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Drainage effects on spatial variability of soil electrical conductivity in a vertisol

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Abstract

Spatial variability of soil electrical conductivity (EC) is characterized in a 33 ha plot before and 2 years after drainage initiation. Measurements of EC were made in a square grid at 50 m spacing and at 0–20, 20–40, 40–60 and 0–60 cm depths. Both mean EC values and coefficients of variation (CV) are reduced after drainage. The frequency histograms show that EC fits to a lognormal distribution before drainage, whereas it seems to be normally distributed after drainage initiation. The bimodality found in histograms before drainage was not observed after it. Spatial structure of soil EC is strongest at 0–20 cm before drainage and it is weaker at greatest depths. Nevertheless, the semi-variogram at 40–60 cm after drainage shows a more remarkable spatial structure. EC spatial variability shows anisotropy before drainage, which was related to topography. However, directional semi-variograms after drainage did not show such anisotropy. In conclusion, drainage not only reduces EC values, but also notably changes EC spatial variability. © 1999 Elsevier Science B.V. All rights reserved.

Keywords: Soil electrical conductivity; Spatial variability; Drainage; Geostatistics; Vertisols

1. Introduction

Modeling soil solute movement is an excellent tool for selecting suitable water management (Van Dam and Feddes, 1994). Nevertheless, the modeling usefulness is considerably affected by soil-salinity spatial variation. Therefore, the spatial distribution of soil salinity must be known and a stochastic–deterministic approach should be

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followed in such models (Van Genuchten, 1994). Several papers have characterized the spatial variability of soil electrical conductivity (EC) by using classic statistical techniques (Sayegh et al., 1954; Wagenet and Jurinak, 1978) as well as geostatistical approaches (Hajrasuliha et al., 1980; Miyamoto and Cruz, 1986; Buraymah and Webster, 1989). Nevertheless, few of them studied the effect of drainage in the spatial variability of soil EC. This paper is addressed to that matter.

2. Materials and methods

The study has been carried out in a drainage experimental plot of 33 ha at Cauto River Valley, in the eastern part of Cuba, at 20 46′ 06″ North and 76 37′36″ West. Bouziques et al. (1992) found two soil units in the plot, associated with their landscape position: slightly hydromorphic and halomorphic Vertisol (Vb unit), located above 39.5 m over sea level and very hydromorphic and halomorphic vertisol (Vd unit), below this elevation. Fig. 1 shows a topographical scheme of the plot, the two soil units and the drain positions. The physical and chemical properties of the soil units were studied by Bouziques et al. (1992).

Castellanos (1993) provided the characteristics of the tested drain solutions. Drains were spaced at 10, 20, 25 and 50 m which are represented in Fig. 1 as Cases A, B, C and D.

The 1:5 soil–water dilution EC was measured in the plot before installing drainage by sampling the soil at 0–20, 20–40, 40–60 and the composite 0–60 cm depths in a square grid 50 m spaced. This procedure was repeated 2 years after drainage initiation. The EC measurements in this last case were obtained in locations as close as possible to the preceding measurements.

The spatial variability of soil EC before and after drainage was characterized through statistical and geostatistical methods. The isotropic EC experimental semi-variograms were determined and automatically fitted to the authorized theoretical models (Journel and Huijbregts, 1978; MacBratney and Webster, 1986) through a weighted least-square procedure (MacBratney and Webster, 1986). The best model was selected following Akaike's criterion. North–South and East–West directional semi-variograms were also determined at each depth. All the geostatistical analyses were made by using the program GEOESTAD (Díaz et al., 1994).

