1:5)−28.55
SO_4^{2-} mg kg^{-1}	SP=1.67 (1:1)			SP=1.35 (1:1) SP=1.32(1:1)+101	SP=1.43 (1:1)−6.67 SP=2.76 (1:2.5)−0.60 SP=4.71 (1:5)−10.14
K^+ mg kg^{-1}	SP=2.78 (1:1)			SP=2.48 (1:1) SP=2.80(1:1)−21.3	SP=1.83 (1:1)−0.20 SP=2.85 (1:2.5)−0.96 SP=4.95 (1:5)−1.21
Na^+ mg kg^{-1}	SP=2.78 (1:1)	SP=0.95 (1:1)−30.5		SP=1.91 (1:1) SP=1.92(1:1)−27.8	SP=1.48 (1:1)−78.21 SP=3.37 (1:2.5)−72.03 SP=8.16 (1:5)−20.68
Ca^{2+} mg kg^{-1}	SP=1.67 (1:1)	SP 0.7(1:1)−9.39		SP=2.10 (1:1) SP=2.10(1:1)+3.37	
Mg^{2+} mg kg^{-1}	SP=1.67 (1:1)	SP=0.7 (1:1)−9.39		SP=2.08 (1:1) SP=2.00(1:1)+22.8	
$Ca^{2+}+Mg^{2+}$ me l^{-1}					SP=2.10 (1:1)−53.91 SP=2.77 (1:2.5)−30.23 SP=4.52 (1:5)−37.86

[a] Units of anion and cations are in me/l.
[b] Coarse textured soils.
[c] Medium textured soils.
[d] Fine textured soils.

Soil salinity can be determined from measurements made 1) on saturated paste extracts of soil samples, 2) on extracts of soil to water suspensions of different ratios, 3) on soil water samples collected *in situ*, usually with vacuum extractors, 4) in soil, using buried porous salinity sensors which imbibe and equilibrate with the soil water, 5) in soil, using four-electrode probes, or 6) remotely by electromagnetic induction techniques (Rhoades and Loveday, 1990). One of these methods may be used depending on different situations.

Unlike the saturated paste extract method, the extraction methods of different soil to water ratios do not attempt to simulate natural soil conditions. Due to the consistency in the amount of water used and objective nature of the method, the extraction methods of different soil water ratios can reduce the difficulties in sample preparation and reproducibility often encountered in saturated paste extract method (USDA, 1954). Ion concentrations and electrical conductivities of the extracts of different soil water ratios are typically lower than those of saturated paste extracts as a result of the increased dilution effect. Despite the differences in results among these methods, many commercial soil salinity laboratories are analyzing soil salinity samples using extraction methods of different soil to water ratios because of its simplicity, reduced monetary and time investments (Franzen, 2003; Zhang et al., 2005).

The results can be converted back and forth from the extracts of different soil to water ratios to saturated paste extracts. Despite of the reports of highly correlated relationships between these two methods, adjustments of the results of soil water ratios to saturated paste extraction are imprecise and inaccurate (Franzen, 2003).

Correlation equations established by different studies to convert measurements of 1:1 soil water ratio to saturated paste equivalents are summarized in Table 1. Excluding Ozcan et al. (2006), studies are concentrated on the comparison of 1:1 soil to water ratio with saturated soil paste (Table 1). Although Ozcan et al. (2006) studied different soil to water ratios, they did not take soil textural classes into consideration and their case

Table 2
Physical and chemical properties of soils used in the study

Parameter[a]	Soil texture		
	Clay	Sand	Loam
pH $_{(1:2.5)}$	6.91	7.15	6.80
EC, dS m^{-1}	0.06	0.08	0.12
Sand, %	24.72	88.72	44.72
Silt, %	34.36	4.36	30.36
Clay, %	40.92	6.92	24.92
K^+, me l^{-1}	0.01	0.01	0.01
Na^+, me l^{-1}	0.17	0.35	0.58
Ca^{2+}, me l^{-1}	0.53	1.43	1.26
Mg^{2+}, me l^{-1}	0.03	0.05	0.06
CO_3^{2-}, me l^{-1}	–	–	–
HCO_3^-, me l^{-1}	0.26	0.13	0.78
Cl^-, me l^{-1}	0.40	0.85	1.00
SO_4^{2-}, me l^{-1}	0.08	0.86	0.13
Water used for saturation paste, ml	205	179	208

[a] EC, anions, and cations are determined in saturated paste extracts.

study were concentrated on the areas intruded by the Agean Sea. However, variations in conversion factors make it necessary to examine and compare further the different soil water extraction methods with saturated soil paste. Furthermore, in soil laboratories, pH is measured in 1:2,5 soil water extracts (Jackson, 1967). If suitable conversion coefficients were determined, EC can also be measured in the same extract allowing to make two measurements at once. Shirokova et al. (2000) reported that the USSR classification of soil salinity used in Central Asia was based on laboratory measurements of the total dissolved salts or chloride concentration in the soil water extract of 1:5.

The objectives of this study were to 1) determine the relationships between the electrical conductivity of saturated paste extract and different soil to water ratios (1:1, 1:2.5, 1:5) depending on soil texture, and 2) determine the relationships between major cations and anions of saturated paste extract and different soil to water ratios of (1:1, 1:2.5, 1:5).

2. Material and methods

2.1. Soil preparation

Three different soil textures, sandy, loamy and clay, were collected in the fields at or around the Akdeniz University campus and brought to the laboratory. The physical and chemical properties of the soils are given in Table 2. Soil texture was determined by hydrometer method (Day, 1982). Four kilograms of soil was weighed and filled in pots. Total number of pots containing different soil textures (three textures), salinity levels (six levels), and replications (three) was 54. The soils in the pots were saturated for one month by capillarity with different saline water of 0.02 (de-ionized water), 0. 4 (tap water), 2, 4, 8 and 16 dS/m. The saline waters were prepared by adding required amounts of NaCl, KCl, and $CaCl_2$ into tap water to obtain each level of salinity. The salinity levels were chosen according to the ranges of salinity classes given by Soil Survey Staff (1951). Each level of artificially salinized soil was replicated three times. Having saturated the soils for one month, the soils are air dried, ground and sieved (2 mm sieve).

