Effect of Fertigation on Soil Salinization and Aggregate Stability

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Abstract: Physicochemical properties of a Haplic Chernozem soil were measured while applying fertigation in a natural grassland during the growing season in a hemiboreal climate with irrigation management based on the decision support system–fertigation simulator (DSS-FS) model. The experimental field was divided into four parcels which were exposed to four different irrigation treatments: fertigation with nutritive solution A [electrical conductivity (EC) $= 2\ \text{mS} \cdot \text{cm}^{-1}$, pH $= 6$), fertigation with nutritive solution B (EC $= 1\ \text{mS} \cdot \text{cm}^{-1}$, pH $= 6$), irrigation with raw water without any injected fertilizers (EC $= 0.27\ \text{mS} \cdot \text{cm}^{-1}$, pH $= 6.5$), and control parcel (no treatment). Rainfall effect on soil desalinization through salt leaching was monitored by comparing the evolution of soil electrical conductivity during and after the growing season. The soil electrical conductivity of the chemigated parcels (parcels A and B) was higher than the control parcels (parcels C and D) at the end of the growing season. This difference decreased significantly, becoming negligible after the winter due to an efficient desalinization effect of rain and snow. **DOI: 10.1061/(ASCE)IR.1943-4774.0000806.**

Author keywords: Irrigation; Chemigation; Fertigation; Soil salinization; Remediation of soil salinization; Aggregate stability; Central Europe; Lowland climate.

Introduction

The injection of nutritive salts (soluble fertilizers), pesticides, and other chemicals into the water pumped through a given irrigation system, which is commonly known as chemigation, allows precise control of the concentration and balance of nutrients. Nevertheless, it is a rather complicated process as many factors must be controlled to produce good and environmentally safe fertigation practices (Moreira Barradas et al. 2012). Irrigation with dissolved fertilizers (if not correctly managed) has an inherent potential to cause excessive soil salinity with a consequent negative effect on both plant and soil properties. After irrigation, the water added to the soil is used by the crop or evaporates directly from the moist soil. The salt, however, is left behind in the soil. If not removed, it accumulates in the soil; this process is called salinization (Brower et al. 1985). Salts are added to the soil with each irrigation. These salts will reduce crop yield if they accumulate in the rooting depth to damaging concentrations (Ayers and Westcot 1985).

The risk of soil salinity formation is always greater in fine-textured (heavy) soils than in coarse-textured soils. This is because sandy soils naturally have larger pores that allow for more rapid drainage. In addition, some salts cause toxic effects in plants and can reduce plant metabolism and growth (Allen et al. 1998).

Any remediation of salt-affected soils requires evaluation and monitoring of salinity. Soil salinity is measured by electrical conductivity (EC) of the soil solution (aqueous extracts of soil). The previous method requires direct sampling of the soil at a given time step and relies on the collection of soil samples and the measurement of EC on aqueous soil extracts. Therefore, it appears difficult to monitor the salt-content changes over time with a fine spatial resolution, because collecting soil samples is intrusive and disturbs the studied environment (soil structure and water flows). Moreover, soil sampling is time consuming and often expensive.

Soil salinity also can be estimated indirectly from measurement of the bulk electrical resistivity (ER, Ωm) or from its inverse, the apparent electrical conductivity (ECa, $\text{dS}\,\text{m}^{-1}$) (Rhoades et al. 1999; Corwin and Lesch 2003). The development of soil sensor systems or geophysical methods for measuring ECa or ER facilitates the collection of larger amounts of spatial data using a less expensive, simpler, and less laborious technique (Adamchuck and Viscarra Rossel 2010). These sensors may or may not be invasive or mounted on vehicles for prospecting. Indeed, it is desirable to use the least invasive method and a fast sensor to collect a large amount of data.

Electrical resistivity sensors and electromagnetic prospections, measuring ER and ECa, respectively, respond to different soil properties, and separation of their effect is often difficult. The bulk ER represents the ability of the soil as a whole to resist an electrical current flux. Many authors (Keller and Frischknecht 1966; Ward 1990) assessed the influence of factors affecting this property, such as clay content, soil moisture, and ionic concentration of soil solution, porosity, and soil temperature.

