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**Effect of Moisture Content, Soil Texture,
Soil Structure, Esp, and Soil
Solution Concentration on Bulk Soil Ec**

I. Shainberg, J.D. Rhoades, H. Frenkel

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EFFECT OF MOISTURE CONTENT, SOIL TEXTURE, SOIL STRUCTURE,
ESP AND SOIL SOLUTION CONCENTRATION ON BULK SOIL EC

Name and Address of Investigators

Principal Investigator: I. Shainberg ✓
Cooperating Investigator (s): J.D. Rhoades (USA) and
H. Frenkel (Israel) ✓

Name and Address of Affiliated Institutions

Principal Institution: Institute of Soils and Water,
ARO, POB 6, Bet Dagan, 50250,
Israel.
Cooperating Institution(s): U.S. Salinity Laboratory,
USDA, Riverside,
California, USA.

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Principal Investigator

Institution's Authorizing Official

I. Shainberg

Yuval Eshdat
Dr. YUVAL ESHDAT
Head, Div. for Research Projects and Budgets
Agricultural Research Organization

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- 1) Soil moisture . 2) Soil texture
- 3) Soil structure

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c. Abstract

The effect of moisture content and soil texture on the electrical conductivity of bulk soil as a function of the electrical conductivity of the soil solution ($EC_a - EC_w$ relations) was determined on undisturbed soils in field experiments. The moisture content had a marked effect on both the slope of the $EC_a - EC_w$ curves and on the intercept, both tend to increase with the increase in moisture content. The formation factor which applies to the soluble ion applies also to the exchangeable ions. Only when the formation factor of the solid phase is included in the calculation of the specific surface conductivity, it is found that this value is independent of the moisture content.

Clay content had a marked effect on the solid conductivity at all moisture contents studied. The effect of clay content on the slopes of the $EC_a - EC_w$ curves is due to its effect on the moisture content. In USA, soil electrical conductivity was calibrated with salinity for 12 soil types, and the calibrations were related to soil properties. The calibration slope was found to be highly correlated with water-holding capacity and saturation percentage, whereas the intercept was highly correlated with clay content. These findings permit the prediction of calibrations for salinity diagnosis applications where direct calibrations are unavailable or unwarranted.

Calibration curves obtained in the laboratory on water-saturated soil columns are very sensitive to entrapped air which affects the calibration slope of $EC_a - EC_w$ by 25 percent or more. This difference in the slope is as large as the difference in slopes between soils having 25 and 50 percent clay. Displacing the entrapped air with CO_2 before saturation reduces the problem and produces a more accurate calibration curve.

d. - Report

The four electrode method enables a direct, instantaneous, in situ measurement of soil salinity (Rhoades and Ineson, 1971; Gupta and Panks, 1972; Rhoades et al., 1976; Rhoades, 1981; Shainberg et al., 1980; Nadler and Frenkel, 1980). Rhoades et al. (1976) derived a theoretical expression for the dependence of bulk soil electrical conductivity, EC_a , on the electrical conductivity (EC) of the soil solution (EC_w) and the volumetric moisture content of the soil, θ . This expression reads

$$EC_a = EC_w (\theta T) + EC_s' \quad [1]$$

where EC_s' is the apparent soil surface electrical conductivity and T is a transmission coefficient. In deriving this expression, Rhoades et al. (1976) assumed that: i) EC_a is made up of the electrical conductivities of the solution phase, EC_w , and that of the soil phase, EC_s' , which behave analogously to two conductors in parallel; and ii) the surface conductivity does not depend on the salinity of the soil solution or on the water content. They also found that the transmission coefficient, T , which is the reciprocal of the tortuosity factor depended on the moisture content of the soil, θ , as described in Eq. 2.