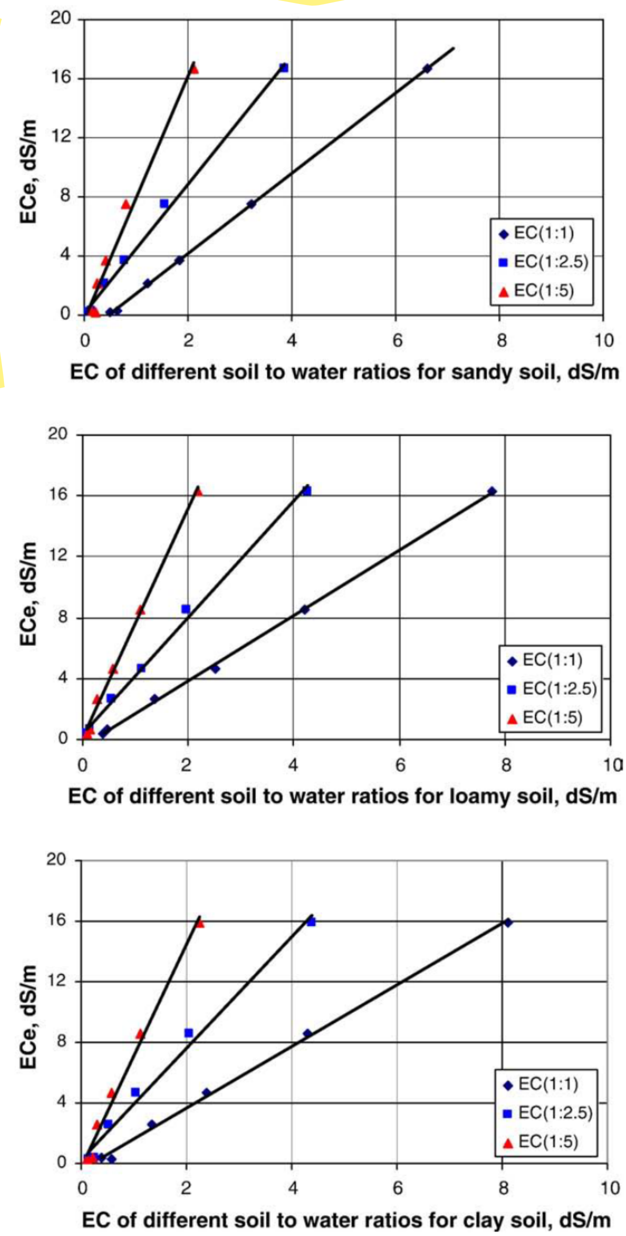

Fig. 1. Relationships of saturated paste electrical conductivity with different soil to water ratios depending on soil texture.

Table 3
Summary statistics for major ions and electrical conductivity of the soil samples used to establish relationships between saturated paste extracts and different soil to water ratios

Statistic	EC	Na^+	K^+	Ca^{2+}	Mg^{2+}	HCO_3^{2-}	Cl^-	SO_4^{2-}
	dS m^{-1}				me l^{-1}			
SP extracts								
Mean	5.34	34.63	0.28	49.05	38.09	0.81	107.58	13.69
Median	3.19	14.80	0.25	29.66	10.55	0.77	52.28	2.22
Standard error	0.77	5.96	0.02	7.06	7.55	0.06	18.07	2.26
Minimum	0.22	0.54	0.03	3.14	1.4	0.19	0.75	0.17
Maximum	17.68	130.51	0.65	174.65	195.83	1.68	406.80	59.63
(1:1) soil to water ratio								
Mean	2.66	15.70	0.18	23.06	14.46	0.31	48.20	5.47
Median	1.58	7.99	0.19	16.16	4.91	0.29	27.75	1.99
Standard error	0.34	2.48	0.01	2.86	3.72	0.02	7.12	1.86
Minimum	0.31	1.17	0.04	4.17	0.93	0.02	5.25	0.28
Maximum	8.35	59.36	0.4	78.1	120.33	0.68	193.55	65.09
(1:2.5) soil to water ratio								
Mean	1.30	8.14	0.11	10.40	4.50	0.44	21.11	1.60
Median	0.67	3.56	0.09	6.02	2.17	0.41	10.25	1.28
Standard error	0.19	1.40	0.01	1.41	0.70	0.02	3.38	0.19
Minimum	0.07	0.21	0.03	0.45	0.50	0.17	0.40	0.03
Maximum	4.50	31.56	0.29	33.32	17.66	0.79	78.55	5.15
(1:5) soil to water ratio								
Mean	0.72	4.30	0.08	5.66	2.82	0.28	11.22	1.37
Median	0.37	1.81	0.07	3.69	1.52	0.24	4.93	0.97
Standard error	0.10	0.72	0.01	0.69	0.39	0.02	1.65	0.16
Minimum	0.08	0.07	0.03	0.79	0.81	0.14	1.00	0.19
Maximum	2.31	15.94	0.21	18.24	10.68	0.82	39.30	4.85

Table 4
Coefficient of determination (r^2) and regression equations describing the relationships of EC between saturated paste extracts (EC_e) and different soil to water ratios depending on soil texture