3. Results

Table 1 shows the basic statistics of EC before and after drainage. EC means before drainage are high at 0–20 cm and decrease with depth. It corresponds to a typical saline profile and is related to the influence of a highly mineralized water table (Bouziques et al., 1992). The coefficients of variation (CV) are elevated, as was commonly found in this soil property (Warrick and Nielsen, 1980; Vauclin, 1982). The highest CV was found at 0–20 cm depth, whereas the lowest CV corresponds to 20–40 cm, which indicates that it is the least variable depth. Average EC is considerably lower after drainage at all depths,

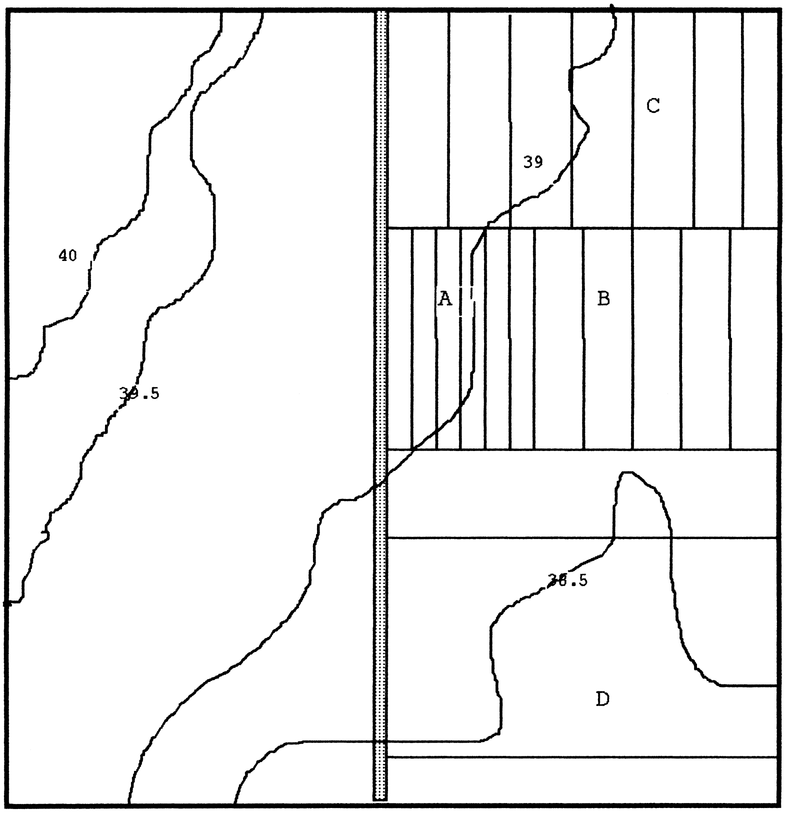


Fig. 1. Plot Scheme, showing the topographical altitudes (40, 39.5, 39 and 38.5 m) as well as the tested drain solution: Case A. Drains spaced at 10 m; Case B. Drains spaced at 20 m; Case C. Drains spaced at 25 m and Case D. Drains spaced at 50 m.

in comparison with that obtained before drainage. After drainage average EC is highest at 40–60 cm, which shows that the water table has no higher influences on soil salinity. The CVs are also lower after than before drainage, hence it could be stated that drainage leads to less spatial variation in soil EC. The lowest EC mean was found after drainage at 20–40 cm, although it was quite similar to the 0–20 cm EC mean. The 20–40 cm depth shows the lowest CV after drainage, just as that occurred before (see Table 1).

The histograms of the 0–60 composite results for EC before and after drainage are given in Fig. 2. As can be seen in Table 1, EC skewness before drainage is always positive. Thus, it seems that soil EC is lognormally distributed in the plot before drainage. It is the most common probability distribution found for this property, as reported by Vauclin (1982). Nevertheless, normal probability could more often be considered for EC spatial distribution after drainage (see Fig. 2(c)). Miyamoto and Cruz (1986), as well as Díaz and Herrero (1992) found normal distributions for soil EC spatial variability. In these papers the EC measurements were made on drained soils. It could be stated that soil EC is in accordance with a lognormal probability distribution before drainage, whereas it

Table 1
Means, standard deviations (SD) and coefficients of variation (CV) of EC; as well as skewness (S) and kurtosis (K) of EC and ln EC before drainage and after drainage