$$T = a\theta + b \quad [2]$$

where a and b are empirical parameters, typical to each soil. Shainberg et al. (1980) and Nadler and Frenkel (1980) showed that Eq. (1) is not valid for soils equilibrated with solutions of electrolyte concentrations below 4 dS m^{-1} . In the low EC_w range, the EC_a - EC_w plots become curvilinear, with an initial rapid increase in EC_a with increase in EC_w which is seemingly greater than that attributable to the conductivity of the added electrolyte alone. This observation lead Waxman and Smits (1968)

and Hadler and Frenkel (1980) to assume that the electrical conductivity of adsorbed cations (or the fraction of adsorbed cations which carried the electrical current) increased with an increase in the electrolyte concentration. Shainberg et al. (1980) pointed out that in soil water systems, an increase in electrolyte concentration should compress the diffuse double layer and hence should reduce the surface conductivity rather than increase the surface conductivity. To explain the $EC_a - EC_w$ curve, Shainberg et al. (1980), following Sauer et al. (1955), added a third element in parallel (in addition to the solid and solution elements in parallel that were suggested by Rhoades et al., 1976), which consist of the solution and soil phase in series. Their derivation leads to the final equation

$$EC_a = EC_w \left(\frac{1}{F} \right) + \frac{EC'_s EC_w}{[(1-d)/d]EC'_s + EC_w} \quad [3]$$

where F , the formation factor, is equal to $\frac{1}{\theta I}$ in Eq. 1, and d is the thickness of the solid phase in the soil-solution system and depends on the clay and electrolyte concentrations in the systems. When $EC_w > EC'_s$, i.e., at high solution concentration, Eq. (3) reduces to

$$EC_a = EC_w \left(\frac{1}{F} \right) + EC'_s \quad [4]$$

which is equivalent to Eq. [1].

At low electrolyte concentration, the second element in Eq. 3 determines the shape of the $EC_a - EC_w$ curve (sharp increase in EC_a with increase in EC_w), whereas at relatively high salt concentration the first linear term becomes dominant, with the second term determining the intercept.

The real specific conductivity of the solid phase, EC_s , which is related to the concentrations and mobilities of the adsorbed cations, can be calculated from the apparent surface conductivity, EC'_s , if one knows the "formation factor" for the exchangeable ions. Cremers et al. (1966) found for clay gels and soils that the same F applies to both the solution and solid phases. The physical explanation for this conclusion is simple. In clay-water systems, the solid crystals are not conductive and the solid conductivity is due to the cations which reside in the diffuse double layer. Any separation of the ions in the soil pores into the solution and adsorbed cations envelope is arbitrary. Thus, the same formation factor applies to both and Eq. [4] becomes

$$EC_a = EC_w \left(\frac{1}{F} \right) + EC_s \left(\frac{1}{F} \right) \quad [5]$$

It should be clear that whereas in deriving Eq. [1] it was assumed that the surface conductivity was independent of the transmission coefficient and the moisture content (Rhoades et al., 1976), Eq. [5] suggests that the surface conductivity depends on both the transmission coefficient and the moisture content ($\frac{1}{F} = \theta T$).

The effect of moisture content, soil texture and cation exchange capacity (CEC) on the EC_a - EC_w curves was obtained mostly in laboratory studies (Gupta and Hanks, 1972; Rhoades et al., 1976; Nadler and Frenkel, 1980). The bulk electrical conductivity was found to increase markedly with ^{an} increase in water content in all studies, so much so that Kirkham and Taylor (1950) tested this method as a possible procedure to measure soil water content. A significant linear relationship was found between bulk conductivity and water content (Gupta and

predict that bulk conductivity depends on the moisture content to the

square power. Rhoades et al. (1976) also found that whereas the moisture content had a marked effect on the slope of the EC_a-EC_w curve, it had no effect on the intercept (EC_s). Conversely, Eq. [5] predicts that the intercept should also be affected by the moisture content. Based on laboratory studies, it was concluded that, in saturation, the slope was independent of the soil texture (Shainberg et al., 1980; Nadler and Frenkel, 1980), whereas Rhoades (1981) found the slope to be correlated with the clay+silt content. These disagreements in the literature are reexamined in this study on undisturbed soil profile in the field.