Soil to water ratios	With intercept		Without intercept	
	Regression equation [a]	r^2	Regression equation [a]	r^2
	Sandy soil		Sandy soil	
1:1	$EC_e=2.72\ x-1.27$	0.99	$EC_e=2.42\ x$	0.98
1:2.5	$EC_e=4.34\ y+0.17$	0.99	$EC_e=4.41\ y$	0.99
1:5	$EC_e=8.22\ z-0.33$	0.98	$EC_e=7.98\ z$	0.98
	Loamy soil		Loamy soil	
1:1	$EC_e=2.15\ x-0.44$	0.99	$EC_e=2.06\ x$	0.99
1:2.5	$EC_e=3.84\ y+0.35$	0.99	$EC_e=3.96\ y$	0.99
1:5	$EC_e=7.58\ z+0.06$	0.99	$EC_e=7.62\ z$	0.99
	Clay soil		Clay soil	
1:1	$EC_e=2.03\ x-0.41$	0.99	$EC_e=1.96\ x$	0.99
1:2.5	$EC_e=3.68\ y+0.22$	0.99	$EC_e=3.75\ y$	0.99
1:5	$EC_e=7.36\ z-0.24$	0.99	$EC_e=7.19\ z$	0.98

[a] x, y, and z are values measured in (1:1), (1:2.5) and (1:5) soil to water ratios, respectively.

2.2. Extract preparation and analysis

Saturated paste extracts were prepared by adding distilled water to approximately 500 g soil sample with stirring until it reached a condition of complete saturation (Rhoades, 1982). The saturated pastes were allowed to equilibrate for 18 h. The extracts obtained by vacuum were filtered using Whatman #42 filter and analyzed for Na^+, K^+, Ca^{2+} and Mg^{2+}according to Fresenius et al. (1988); and Cl^-, CO_3^{2-}, and HCO_3^- according to Ayyıldız (1976). SO_4^{2-} was calculated by subtracting the total amounts of anions such as Cl^-, CO_3^{2-}, and HCO_3^- from total amounts of cations. The same vacuum was applied to obtain extracts for saturation paste and different soil to water ratios.

(1:1) soil to water ratio suspensions were prepared by adding 100 ml of distilled water to 100 g of oven-dried soil sample. The containers including suspensions were shaken for 1 min by hand 4 times at 30-minute intervals (Rhoades, 1982). The extracts obtained from the suspensions were filtered using Whatman #42 filter and analyzed using the same methods as with the saturated paste extracts.

(1:2.5) soil to water ratio suspensions were prepared by adding 75 ml of distilled water to 30 g of oven-dried soil sample. The containers including suspensions were shaken for 1 min by hand 4 times at 30-minute intervals (Rhoades, 1982). The suspensions were filtered using Whatman #42 filter to obtain the extracts. The extracts were analyzed using the same methods as with the saturated paste extracts.

(1:5) soil to water suspensions were prepared by adding 75 ml of distilled water to 15 g of oven-dried soil sample. The containers including suspensions were shaken for 1 min by hand 4 times at 30-minute intervals (Rhoades, 1982). The suspensions were filtered using Whatman #42 filter to obtain the extracts. The extracts were analyzed using the same methods as with the saturated paste extracts.

2.3. Statistical analyses

Statistical analysis was carried out using the MSTAT-C software. Means were compared by analysis of variance (ANOVA) and the LSD test at $p \leq 0.05$.

3. Results and discussion

The summary statistics for major ions and electrical conductivity of the soil samples are given in Table 3. Electrical conductivities of the soil samples studied ranged from 0.22 to 17.68 dS/m for the saturated paste extracts, from 0.31 to

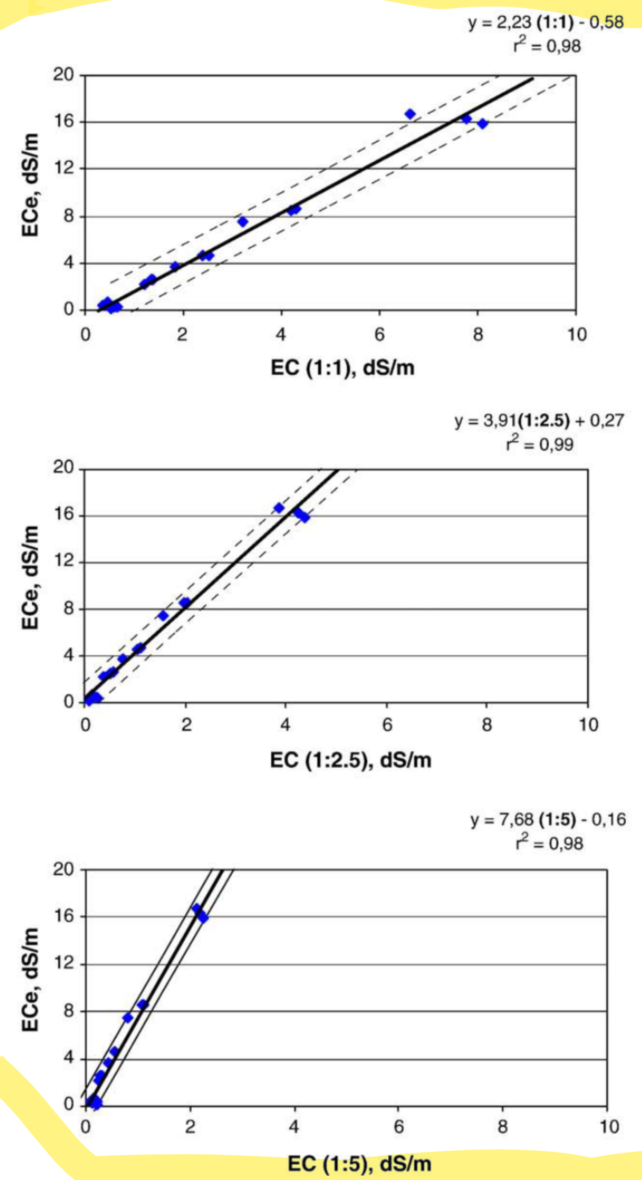

Fig. 2. Relationships of saturated paste electrical conductivity with different soil to water ratios for combined soil texture data.