Depth (cm)	Mean EC	SD	CV (%)	EC		ln EC	
	($dS\ m^{-1}$)			S	K	S	K
Before drainage							
0–20	4.181	3.291	78.72	1.140	4.062	−0.60	2.768
20–40	3.645	2.668	73.19	2.267	13.606	−0.903	3.485
40–60	3.059	2.256	73.75	1.652	7.058	−0.503	3.075
0–60	3.628	2.346	64.55	0.910	3.802	−0.804	3.346
After drainage							
0–20	2.032	1.129	55.54	0.473	3.025	−0.970	3.271
20–40	1.982	0.915	46.16	−0.341	2.206	−0.341	2.206
40–60	2.393	1.285	53.71	0.636	3.289	−0.900	3.603
0–60	2.137	1.004	47.00	0.000	2.178	−1.185	3.907

is normally distributed after drainage. An anthropic effect is introduced by drainage which destroys the natural lognormal probability distribution of soil EC spatial variability.

On the other hand, as can be seen in Fig. 2(b), not one but two distributions are found in the histogram of 0–60 cm ln EC before drainage. This bimodality is related to the heterogeneity of soil EC data (Vauclin, 1982; Myers, 1991). It agrees with the two different soil units found by Bouziques et al. (1992) in the plot. Otherwise, as shown in Fig. 2(c) and (d), the 0–60 cm histograms after drainage of neither EC nor ln EC show a clear bimodality. Salt leaching, due to drainage, has minimized the difference between EC at the two soil units. It leads to a more uniform distribution shown in Fig. 2(c) and (d) and agrees with the lower CV found after drainage at all depths.

The experimental EC isotropic semi-variograms at each depth, before and after drainage, are shown in Fig. 3. The adjusted theoretical models are given in Table 2. The

Table 2
Model, nugget, sill and ranges of the EC isotropic semivariograms before and after drainage

Case	Depth (cm)	M	Nugget ($dS^2\ m^{-2}$)	Sill ($dS^2\ m^{-2}$)	Range
BD	0–20	L	6.5	12.5	500
	20–40	G	4.5	7.0	128
	40–60	S	1.9	5.4	135
	0–60	S	1.4	4.7	291
AD	0–20	S	0.74	1.26	323
	20–40	S	0.30	0.95	401
	40–60	S	0.24	1.65	175
	0–60	S	0.32	1.01	226

BD Before drainage.
L Linear semivariogram.
AD After drainage.
G Gaussian semivariogram.
S Spherical semivariogram.