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Note. This manuscript was submitted on February 28, 2014; approved on July 24, 2014No Epub Date. Discussion period open until 0, 0; separate discussions must be submitted for individual papers. This paper is part of the ***Journal of Irrigation and Drainage Engineering***, © ASCE, ISSN 0733-9437/(0)/$25.00.

Another important factor, connected to soil degradation and erosion, is the aggregate stability. Soil aggregates are groups of soil particles that bind to each other more strongly than to adjacent particles. The resistance of the soil against external destructive effects such as rainfall, runoff, and wind is defined as soil aggregate stability and is one of the most important indicators of soil degradation.

Beside the effect of external factors, soil aggregate stability is affected by many intrinsic soil properties, e.g., organic matter, texture, porosity, etc., and by land use management (Angers and Caron 1998; Barthes and Roose 2002; Cerda 2000; Six et al. 2000).

Under rainfall conditions and low soil aggregate stability, the breakdown process of aggregates produces small soil particles that may then be displaced and reoriented into a more continuous structure, leading to undesirable consequences such as poor infiltration, surface sealing, and crusting (Boiffin 1984; Loch and Foley 1994; Moore and Singer 1990; Romkens et al. 1977).

Le Bissonnais (1996) stated that, among the many methods that have been applied for soil aggregate stability measurement, there is no single methodology that applies to all soils in any circumstance. Amezketa (1999) summarizes these reasons as follows:

- Different mechanisms of aggregate destabilization or disintegration of soil macroaggregates into microaggregates, such as slaking, clay dispersion, and clay swelling;
- Different scales of stability determination; and
- Different types of methodologies with diverse test protocols, based on different disintegration patterns and assessment of the aggregates' capacity to stand against wetting or mechanical forces.

According to Shindi et al. (2011) and Saad et al. (2011), the content of water-stable aggregates increases with the increase of irrigation water salinity. Bullock et al. (1988) and Lehrsch et al. (1991) studied freezing as one process that affects aggregate stability. They state that aggregate stability decreases with increasing soil water content at the time of freezing.

Material and Methods

The study was conducted from March 27, 2012 to March 7, 2013 at the experimental station of the Czech University of Life Sciences Prague located at 50°8′N and 14°23′E, 286 m a.s.l. According to Miháliková et al. (2013), the soil is an Udic Haplustoll or Haplic Chernozem of loamy texture on an aeolic loessial substrate, fine earth with 22–32.5% sand, 39.5–54% silt, and 22–28% clay, and topsoil with 2.5% DM of total organic carbon and 7.8% DM of calcium carbonate. The boundary between the A and C horizons lies at approximately 35 cm with the transitional A/C horizon approximately 10 cm thick. The saturated hydraulic conductivity (100-cm^3 cores) is between 6×10^{-4} and 4×10^{-1} $cm \cdot min^{-1}$. The total porosity varies between 0.40 (plough sole) and 0.54 (topsoil) $cm^3 \cdot cm^{-3}$ with a mean value of 0.457 $cm^3 \cdot cm^{-3}$ (0–100 cm). The average water retention curve obtained from 100-cm^3 cores can be approximated, e.g., by the van Genuchten (1980) equation with moisture content at field capacity (θ_{fc}), moisture content at wilting point (θ_{wp}), root depth (Z_r) (considered in this study), and total available water (TAW), given in Table 1. Grass was sown in soil in spring 2009 and has been maintained since then as short lawn. The site was neither irrigated nor tile drained. The grass often suffered from water stress. The terrain is flat. Local short-term ponding of water can be observed on the soil surface during very intense rainstorms. It quickly disappears as soon as the rain intensity decreases.

Table 1. Information on Soil Properties Used (Data from Miháliková et al. 2013)

Soil parameter	Value
Field capacity Θ_{fc}	34%
Wilting point Θ_{wp}	21%
Root depth Z_r	30 cm
Total available water TAW	39 mm

Experimental Field

The total studied area consisted of an area of 8 m^2 divided into four parcels (A, B, C, and D) of 2 m^2 each, submitted to four different irrigation treatments as described later. Each parcel was subdivided into three subparcels—S1 (sample 1), S2 (sample 2), and S3 (sample 3)—allowing the collection of six samples per parcel (three samples at a depth of 10 cm and another three samples at a depth of 20 cm) at three different times after the growing season (September, November, and January) for salinity assessment and evaluation of aggregate stability.