The objectives of this study are: 1) to determine if the moisture content has an effect on the intercept of the EC_a-EC_w curves; 2) to reexamine the dependence of the slope on the soil texture and the moisture content; 3) to determine the effect of clay content on the intercept and the solid conductivity, and 4) to correlate the experimental results with theoretical predictions. The experimental results were collected in field studies on an undisturbed soil profile. The soil moistures were all above "field capacity", assuming that at this range the four-electrode probe has its highest potential in assessing soil salinity, and in the measurement of flow of water and salts in the soil profile. In this moisture range; when the water content is decreased by drainage, salt is removed with the water and the salinity of the remaining soil water remains nearly constant and is determined by the salinity of the irrigation water.

Materials and Methods

The bulk soil EC as a function of both EC of the soil solution and EC of the soil extract, at various moisture

1 contents, was determined on three soils at the Volcan Center in
2 in Bet Dagan, Israel. The clay content in the three soils was 10, 16
3 and 45 %, respectively, and the dominant clay was montmorillonite with
4 some kaolinite. Additional properties of the three soils, together
5 with their international nomenclature, are presented in Table 1.

6 The EC_a - EC_w relations were obtained using the field calibration
7 method and the four-electrode salinity probe development by Rhoades and
8 van Schilfgaarde (1976). The salinity probe was obtained from Mortex
9 Corp. (model SCT) and was used to determine the EC_a values of small
10 bodies of field soil that had been artificially salinized by leaching
11 with excess solutions of salinity of 1.0, 4.0, 6.0, 10 and 15 $dS\ m^{-1}$
12 and constant SAR value ($SAR=5$). The leaching was done using a 50-cm diame-
13 ter by 35-cm-long metal cylinder driven about 10 cm into the soil. An
14 area of soil surrounding the cylinder at a distance of 20 cm from the
15 cylinders was also leached with the same solutions. To complete the
16 leaching for the loamy sand, loam and clay soil, 1, 1 and 2 days were
17 needed, respectively. One hour after the impounded waters had infil-
18 trated into the soils, access holes were made using an Oelfield soil
19 sampler to a depth of 30 cm. Soil was sampled at a depth of 15 to 30
20 cm, its moisture content determined gravimetrically, a saturated paste
21 was prepared, and the electrical conductivity of the saturated paste
22 extract, EC_e , was determined (U.S. Salinity Laboratory Staff, 1954).
23 The salinity probe was inserted down the access hole centered
24 at a depth of 22.5 cm, and the electrical conductivity was
25 measured. The same procedure was repeated after 6, 24, 48 and 72 h.
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After 72 h, it was assumed that the soil was drained to field capacity. At the intermediate times, intermediate moisture contents were obtained and the EC_a of the soil at these moisture contents was measured.

Results and Discussion

The moisture content at field capacity and the saturation percentage (SP) of the three soils are also presented in Table 1. It is evident that, at field capacity, the soil solutions were diluted with distilled water (to prepare the soil pastes) by the factors 4.0, 2.4 and 2.2 for the loamy sand, loam and clay soils, respectively. This expresses itself in Fig. 1, where the electrical conductivity of the soil extracts, for soils sampled at field capacity, is presented as a function of the EC of the solutions used to leach the soil profile. Since excess solution was used and evaporation was prevented, it was assumed that the EC of the soil solution was equal to the EC of the leaching solutions. It is evident that both the slopes and intercepts of the lines relating EC_e to EC_w depend on the texture of the soil, both increasing with/increase in clay content. This suggests that EC_e is not related only to the soil solution salinity but depends also on the dilution ratio by which the soil sample, at field capacity, was diluted with distilled water to prepare the saturated paste. If we multiply the measured EC_e value of, for example, the profile leached with solution of $EC_w = 10$ dS/m, by the respective dilution factors, we obtain the values 8.8, 10.56, 10.56 dS/m for the loamy sand, loam and clay soils, respectively, which indicate that the dilution factor