8.35 dS/m for (1:1) soil to water ratio, from 0.07 to 4.5 dS/m for (1:2.5) soil to water ratio, and from 0.08 to 2.31 dS/m for (1:5) soil to water ratios. As the soil to water ratio increased the EC is decreased because of dilution effects as suggested by USDA (1954) and Rhoades (1982).

The highest ion concentration was measured in Cl (Table 3) because the NaCl, KCl, and $CaCl_2$ salts were used in the salinization process. Mean ion concentrations and electrical conductivities for saturated paste extracts were almost two fold greater than that of the (1:1) soil to water extracts, about four fold greater than that of the (1:2.5) soil to water ratios, and approximately eight fold greater than that of the (1:5) soil to water ratios. In other words, when soil to water ratios are increased about two fold, approximately two fold diluted values are measured. Zhang et al. (2005) are also reporting about two fold dilution when they compared the saturated paste result with (1:1) soil to water ratio.

3.1. EC of different soil to water ratios

The electrical conductivity of saturated paste (EC_e) versus different soil to water ratios for sandy, loamy, and clay soil is presented in Fig. 1. The slopes of the regression lines for three of the soil texture are increasing depending on soil to water ratios as a result of dilution effect (Fig. 1). The results are also given in Table 4 with and without intercept values for the regression equation. Electrical conductivity of saturated paste extract was highly correlated with different soil to water ratios for all soil textures. Neither the slopes nor the determination coefficients are changed drastically when intercepts are not included in the regression equations (Table 4). Franzen (2003) gives also equations for coarse, medium, and fine soil textures for (1:1) soil to water ratio (Table 1). The slopes of the regression equations of coarse, medium and fine soils given by Franzen (2003) are 3.01, 3.01, and 2.96, respectively, for (1:1) soil to water ratios. The slopes obtained in this study for sandy, loamy, and clay textures are 2.72, 2.15, and 2.03, respectively, for (1:1) soil to water ratios (Table 4). The differences in results can be attributed to the clay content as well as clay types. When the soil texture is changing from coarse to fine, a decreasing trend in the slopes are observed both in our results and Franzen's (2003) results. The same trend in slopes is also observed for (1:2.5) and (1:5) soil to water ratios (Table 4). This can be explained by the fact that all salts cannot be easily washed out of the soil when clay content is high. Clay surfaces are negatively charged and can adsorb ions more than sandy soils do. Electrical conductivity is a lumped parameter depending on the amount of ions in the solution. Most of the salts in sandy soils are washed into the solution resulting to higher values of electrical conductivity.

Examining the results of electrical conductivity given in Table 4 and Fig. 1 shows that the slopes are at close proximity of 2, 4, and 7.5 for (1:1), (1:2.5), and (1:5) soil to water ratios, respectively, for three of the soil textures. In other words, soil to water ratio is more pronounced than soil textures. The idea that soil to water ratio is more pronounced than soil texture leads one to combine data of soil textures into one graph as shown in Fig. 2. The dashed lines in Fig. 2 represent the 95% confidence interval for the regression line. Ion concentrations together with electrical conductivities are presented in Table 5 with and without intercept to be able to compare with already published results since some of them are omitting the intercept in regression equations when they presented the result. The results show that values of saturated paste extracts are highly correlated with the values obtained in different soil to water ratios. The lowest coefficient of determination was obtained in K^+ while the highest was in Na^+ when all soil to water ratios were examined (Table 5).

Table 5
Coefficient of determination (r^2) and regression equations describing the relationships between saturated paste extracts (SP) and different soil to water ratios for combined soil textures

Parameter	With intercept		Without intercept	
	Regression equation [a]	r^2	Regression equation [a]	r^2
EC, dS m^{-1}	SP = 2.23 x − 0.58	0.98	SP = 2.11 x	0.98
Cl^-, me l^{-1}	SP = 2.41 x − 8.48	0.90	SP = 2.33 x	0.90
K^+, me l^{-1}	SP = 1.35 x + 0.03	0.64	SP = 1.49 x	0.63
Na^+, me l^{-1}	SP = 2.32 x − 1.74	0.93	SP = 2.27 x	0.93
Ca^{2+}, me l^{-1}	SP = 2.25 x − 2.87	0.83	SP = 2.18 x	0.83
Mg^{2+}, me l^{-1}	SP = 1.75 x + 12.80	0.74	SP = 1.95 x	0.70
EC, dS m^{-1}	SP = 3.91 y + 0.27	0.99	SP = 4.00 y	0.98
Cl^-, me l^{-1}	SP = 5.27 y − 3.70	0.97	SP = 5.20 y	0.97
K^+, me l^{-1}	SP = 2.24 y + 0.04	0.81	SP = 2.49 y	0.80
Na^+, me l^{-1}	SP = 4.23 y + 0.20	0.99	SP = 4.24 y	0.99
Ca^{2+}, me l^{-1}	SP = 4.96 y − 2.49	0.97	SP = 4.84 y	0.97
Mg^{2+}, me l^{-1}	SP = 10.54 y − 9.28	0.96	SP = 9.63 y	0.94
EC, dS m^{-1}	SP = 7.68 z − 0.16	0.98	SP = 7.57 z	0.98
Cl^-, me l^{-1}	SP = 10.81 z − 13.71	0.97	SP = 10.24 z	0.97
K^+, me l^{-1}	SP = 2.57 z + 0.06	0.55	SP = 3.12 z	0.51
Na^+, me l^{-1}	SP = 8.22 z − 0.70	0.99	SP = 8.16 z	0.99
Ca^{2+}, me l^{-1}	SP = 9.98 z − 7.50	0.96	SP = 9.25 z	0.95
Mg^{2+}, me l^{-1}	SP = 18.86 z − 15.05	0.97	SP = 16.24 z	0.93

[a] x, y, and z are values measured in (1:1), (1:2.5) and (1:5) soil to water ratios, respectively.