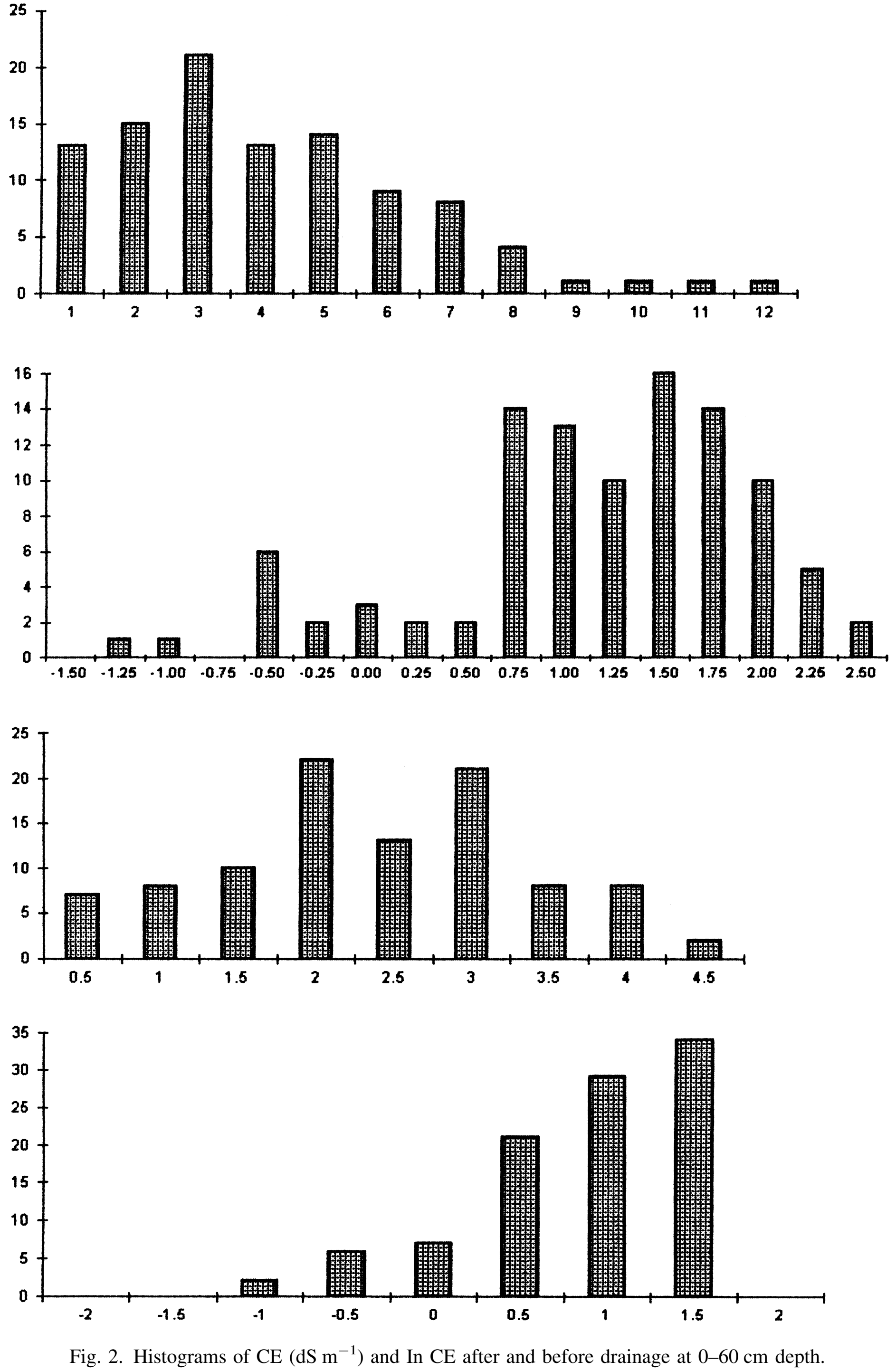


Fig. 2. Histograms of CE (dS m^{-1}) and In CE after and before drainage at 0–60 cm depth.