1 explains most of the discrepancy. The presence of CaCO_3 , which is
2 slightly soluble accounts for the relatively high values of EC_e in the
3 loam and clay soils. The inaccuracy in determining the SP in sandy
4 soils (U.S. Salinity Laboratory Staff, 1954) accounts for the
5 relatively low value of the product ($\text{EC}_e \times \text{dilution factor}$) in the loamy
6 sand soil. The presence of CaCO_3 also accounts for the positive
7 values of the intercept in Fig. 1. When distilled water is mixed with
8 salt free soil, CaCO_3 and primary mineral dissolution determine the
9 electrolyte concentration in the soil solution (Shainberg *et al.*, 1981).
10 The extent of CaCO_3 dissolution is enhanced by the presence of
11 exchangeable sodium and magnesium which, by exchange reaction, act as
12 sink to the dissolved calcium. Thus, the rate of CaCO_3 dissolution
13 increases with an increase in the CEC of the soil.

14 In most of the works of Rhoades and co-workers (1971, 1976, 1981)
15 the $\text{EC}_a - \text{EC}_e$ calibration curves were studied. The justification was
16 that soil salinity is determined conventionally by measuring the
17 electrical conductivity of the extract, EC_e , of the saturated soil
18 paste. Under most conditions Rhoades *et al.* (1976, 1981) found that
19 EC_e and bulk soil electrical conductivity (EC_a) were highly correlated.
20 It is evident from the above discussion that when the effect of soil
21 texture on $\text{EC}_a - \text{EC}_w$ is to be investigated and sandy soils are to be
22 included in the study, the dilution error involved in using EC_e of
23 sandy soils should be considered. The U.S. Salinity Laboratory Staff
24 (1954), in recognizing the dilution error involved with the saturated
25 paste extract of coarse textured soils, suggested that the conductivity
26 of the "twice-saturation" extract, typical to sandy soils, should be
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1 doubled before using the standard saturation extract scale for
2 salinity evaluation. This procedure is not practical in this study, and
3 thus the effect of the actual EC_w on the EC_e of the soil is studied.
4 This reasoning is demonstrated further in Figs. 2 and 3.

5 In Fig. 2 the bulk EC at field capacity is presented as a
6 function of the EC of the extract, whereas in Fig. 3 the bulk EC is
7 presented as a function of the EC of the solutions used to leach the
8 soil. Since excess solution was used and evaporation was prevented,
9 it was assumed that the EC of the soil solution is equal to the EC
10 of the leaching solution. Considering first Fig. 2, a linear
11 correlation was obtained between EC_a and EC_e (as observed also by
12 Rhoades and co-workers, 1971, 1976, 1981). However, the effect of
13 clay content and saturation percentage on the slope and intercepts
14 was different from that obtained by Rhoades (1981). Whereas the
15 slopes predicted by Rhoades' equations for our three soils (their
16 saturation percentages are given in Table 1) were 8.95, 6.75 and 2.57,
17 our experimental values were 3.70, 2.94 and 1.85 for the loamy sand,
18 loam and clay soil, respectively. In this comparison it should be
19 noted that in Rhoades' equation $EC_e - EC_a$ slope is given, whereas in this
20 treatment $EC_a - EC_e$ slope (Fig. 2) is discussed. The slopes in Fig. 2
21 are the reciprocals of the values presented in this paragraph.
22 Similarly, the intercepts' values, according to Rhoades (1981), were
23 to be .149, .372 and 1.088 dS/m for the loamy sand, loam and clay soil,
24 respectively, whereas we obtained (Fig. 2) the values .05, .23 and
25 .58 dS/m for the same soils, respectively. It is evident that the
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correlation obtained by Rhoades (1981) for the silty soils in the U.S.A. between the EC_a - EC_e calibration curve parameters and the soil properties can not be extended to our soils. The contribution of the silt fraction to both the CEC and water-soil interaction is probably the main reason for the discrepancy between the Arizona and Imperial Valley soils in U.S.A. (Rhoades, 1981) and the Israeli soils. In the U.S. soils the percentage of silt was high (40%) and the silt + clay content determined the CEC of the soils and its saturation percentages (Rhoades, 1981). Conversely, in Israel, the percentage of silt in the loamy sand and loam soils was low (~10%), and the soil water properties are determined by the clay content alone (Banin and Amiel, 1969). The higher slopes obtained for the silty soils in the U.S.A. suggest that the silt content increases the formation factors and the tortuosity of the current conducting paths in the soil. Consequently, only the clay soil from Israel, which contains 28% silt, gives a calibration slope which can reasonably be predicted by the equation developed by Rhoades (1981) for the silty soils.