Table 6
Variance analyses results with respect to EC, anion and cation

Source of variation	d.f	Characteristic (variable)							
		EC	Na^+	K^+	Ca^{2+}	Mg^{2+}	HCO_3^{2-}	Cl^-	SO_4^{2-}
Method (M)	3	***	***	***	***	***	***	***	***
Texture (T)	2	***	***	***	***	***	***	***	***
Saline water application (SWA)	5	***	***	***	***	***	***	***	***
(M × T)	6	***	NS	***	***	***	***	***	***
(M × SWA)	15	***	***	***	***	***	***	***	***
(T × SWA)	10	***	NS	***	***	***	***	***	***
(M × T × SWA)	30	***	NS	***	***	***	***	***	***
Error	144								
Total	215								

[NS]Not significant, ***Significant at $p < 0.001$.

Table 7
The average values of EC, anion and cation in different methods

Method	Characteristic (variable)							
	EC	Na^+	K^+	Ca^{2+}	Mg^{2+}	HCO_3^{2-}	Cl^-	SO_4^{2-}
SP extracts	5.34 a	34.64 a	0.28 a	49.06 a	34.09 a	0.81 a	107.58 a	13.69 a
(1:1) soil to water ratio	2.66 b	15.70 b	0.18 b	23.06 b	14.46 b	0.31 c	48.20 b	5.47 b
(1:2.5) soil to water ratio	1.30 c	8.15 c	0.11 c	10.40 c	4.49 c	0.44 b	21.11 c	1.60 c
(1:5) soil to water ratio	0.72 d	4.30 d	0.08 d	5.66 d	2.82 d	0.28 d	11.22 d	1.37 c
LSD	0.10	1.09	0.01	1.08	0.40	0.02	1.14	1.28

Different letters show different means according to LSD test results at 5% confidence interval.

An increasing slope for the regression equations of electrical conductivity and ion concentrations was observed when soil to water ratio is increased from (1:1) to (1:5), indicating that additional water causes dilution. In a sense, the slopes of the regression equations can be considered as a dilution ratio. Examining the results given in Table 5 shows that the slopes of the regression equations are increasing approximately two fold. The amount of water in different soil to water ratios was increased also two fold, indicating that the results are consistent.

Considering the higher coefficients of determination obtained, as seen in Table 5, the results are similar to those reported by other researchers who also found that highly significant relationships existed between saturated paste extracts and different soil to water ratios (Shirokova et al., 2000, Zhang et al., 2005, Ozcan et al., 2006). For electrical conductivity of soil to water ratio of (1:1), the slope of 2.11 when the intercept is omitted is slightly higher than those reported by Zhang et al. (2005) and Ozcan et al. (2006) whereas it is less than the theoretically derived value of USDA (1954). Shirokova et al. (2000) gives the value of 3.64 while the same authors cite the value of 2.2 from Landon (1991) for the same soil to water ratio. The slopes of the electrical conductivities of (1:2.5) and (1:5) soil to water ratios including the intercept found in this study are higher than those given by Ozcan et al. (2006). These differences in results reported by various researchers may stem from the amount of clay content of soil samples as well as the type of clay.

3.2. Ion concentration of different soil to water ratios

Highly significant relationships existed between ions extracted from saturated paste and different soil to water ratios with coefficients of determination ranging from 0.64 to 0.93 for (1:1), from 0.81 to 0.99 for (1:2.5), and from 0.55 to 0.99 for (1:5) soil to water ratios (Table 5). The slopes obtained in this study for (1:1) soil to water ratio are less than those reported by USDA (1954) whereas they are slightly higher than that of the slopes reported by Zhang et al. (2005) for Cl^-, Na^+, and Ca^{2+}, and slightly less for K^+, and Mg^{2+}. The slopes of the regression lines obtained in this study are in accord with that of the slopes reported by Ozcan et al. (2006) for different soil to water ratios. The differences in results can be attributed to soil clay content, clay type as well as artificially salinized soils used in this study.

3.3. Statistical analyses of the data

The results of the statistical analyses with respect to EC (dS m^{-1}), anions and cations (me l^{-1}) are given in Table 6 whereas the averages of them in different methods, soil textures and saline water applications are presented in Tables 7–9, respectively. It was found that all the parameters examined are statistically different ($p \le 0.001$) (Table 6). The average values of EC, anions and cations in different soil to water ratios formed a group according to LSD ($p \le 0.05$) (Table 7). Except for EC of loamy and clay textured soil and HCO_3^{2-} concentration of sandy and loamy soil, the average values of EC, anions and cations in different soil textures formed a group according to LSD ($p \le 0.05$) (Table 8). This means that the differences in averages are statistically significant. In this case the regression equation derived for combined soil textures cannot be used. Instead, the regression equations given in Tables 10–12 for sandy, loamy and clay soils, respectively, should be used. Except for de-ionized water and tap water, the results of different saline water applications are also statistically different (Table 9). That means that the range in saline water applications was chosen correctly.

Table 8
The average values of EC, anion and cation in different soil textures

Texture	Characteristic (variable)							
	EC	Na^+	K^+	Ca^{2+}	Mg^{2+}	HCO_3^{2-}	Cl	SO_4^{2-}
Sand	2.31 b	15.70 ab	0.20 a	17.35 c	15.20 b	0.47 a	44.08 b	3.92 b
Loam	2.61 a	16.64 a	0.19 b	22.98 b	21.67 a	0.48 a	54.20 a	6.83 a
Clay	2.60 a	14.76 b	0.09 c	25.80 a	8.02 c	0.43 b	42.80 c	5.85 a
LSD	0.09	0.94	0.007	0.94	0.35	0.02	0.99	1.11

Different letters show different means according to LSD test results at 5% confidence interval.