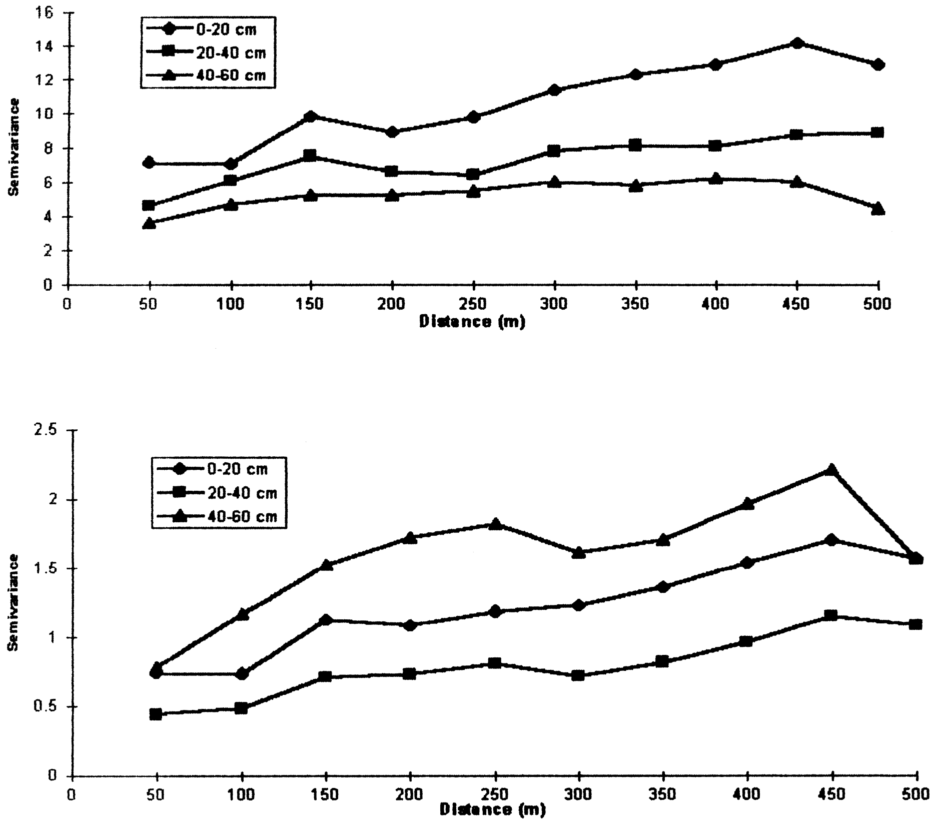


Fig. 3. Isotropic semivariograms of EC before and after drainage at each depth.

strongest spatial structure before drainage was found at 0–20 cm depth, which is in accordance with the high mean and CV values obtained at this depth. A linear model was provided in this case, indicating that no second-order stationarity must be expected (Journel and Huijbregts, 1978; MacBratney and Webster, 1986). It agrees with the difference between the two soil units and the bimodality found in the 0–60 cm ln EC histogram before drainage (Fig. 2(b)). A weaker spatial structure was found at 20–40 cm and almost a pure nugget semi-variogram (Journel and Huijbregts, 1978; Warrick et al., 1986) at 40–60 cm. These results are in complete correspondence with the CV found before drainage (see Table 1). Therefore, the spatial structure of soil EC before drainage is very high at the soil surface and decreases with depth.

Otherwise, the EC semi-variograms after drainage (Fig. 3) show a different behavior. The strongest spatial structure was found at 40–60 cm and, as shown in Table 2, this semi-variogram yields a transitive model (MacBratney and Webster, 1986). The semi-variogram found at 0–20 cm after drainage was adjusted to a spherical model. The nugget and sill of this semi-variogram are considerably lower than those found before drainage at this depth (see Table 2). All this is because drainage has minimized the difference between Vb and Vd soil salinity and hence the non-stationarity found at 0–20 cm before

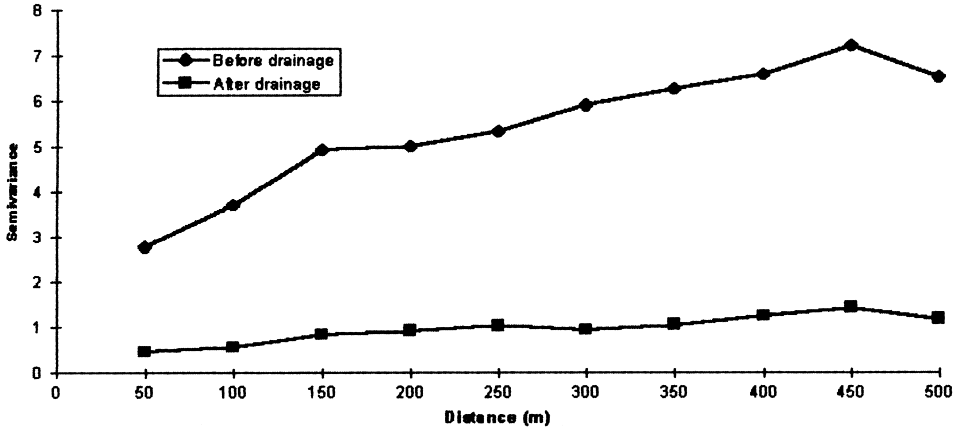


Fig. 4. Isotropic semivariograms of EC before and after drainage at 0–60 cm depth.

drainage is now in a transitive spatial structure. It agrees with the more homogeneous histograms found for EC after drainage, as shown in Fig. 2(b). The weakest spatial structure was found after drainage at 20–40 cm, which was already reported as the less variable depth. As it was obtained before drainage, there is a clear agreement between the semi-variograms of Fig. 3 and the CV shown in Table 1.