A theoretical discussion of the line parameters in Fig. 2 is not possible because EC_e is only related to the system on which EC_a was measured but is not a property of the same system. In Fig. 3 the bulk EC as a function of the soil solution EC at field capacity is presented. It is evident that the clay content has an effect on both the slope of the EC_a - EC_w lines and on the intercept. In a previous study, on saturated soil columns, Shainberg et al. (1980), found no effect of clay content on the slope of EC_a - EC_w plots. Thus, it seems that the

1 effect of clay content on the slope (and the formation factor)
2 in this study is through the effect of clay content on the amount of
3 water retained in the soil at field capacity (Table 1). The effect of
4 the clay (and the cation exchange capacity of the soil) on the intercept
5 has been demonstrated already (Rhoades *et al.*, 1976; Rhoades,
6 1981; Shainberg *et al.*, 1980). However, a quantitative discussion of
7 the intercept values and how they are related to the soil surface
8 conductivity is possible only following a discussion of the effect of
9 moisture content on the formation factor of the solution and solid
10 phases, respectively.

11 a) Effect of moisture and clay content on $EC_a - EC_w$ curves.

12 As described in the Methods section, the soils were leached with
13 waters of various salinities, and the moisture, EC_e , and EC_a were
14 determined as function of time. The changes in these parameters with
15 time for the loam soil leached with solution of, for example, $EC_w =$
16 4.0 dS/m, are presented in Fig. 4. The changes with time for the
17 loamy sand soil were similar. The changes in moisture content, EC_a
18 and EC_e for the clay soil were minimal and within experimental errors.
19 Thus, in this paper only the effect of moisture content on $EC_a - EC_w$
20 curves for the loamy sand and loam soils is discussed.

21 According to Fig. 4, it is expected that both water content and
22 EC_a (which depends on water content) decrease with time as a result
23 of water drainage. It is seen that EC_e also decreases with time.
24 This change in EC_e is not due to changes in soil salinity but rather
25 reflects the fact that the moisture content in the soil decreased with
26 time. A soil sample with higher moisture content and the same soil
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1 solution salinity will give higher EC_e value compared with soil having
2 with lower solution content. This is because the amount of salt in
3 soil sample depends on the amount of solution present in the soil
4 when the salinity of the solution remains constant.

5 From experimental data similar to those presented in Fig. 5 and 6,
6 plots in Fig. 5 and 6 for loamy sand and loam soils, respectively, were
7 drawn. The following observations were made:

8 i) At relatively high saline solutions ($EC_w > 4.0$ dS/m), EC_a is
9 a linear function of EC_w as predicted from Eq. 1 and Eq. 3. The slopes
10 of these lines depended markedly on the clay and moisture content.