Parcel A was submitted to fertigation with nutritive solution A ($EC = 2$ $mS \cdot cm^{-1}$, $pH = 6$). The combination of nutritive salts was designed by the decision support system–fertigation simulator (DSS-FS) model (Moreira Barradas et al. 2012) to respond to a scenario of a high-demanding crop (in this case, the decision was made to simulate tomato production with an expected production of 80 t/ha). This formulation by itself resulted in a lower salinity than the desired 2 mS/cm; therefore, a combination of sodium bicarbonate and citric acid was added into the nutritive solution to correct the salinity to the desired value of 2 $mS \cdot cm^{-1}$. The proportion between the concentration of citric acid and bicarbonate was chosen to ensure a final pH of 6.0.

Parcel B was submitted to fertigation with nutritive solution B ($EC = 1$ $mS \cdot cm^{-1}$, $pH = 6$). The nutrient formulation was made in the same way as described for parcel A, and the salinity was then adjusted to the desired value of 1 $mS \cdot cm^{-1}$ with a pH of 6.0 resorting to a combination of citric acid and sodium bicarbonate added into the nutritive solution as in parcel A.

Parcel C was submitted to conventional irrigation without nutrition (natural values of $EC = 0.27$ $mS \cdot cm^{-1}$ and $pH = 6.5$ from the source of drinking water supply have not been altered).

Parcel D received no treatment (control parcel).

The use of sodium bicarbonate to adjust the salinity is very adequate, as natural water sources such as aquifers, rivers, etc. are (in most cases) rich in bicarbonate. The DSS-FS fertigation simulator (Moreira Barradas et al. 2012) was used to manage the irrigation scheduling [scheduling based on the Food and Agriculture Organization of the United Nations (FAO) methodology described by Allen et al. 2012) and the formulation of the nutritive solution.

The field capacity of the soil is 34%, wilting point 21%, and the fraction of the readily available water (RAW) was considered as 50% of the TAW with the roots at 30 cm. The TAW (Allen et al. 1998) in this scenario is 39 mm (it was rounded to 40 mm) and the RAW is 20 mm (if estimated using the mentioned values of field capacity and wilting point at a root depth of 30 cm). At the beginning of the experiment, a volume equivalent to the soil total available water at a depth of 30 cm (40 L/m^2) was applied to ensure that the soil was restored to field capacity (assuming that saturation by excess irrigation would rapidly give place to field capacity through gravitational losses). From then on, readily available water for the same soil at the same depth ($RAW = 20$ L/m^2) was applied (until the end of the experiment) every time the equivalent amount was estimated to have been depleted by evapotranspiration.

TAW and RAW have been estimated according to Allen et al. (1998) as follows:

$$\mathrm{TAW} = 1{,}000(\theta_{\mathrm{FC}} - \theta_{\mathrm{WP}})Z_r \quad (1)$$

where TAW = the total available water in the root zone (mm), θ_{FC} = water content at field capacity ($\mathrm{m}^3\,\mathrm{m}^{-3}$), θ_{WP} = water content at welting pint ($\mathrm{m}^3\,\mathrm{m}^{-3}$), and Z_r = the rooting depth (mm).

In the present research, Eq. (1) was used with the following values: $Z_r = 30$ cm, with $\theta_{\mathrm{FC}} = 34\%$ and $\theta_{\mathrm{WP}} = 21\%$.

RAW is therefore a fraction of TAW (in this case 50%).

The accuracy of the estimation of soil water depletion was [32] continuously monitored, resorting to 6 5TE sensors installed at a soil depth of 20 cm in parcels A, B, and C.

[33] The $\mathrm{ECH_2O}$ system sensors, data loggers, and software have been used to collect soil information. The 5TE sensor makes three measurements (volumetric water content, temperature, and EC) independently and determines volumetric water content (VWC) by measuring the dielectric constant of the media using capacitance/frequency domain technology. Six sensors have been installed at a depth of 20 cm, two at each parcel (parcels A, B, and C).

The sensor outputs make it possible to plot the bulk electrical conductivity versus the volumetric water content.