Fig. 4 shows the isotropic semi-variograms of 0–60 cm soil EC before and after drainage. As can be seen in the figure, the spatial structure of soil EC after drainage could be neglected in comparison with that obtained before drainage. The same result can also be achieved by observing the sills and nuggets found for the isotropic semi-variograms at all depths after drainage (see Table 2). These sills and nuggets are much lower than those obtained before drainage at the same depths. Furthermore, the decrease of EC spatial structure after drainage is in accordance with the homogeneity of EC histograms after drainage, as was above discussed.

The directional North–South (N–S) and East–West (E–W) EC semi-variograms at 0–60 cm before and after drainage can be seen in Fig. 5. The E–W 0–60 cm EC semi-variogram before drainage (Fig. 5(a)) shows linear behavior. According to Fig. 1, the main change in soil salinity in the plot must be from West to East. It is because the non-saline Vb unit extends as a narrow band in the N–S direction and the general topographical slope is in the E–W direction. Bouziques et al. (1992) also pointed out that salinity in the plot was closely related to topography; thus the linear behavior shown in the E–W 0–60 EC semi-variogram is an expected result. The N–S 0–60 EC semi-variogram before drainage reveals a weak spatial structure, which is in correspondence with the above expressed structure.

Fig. 5(b) shows the N–S and E–W 0–60 cm semi-variograms after drainage. As can be seen in the figure, differences between both semi-variograms are much lower than before drainage (Fig. 5(a)). It is because differences between the two soil units are minimized by drainage, as was already pointed out. The similarity between N–S and E–W semi-variograms of Fig. 5(b) suggests an isotropic behavior for EC spatial variation after drainage.

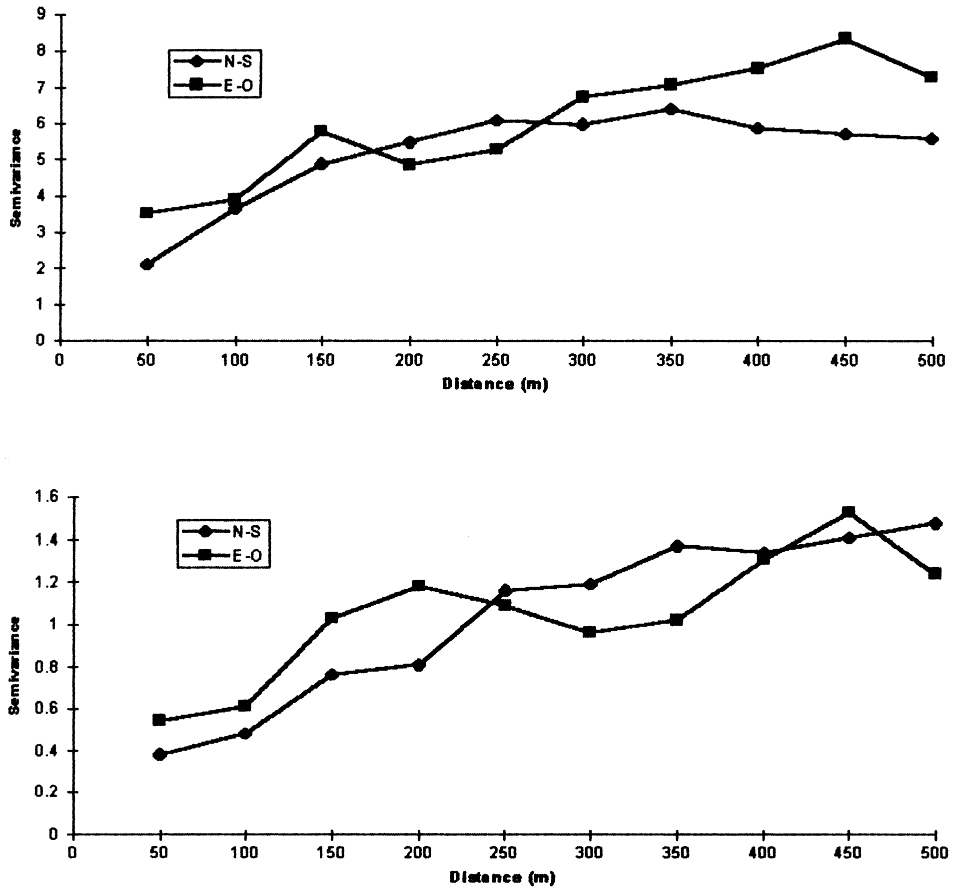
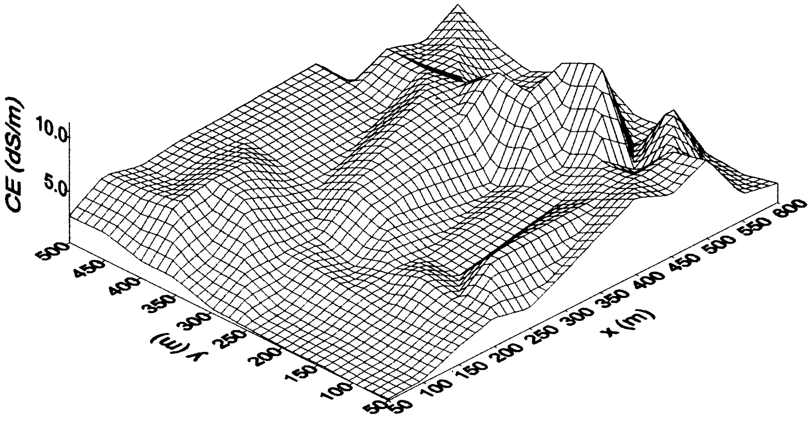