Table 9
The average values of EC, anion and cation in saline water applications

Saline water applications	Characteristic (variable)							
	EC	Na^+	K^+	Ca^{2+}	Mg^{2+}	HCO_3^{2-}	Cl^-	SO_4^{2-}
De-ionized water	0.26 e	0.72 e	0.10 d	2.69 e	1.21 e	0.61 a	2.98 e	1.18 d
Tap water	0.33 e	1.08 e	0.09 e	3.55 e	1.64 e	0.55 b	4.30 e	1.49 d
2 dS/m	1.13 d	4.79 d	0.15 c	11.02 d	3.84 d	0.43 c	17.74 d	1.64 d
4 dS/m	2.02 c	10.01 c	0.16 c	19.01 c	7.60 c	0.36 d	32.33 c	4.08 c
8 dS/m	3.74 b	22.74 b	0.20 b	33.41 b	19.22 b	0.36 d	67.09 b	8.13 b
16 dS/m	7.54 a	54.84 a	0.28 a	62.60 a	56.27 a	0.44 c	157.71 a	16.68 a
LSD	0.13	1.33	0.01	1.33	0.49	0.02	1.39	1.57

Different letters show different means according to LSD test results at 5% confidence interval.

3.4. Validation of EC of different soil to water ratios

The regression equations of electrical conductivity obtained for (1:1), (1:2.5), and (1:5) soil to water ratios are validated against the corresponding data given by Shirokova et al. (2000), as shown in Fig. 3. Data taken from Shirokova et al. (2000) are less than 20 dS/m. The average of measured EC_e for Shirokova et al. (2000) is 7.83 dS/m whereas the computed EC_e using the regression equations obtained are 4.93, 9.07, and 10.84 dS/m for (1:1), (1:2.5), and (1:5) soil to water ratios, respectively. The discrepancies between the average measured and predicted values are −37%, 15%, and 38% for (1:1), (1:2.5), and (1:5) soil to water ratios, respectively. Ozcan et al. (2006) reported that predictions of (1:1) soil to water ratio were closer to the measured data than (1:2:5), and (1:5) soil to water ratios whereas Shirokova et al. (2000) expressed that (1:1) and (1:2.5) soil to water ratios could be used equally well to estimate saturated paste electrical conductivity.

4. Conclusions

The results of statistical analyses showed that soil texture is affecting saturated soil paste electrical conductivities (EC_e), anion and cation concentrations for different soil to water ratios. Both combined and soil specific regression equations are derived and presented in the paper. The choice whichever to use are left to the reader. When more precise

Table 10
Coefficient of determination (r^2) and regression equations describing the relationships between saturated paste extracts (SP) and different soil to water ratios for sandy soil

Parameter	With intercept		Without intercept	
	Regression equation [a]	r^2	Regression equation [a]	r^2
(1:1) soil to water ratio				
EC, dS m^{-1}	SP = 2.72 x − 1.27	0.99	SP = 2.42 x	0.98
Cl^-, me l^{-1}	SP = 4.04 x − 49.30	0.98	SP = 3.33 x	0.92
K^+, me l^{-1}	SP = 2.03 x − 0.19	0.48	SP = 1.31 x	0.41
Na^+, me l^{-1}	SP = 2.75 x − 6.45	0.99	SP = 2.55 x	0.99
Ca^{2+}, me l^{-1}	SP = 4.88 x − 33.82	0.70	SP = 3.14 x	0.59
Mg^{2+}, me l^{-1}	SP = 5.34 x − 10.81	0.99	SP = 4.88 x	0.97
(1:2.5) soil to water ratio				
EC, dS m^{-1}	SP = 4.34 y + 0.17	0.99	SP = 4.41 y	0.99
Cl^-, me l^{-1}	SP = 6.16 y − 6.42	0.99	SP = 6.02 y	0.99
K^+, me l^{-1}	SP = 2.28 y + 0.03	0.82	SP = 2.49 y	0.81
Na^+, me l^{-1}	SP = 4.46 y + 0.44	0.99	SP = 4.48 y	0.99
Ca^{2+}, me l^{-1}	SP = 5.36 y + 0.02	0.99	SP = 5.36 y	0.99
Mg^{2+}, me l^{-1}	SP = 11.13 y − 6.85	0.99	SP = 10.52 y	0.99
(1:5) soil to water ratio				
EC, dS m^{-1}	SP = 8.22 z − 0.33	0.98	SP = 7.98 z	0.98
Cl^-, me l^{-1}	SP = 10.81 z − 13.71	0.97	SP = 10.24 z	0.97
K^+, me l^{-1}	SP = 2.51 z + 0.08	0.72	SP = 3.08 z	0.67
Na^+, me l^{-1}	SP = 8.36 z + 0.65	0.99	SP = 8.42 z	0.99
Ca^{2+}, me l^{-1}	SP = 10.63 z − 7.48	0.98	SP = 9.75 z	0.97
Mg^{2+}, me l^{-1}	SP = 18.23 z − 12.29	0.98	SP = 16.40 z	0.96

[a] x, y, and z are values measured in (1:1), (1:2.5) and (1:5) soil to water ratios, respectively.