11 ii) In the dilute concentration range, EC_e is not linearly related
12 to EC_w . In the dilute solution ($EC_w = 1.0$ dS/m), EC_a values were always
13 below the extrapolated straight lines. The deviation from the straight
14 line seems to be affected by both the clay and moisture content. This behavior
15 which is predicted by Eq. 3 was discussed in detail in a
16 previous paper (Shainberg et al., 1980). They showed that the assump-
17 tion that the soil EC may be regarded as resulting from two parallel
18 conductors- a liquid phase with electrical conductivity of EC_w , and a
19 solid phase with surface conductivity of EC_s - is not realistic. They
20 argued that most of the current in bulk soil is transferred through
21 the solid and solution phases in series. This, more realistic, model
22 explains the deviation from the straight line at the low salinity
23 range, and simplify to the straight line equation (Eq. 1) at the medium
24 to high salinity range.

25 iii) The intercepts of the straight lines depend both on the clay
26 content (and CEC) and on the moisture content of the soil. Since the
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1 intercept values are related to the apparent electrical conductivity
2 of the soil particles (Eq. 1 and 3), and the adsorbed cations
3 carrying the current, it is to be expected that σ_s increases with an
4 increase in the CLC of the soil. However, Rhodes et al. (1977) also
5 assumed that the apparent surface conductivity as determined by the
6 intercept was also not affected by the moisture content. In this study
7 we observed that the intercept was a function of the moisture content
8 and tends to increase with an increase in moisture content. This
9 observation is in line with the physical description of the surface
10 conductivity which leads to Eq. 5. Only the specific surface
11 conductivity does not depend on the moisture content, in the moisture
12 range above field capacity. At this moisture range, the equivalent
13 conductivity and the mobility of the adsorbed cation are not affected
14 by the moisture content. However, the apparent solid conductivity,
15 which is equal to the intercept, is affected by the tortuosity of the
16 electric path, which does depend on the moisture content. Since most
17 of the solid conductivity is due to exchangeable ions and the
18 exchangeable cations reside in the same pore solution where the
19 soluble ions are, any change in the formation factor which the
20 soluble ions experience (= changes in slope), applies also to the
21 exchangeable ions.

22 The specific electrical conductivity of the exchangeable ions
23 can be calculated from the intercepts in Figs. 3, 5 and 6 and Eq. 5
24 ($EC_s = F \cdot EC'_s$ where EC'_s is the intercept), and the results are summar-
25 ized in Table 2. It is evident from Table 2 that whereas the inter-
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cept and the apparent surface conductivity depend on the moisture content, the real specific surface conductivity was independent of the moisture content and depended only on the clay content and the CEC of the soil.

The specific conductivity of the exchangeable ions, like that of ions in solution, can be used to calculate the equivalent conductivity and the mobility of adsorbed cations. The equivalent conductivity of the adsorbed cations, λ^+ , is calculated as follows

$$\lambda^+ = \frac{EC_s \cdot 1000}{C^*} \quad [9]$$

where C^* , the concentration of exchangeable cations in the soil solution, may be estimated from the equation

$$C^* = \frac{CEC \cdot \rho}{\theta} \quad [10]$$

where ρ is the bulk density of the soil particles ($\rho = 1.4 \text{ Mg.m}^{-3}$) and the other terms have been defined. The concentration of the exchangeable ions in the soil solution is also given in Table 2. From Eqs. 9 and 10, and the known parameters of the soils (Table 1), the equivalent conductivity of the adsorbed cation can be calculated and is also given in Table 2.

The dominant cation in the exchange complex of the soils is Ca and the equivalent conductivity of Ca^{++} in bulk solution is 59.5 $\text{cm}^2/\text{equivalent}$. It is evident from Table 2 that the average equivalent conductivity of exchangeable Ca^{++} in Ca-soils is about $(\frac{3.13 \cdot 100}{59.5} = 5.3\%)$ of that in infinite dilution. The low conductivity of exchangeable Ca^{2+} is in line with previous observations (Shainberg and Kemper, 1966; Shainberg et al., 1980 and Nadler and Frenkel, 1980) that a relatively large portion of the adsorbed Ca^{2+} is on internal

surfaces of the tactoids where its mobility is extremely low.