Fig. 5. Directional semi-variograms of 0–60 cm EC.

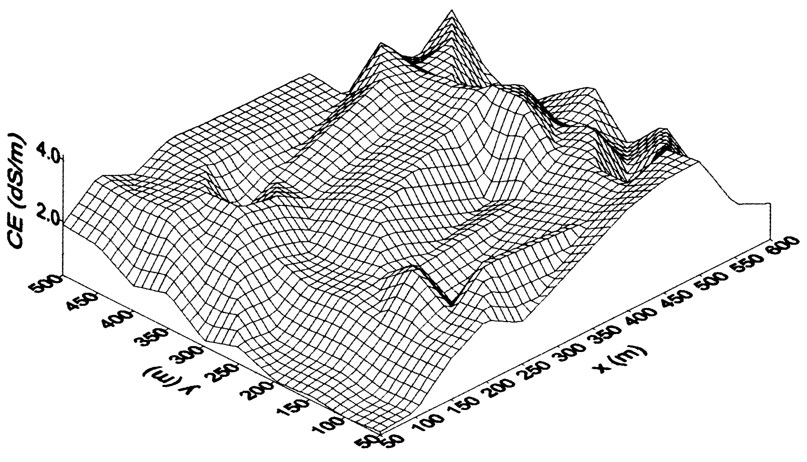
The 0–60 cm salinity maps before and after drainage are given in Fig. 6. Before drainage (Fig. 6(a)) high EC values were found in the plot and the EC spatial variation is mainly from West to East. After drainage (Fig. 6(b)) salinity is much lower and the differences between the two soil units are less remarkable.

4. Conclusions

Drainage reduces both soil EC values and its spatial variation. As a result of drainage the natural lognormal probability distribution of soil EC spatial variability turns to a normal probability distribution. Salt leaching due to drainage leads to a more uniform EC histogram, eliminating the bimodality found in such histograms before drainage. The topographic-caused spatial structure of soil EC in natural conditions disappears after drainage. The resulting spatial structure is more isotropic and very much weaker.



A. Before drainage.



B. After drainage.

Fig. 6. EC salinity maps at 0–60 cm depth.

According to the results found, the soil EC spatial distribution is quite different in drained fields as compared to natural soils. Therefore, such studies concerning drainage efficiency in land reclamation of saline soils as well as those concerning solute-movement modeling in saline soils should follow different approaches for considering EC spatial distributions in drained or undrained soils.

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