The electrical conductivity of soil solution has been calculated based on the relationship between soil volumetric water content (θ) and bulk electrical conductivity (EC_b), using the following [34] Decagon equation (2012):

$$\mathrm{EC}_w = \frac{\mathrm{EC}_b}{(0.94 \times \theta^{1.514})} \quad (2)$$

where EC_w = electrical conductivity of soil solution (mS/cm), EC_b = bulk electrical conductivity (mS/cm), and θ = volumetric water content ($\mathrm{m}^3/\mathrm{m}^3$).

The daily weather data were monitored through the meteorological station of the Department of Water Resources experimental site and the Institute of Atmospheric Physics in Suchdol, using [35] TightVNC, a remote control software package. The reference crop evapotranspiration was estimated with the DSS-FS model (Moreira Barradas et al. 2012), which runs the FAO 56 combination equation (Allen et al. 1998).

The soil aggregate stability variation during the experimentation period was assessed resorting to the wet sieving apparatus, methodology described by Kemper and Rosenau (1986).

A mass of 4.0 g of 2–5-mm air-dried aggregates was placed in the sieves of the wet sieving apparatus and washed in cans with distilled water for 3 min. The cans were afterwards replaced with others con- [36] taining a dispersing solution (2 g of sodium hexametaphosphate/L), and the sieving continued until only the sand particles (and root fragments) were left on the sieves. Both sets of cans were placed in an oven and dried at 110°C. After drying, the weight of materials of unstable and stable aggregates was determined. Dividing the weight of the stable aggregates over the total aggregate weight (without sand particles >0.25 mm) gives an index for the aggregate stability.

$$\mathrm{WSA} = \frac{W_{\mathrm{ds}}}{W_{\mathrm{ds}} + W_{\mathrm{dw}}} \quad (3)$$

[37] where WSA = the index of water-stable aggregates (-), W_{ds} = the weight of aggregates dispersed in dispersing solution (g), and W_{dw} = the weight of aggregate dispersed in distilled water (g).

To investigate the effect of soil desalinization (represented in decreasing of soil salinity due to leaching of fertilizers) and evolution of aggregate stability (represented in water stable aggregate), six soil samples (three samples at 10-cm depth and another three at 20-cm depth) were taken from each parcel after the growing season and at three different times during the experimental period: [38] September 15th (end of growing season), November 15th, and January 15th.

Quantitative determination of total soil salinity by soil ethanol extract conductivity has been measured according to Kemper and Rosenau (1986) as follows: 15 g of dry soil was mixed with 75 mL of ethanol in a plastic flask, the mixture was shaken in a reciprocating shaker for 45 min, then the soil suspension was filtered and the electrical conductivity was measured by a conductometer.

In this work, soil levels of salinization have been classified according to the EC of soil water extracts and the EC of soil ethanol extracts as described by the USDA Salinity Laboratory (1969).

Results and Discussion

Electrical Conductivity

Monitoring Using the Decagon $\mathrm{ECH_2O}$ System

Fig. 1 shows the 5TE sensors' average measurements of the EC_w (EC by water extract) in each parcel (A, B, and C). The results of Fig. 1 can be compared to the classification according to soil water extracts (USDA).

The continuous soil EC_w monitoring by the Decagon $\mathrm{ECH_2O}$ system of the 5TE sensors shows that the soil EC_w varied along the experimentation between the classes of no salinity and slightly salinized (according to the USDA classification). At the end of the experimental period, all the parcels (A, B, and C) reported a situation of no salinity.

The peaks of EC shown in Fig. 1 are due to variations in soil moisture content during the experimental season directly affecting the concentration of salts in the soil solution.

The relation between the volumetric soil moisture content θ and the EC_w can be observed in Fig. 2 (related to parcel A at both depths). Parcels B and C were also monitored.