Table 11
Coefficient of determination (r^2) and regression equations describing the relationships between saturated paste extracts (SP) and different soil to water ratios for loamy soil

Parameter	With intercept		Without intercept	
	Regression equation [a]	r^2	Regression equation [a]	r^2
(1:1) soil to water ratio				
EC, dS m^{-1}	SP = 2.15 x − 0.44	0.99	SP = 2.06 x	0.99
Cl^-, me l^{-1}	SP = 2.26 x − 3.16	0.99	SP = 2.23 x	0.92
K^+, me l^{-1}	SP = 1.40 x + 0.08	0.71	SP = 1.73 x	0.67
Na^+, me l^{-1}	SP = 1.97 x + 0.02	0.98	SP = 1.97 x	0.98
Ca^{2+}, me l^{-1}	SP = 2.14 x − 5.28	0.94	SP = 2.01 x	0.94
Mg^{2+}, me l^{-1}	SP = 1.55 x + 11.18	0.95	SP = 1.68 x	0.92
(1:2.5) soil to water ratio				
EC, dS m^{-1}	SP = 3.84 y + 0.35	0.99	SP = 3.96 y	0.99
Cl^-, me l^{-1}	SP = 5.09 y + 7.05	0.99	SP = 5.23 y	0.99
K^+, me l^{-1}	SP = 2.13 y + 0.06	0.59	SP = 2.52 y	0.57
Na^+, me l^{-1}	SP = 3.71 y + 2.84	0.98	SP = 3.86 y	0.98
Ca^{2+}, me l^{-1}	SP = 4.81 y − 0.81	0.97	SP = 4.77 y	0.97
Mg^{2+}, me l^{-1}	SP = 11.11 y − 13.01	0.98	SP = 9.85 y	0.96
(1:5) soil to water ratio				
EC, dS m^{-1}	SP = 7.58 z + 0.06	0.99	SP = 7.62 z	0.99
Cl^-, me l^{-1}	SP = 11.54 z − 6.50	0.99	SP = 11.24 z	0.99
K^+, me l^{-1}	SP = 2.08 z + 0.17	0.44	SP = 3.58 z	0.43
Na^+, me l^{-1}	SP = 7.72 z + 0.73	0.98	SP = 7.79 z	0.98
Ca^{2+}, me l^{-1}	SP = 10.42 z − 5.63	0.96	SP = 9.76 z	0.95
Mg^{2+}, me l^{-1}	SP = 21.39 z − 21.17	0.99	SP = 17.49 z	0.93

[a] x, y, and z are values measured in (1:1), (1:2.5) and (1:5) soil to water ratios, respectively.

results are required, the equations based on soil texture could be used.

Based on the results of the highly correlated regression equations obtained, it can be concluded that extracts of (1:1), (1:2.5) or (1:5) soil to water ratios can be used to estimate saturated paste electrical conductivity and ion concentrations of soils. However, when the results of the validation are taken into account, it seems that soil water ratio of (1:2.5) matches the measured data well. The benefits of converting results of (1:1), (1:2.5) or (1:5) soil to water ratios to saturated paste extracts equivalents are potentially large. Soil salinity laboratories can minimize the cost and time associated with soil salinity analysis by using less costly methods of different soil to water ratios while still maintaining a high level of accuracy and precision.

A specific benefit of measuring electrical conductivity and ion concentration using extracts of (1:2.5) soil to water ratio is that the measurements can be conducted on the samples prepared for pH measurements. The soil water slurry of (1:2.5) prepared for pH measurements can be extracted and used for further measurements, minimizing time and cost associated with soil salinity studies.

However, one should keep in mind that the converted results of (1:1), (1:2.5) or (1:5) soil to water ratios are not as precise as results of saturated paste extracts, although adjusted results can be accurate in approximation of saturated paste measurements.

Table 12
Coefficient of determination (r^2) and regression equations describing the relationships between saturated paste extracts (SP) and different soil to water ratios for clay soil

Parameter	With intercept		Without intercept	
	Regression equation [a]	r^2	Regression equation [a]	r^2
(1:1) soil to water ratio				
EC, dS m^{-1}	SP = 2.03 x − 0.41	0.99	SP = 1.96 x	0.99
Cl^-, me l^{-1}	SP = 2.09 x − 11.01	0.99	SP = 1.98 x	0.99
K^+, me l^{-1}	SP = 1.49 x + 0.02	0.69	SP = 1.69 x	0.68
Na^+, me l^{-1}	SP = 2.32 x − 0.28	0.85	SP = 2.32 x	0.85
Ca^{2+}, me l^{-1}	SP = 2.25 x − 7.33	0.99	SP = 2.10 x	0.98
Mg^{2+}, me l^{-1}	SP = 2.52 x + 2.41	0.90	SP = 2.65 x	0.89
(1:2.5) soil to water ratio				
EC, dS m^{-1}	SP = 3.68 y + 0.22	0.99	SP = 3.75 y	0.99
Cl^-, me l^{-1}	SP = 4.72 y − 12.02	0.98	SP = 4.46 y	0.98
K^+, me l^{-1}	SP = 3.59 z − 0.04	0.81	SP = 2.93 z	0.78
Na^+, me l^{-1}	SP = 4.47 z − 2.61	0.99	SP = 4.34 z	0.99
Ca^{2+}, me l^{-1}	SP = 5.04 z − 9.61	0.98	SP = 4.61 z	0.96
Mg^{2+}, me l^{-1}	SP = 6.69 y − 1.66	0.88	SP = 6.44 y	0.88
(1:5) soil to water ratio				
EC, dS m^{-1}	SP = 7.36 z − 0.24	0.99	SP = 7.19 z	0.98
Cl^-, me l^{-1}	SP = 9.75 z − 21.03	0.99	SP = 8.82 z	0.97
K^+, me l^{-1}	SP = 3.58 z + 0.18	0.72	SP = 3.02 z	0.70
Na^+, me l^{-1}	SP = 8.34 z − 2.98	0.99	SP = 8.06 z	0.99
Ca^{2+}, me l^{-1}	SP = 9.71 z − 12.98	0.97	SP = 8.60 z	0.95
Mg^{2+}, me l^{-1}	SP = 13.95 z − 7.69	0.92	SP = 11.65 z	0.87

[a] x, y, and z are values measured in (1:1), (1:2.5) and (1:5) soil to water ratios, respectively.