Table 1: Physical and chemical characteristics of the soils

Soil type	International classification	Mechanical composition			CaCO ₃ %	CEC cmol(p ⁺)kg ⁻¹	Moisture content, %		Dilution ratio
		sand %	silt %	clay %			Field capacity	Saturation percentage	
Loamy sand	Rhodosseralf	88	5	7	traces	4.6	6.5	26.0	4.0
Loam	Rhodoxersalf	77	7	16	.3	14.5	15	36.0	2.4
Clay	Raploxersalf	27	28	45	.9	30.1	25.0	55.0	2.2

Table 2: EC_e - θ straight line parameters

Soil type	Volumetric moisture content, θ (m^3/m^3)*	Slope	Intercept dSm^{-1}	EC_e Intercept slope dSm^{-1}	C^+ $kmol(p^+)m^{-3}$	Electrical conductivity of absorbed ions dSm^{-1}
Loamy sand	.091	.052	.10	1.92	.71	1.35
	.119	.060	.12	2.00	.54	1.40
	.147	.078	.15	1.92	.44	1.45
Loam	.204	.142	.32	2.25	.995	2.26
	.228	.173	.38	2.20	.89	2.47
	.238	.190	.50	2.63	.85	3.09
Clay	.325	.22	.95	4.32	1.30	3.22

* The volumetric moisture content, θ , is related to the moisture content ( ) in Table 1 by $\theta = p_w \cdot \rho$, where ρ , the bulk density of the three soils are 1.4, 1.4 and 1.3 Mg/m^3 for the loamy sand, loam and clay soils, respectively.

Figure legends

- Fig. 1: The electrical conductivity of the soil extract as a function of the soil solution EC (soils sampled at field capacity).
- Fig. 2: The bulk EC (at field capacity) as a function of the EC of the extract.
- Fig. 3: The bulk EC (at field capacity) as a function of the soil solution EC.
- Fig. 4: The changes in moisture content, EC of the extract and bulk soil EC as a function of drainage time.
- Fig. 5: Bulk soil EC as a function of soil solution EC for three moisture contents in the loamy sand.
- Fig. 6: Bulk soil EC as a function of soil solution EC for three moisture contents in the loamy soil.

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LS, $\theta = 0.091$
 LOAM, $\theta = 0.21$
 CLAY, $\theta = 0.33$

e. Evaluation of the research achievements

The objectives outlined in the proposal were maintained. Only the effect of moisture contents above field capacity were studied.

f. Description of cooperation

The cooperation between the investigators in Israel was very productive. The cooperation with the US Scientist was in the form of consultations and discussion of the experimental set-up and the results. The different approaches of the two principal investigators resulted in better understanding and better appreciation of the difficulties - theoretical and application that are encountered by the scientist who tries to expand the use of the method in field studies.

h. Benefit to agriculture

Simpler and better means of monitoring soil salinity in irrigated agriculture is one of the essential requirements for more efficient irrigation. The electrical conductivity methods are among the best available for monitoring soil salinity. Theoretical understanding of the processes governing electrical conductivity in porous media is essential for expanding the use of the method. It is hoped that this study contributes something in this direction.

i. Published papers

- 1) Frenkel, H., A. Nadler and I. Shainberg (1983) Effect of entrapped air on $EC_a - EC_w$ calibration curves as measured in a soil column. Soil Sci. Soc. Am. J. 47: 1036-1038.
- 2) Rhoades, J.D. (1981) Predicting bulk soil EC versus saturation paste extract EC calibrations from soil properties. Soil Sci. Soc. Am., J. 45: 42-44.
- 3) Shainberg, I., N. Alperovitch and H. Frenkel (1984) Effect of soil texture and moisture content on bulk soil electrical conductivity under field conditions. Soil Sci. Soc. Am. J. 48.