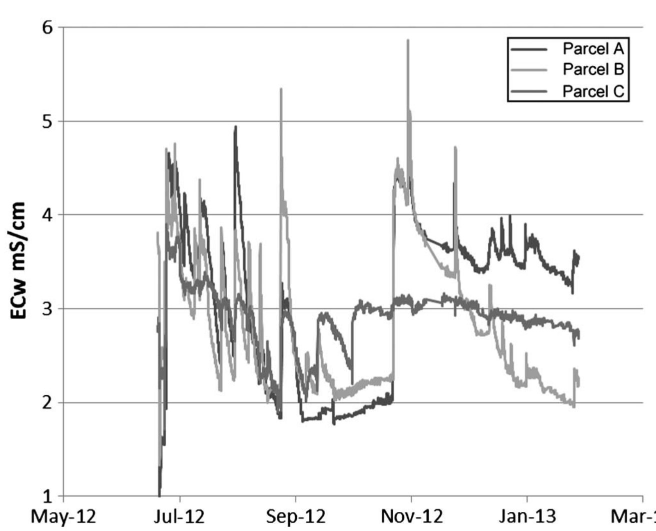

Fig. 1. Evolution of EC_w in the experimental field over time F1:1

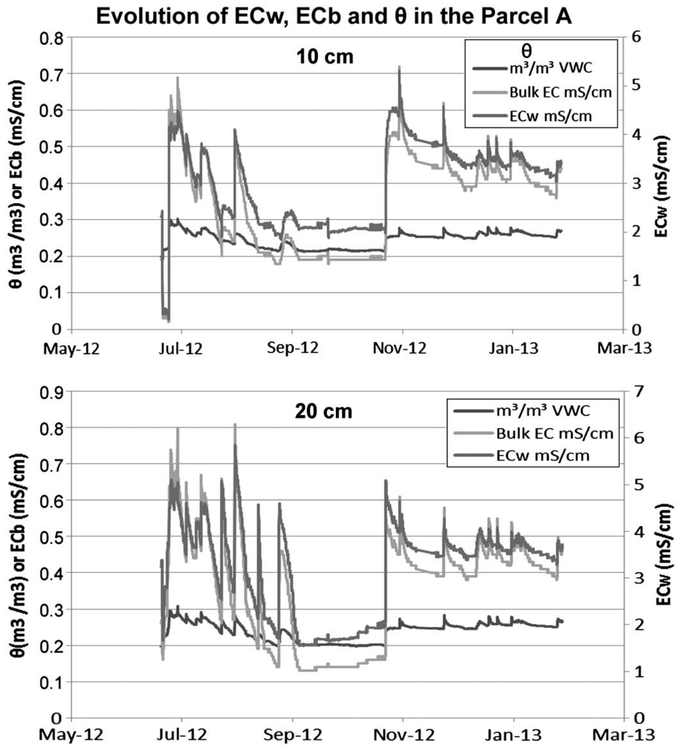

Fig. 2. Comparing EC_b, EC_w, and θ during the experimental period in parcel A at both depths

Quantitative Determinations of Soil EC

The measured electrical conductivity in parcels A, B, and C was higher by the end of the growing season, in September 2012, but decreased significantly in November and January due to the desalinization effect of rain and melting snow, becoming equivalent to the control parcel (parcel D) in November 2013 (2 months later).

As for the laboratory EC testing in ethanol extract, the Figs. 3–5 show the average values of three different samples collected on each parcel (subparcels S1, S2, and S3) at two different depths and at three different times (September, November, and January).

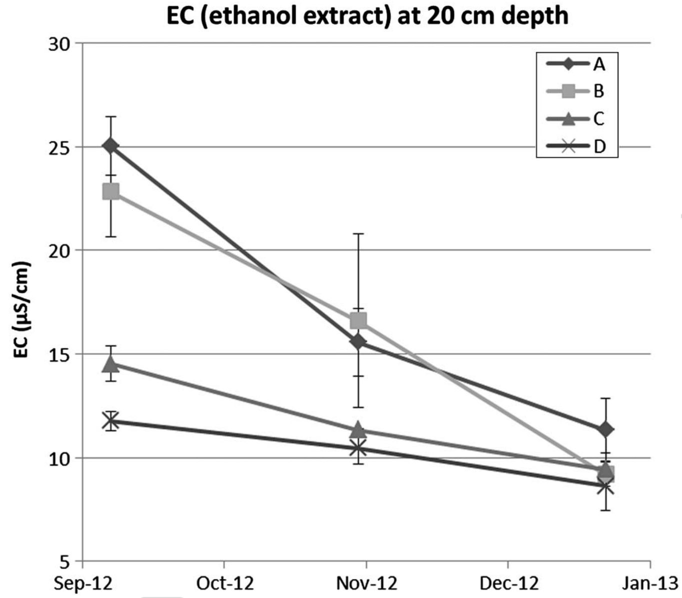

Fig. 4. Evolution of the average EC (in ethanol extract) in the four parcels at 20-cm depth

The ANOVA results in Table 2 show that, immediately after the irrigation season (September), there were considerable differences between the four parcels, with the fertigated parcels showing higher values of salinity than the nonfertigated parcel and the control parcel.