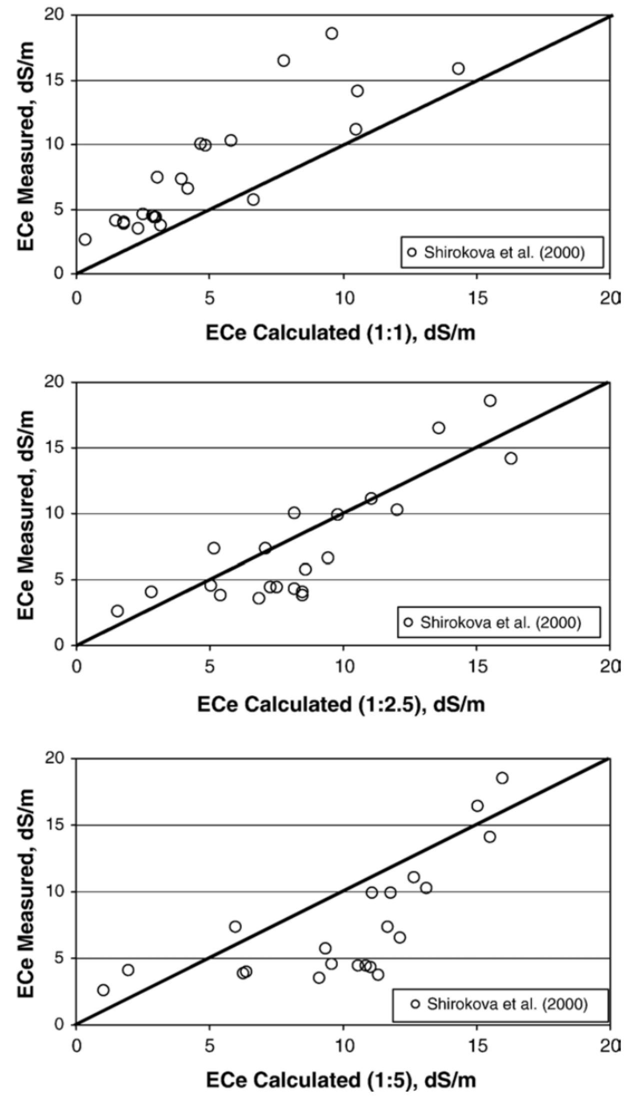

Fig. 3. Validation of the regression equations obtained for different soil to water ratios.

Acknowledgment

The authors are grateful to the Scientific Research Administration Unit of Akdeniz University, Antalya, Turkey.

References

Ayyildiz, M., 1976. Sulama suyu kalitesi ve sulamada tuzluluk problemleri, A. Ü. Ziraat Fakültesi. Ders Kitabı No: 199. . Yayınları No: 636Ankara-Türkiye.

Day, P.R., 1982. Particle Fractionation and Particle Size Analysis. SSSA, Madison, Wisconsin, p. 545. USA.

Franzen, D., 2003. Managing Saline Soils in North Dakota. North Dakota State University Extension Service, Fargo. Available online at http://www.ag.ndsu.edu/pubs/plantsci/soilfert/sf1087-1.htm (verified on October 10, 2006).

Fresenius, W., Quentin, K.E., Schneidler, W., 1988. Water Analysis a Practical Guide to Physico-Chemical, Chemical and Microbiological Water Examination and Quality Assurance. Springer-Verlay, Berlin. ISBN: 3-540-17723.

Hogg, T.J., Henry, J.L., 1984. Comparison of 1:1 and 1:2 suspensions and extracts with the saturation extract in estimating salinity in Saskatchewan soils. Can. J. Soil Sci. 64, 669–704.

Jackson, M.C., 1967. Soil Chemical Analysis. Prentice Hall of India Private Limited, New Delhi, USA.

Landon, J.R., 1991. Booker Tropical Soil Manual. Booker Tate Limited.

Ozcan, H., Ekinci, H., Yigini, Y., Yuksel, O., 2006. Comparison of four soil salinity extraction methods. Proceedings of 18th International Soil Meeting on "Soil Sustaining Life on Earth, Managing Soil and Technology", May 22–26, 2006, Sanlıurfa, Turkey, p. 697–703.

Pitman, M., Lauchli, A., 2002. Global impacts of salinity and agricultural ecosystems. In: Lauchli, A., Lüttge, U. (Eds.), Salinity: Environment–Plants–Molecules. Kluwer Academics, pp. 3–20.

Qadir, M., Ghafoor, A., Murtaza, G., 2000. Amelioration strategies for saline soils. Land Degrad. and Develop. 11, 501–521.

Rhoades, J.D., 1982. Soluble salts, In: Page, A.L. (Ed.), Methods of Soil Analysis, Part 2, Second Edition, American Society of Agronomy, Inc., Madison, WI, USA, p. 167–179. Agronomy Monograph No 9.

Rhoades, J.D., Loveday, J., 1990. Salinity in irrigated agriculture. In: Stewert, B.A., Nielsen, D.R. (Eds.), Irrigation of Agricultural Crops. ASAE, Madison, WI, p. 1089–1142. Agronomy Monograph No 30.

Rhoades, J.D., Manteghi, N.A., Shouse, P.J., Alves, W.J., 1989. Estimating soil salinity from saturated soil–paste electrical conductivity. Soil Sci. Soc. Am. J. 53, 428–433.

Shirokova, Y., Forkutsa, I., Sharafutdinova, N., 2000. Use of electrical conductivity instead of soluble salts for soil salinity monitoring in Central Asia. Irrig. Drain. Syst. 14, 199–205.

Soil Survey Staff, 1951. Soil Survey Manual. Agricultural Research Administration, U.S. Dept. Agriculture. Handbook No: 18.

USDA, 1954. Diagnoses and improvement of saline and alkali soils. Agric. Handbook No. 60. USSL, Riverside, CA, USA.

Zhang, H., Schroder, J.L., Pittman, J.J., Wang, J.J., Payton, M.E., 2005. Soil salinity using saturated paste and 1:1 soil to water extract. Soil Sci. Soc. Am. J. 69, 1146–1151.