There were no more significant differences between the EC of the four experimental parcels after November.

EC of Parcel A: High Salinity (2 mS/cm)

At 10-cm depth, the highest and lowest measured EC values were 43.1 and 12.8 $\mu s/cm$ in September and January, respectively.

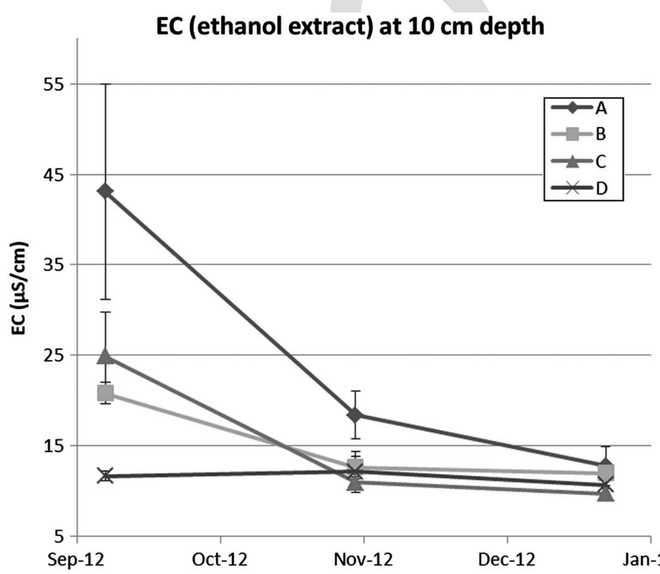

Fig. 3. Evolution of the average EC (in ethanol extract) in the four parcels at 10-cm depth

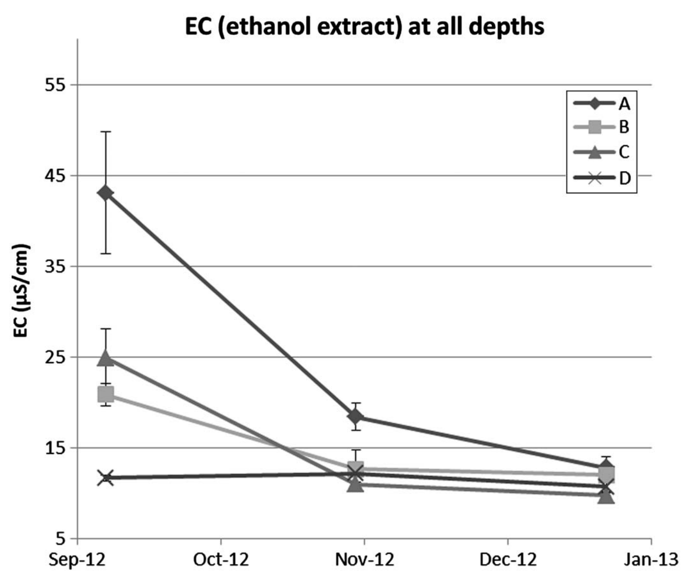

Fig. 5. Evolution of soil EC in ethanol extract; averages at all depths

Table 2. ANOVA Results (EC) Generated by Excel 2010 (Microsoft) between the Four Experimental Parcels (A, B, C, and D) for a 95% Confidence Interval

Source of variation	SS	df	MS	F	P-value	F crit
September						
Depth: 10 cm						
Between groups (parcels)	1564.5	3	521.499	4.09685	0.04915	4.06618
Within groups (parcels)	1,018.34	8	127.293	—	—	—
Total	2,582.84	11	—	—	—	—
Depth: 20 cm						
Between groups (parcels)	367.583	3	122.528	20.8174	0.00039	4.06618
Within groups (parcels)	47.0867	8	5.88583	—	—	—
Total	414.669	11	—	—	—	—
November						
Depth: 10 cm						
Between groups (parcels)	99.8233	3	33.2744	3.18213	0.08462	4.06618
Within groups (parcels)	83.6533	8	10.4567	—	—	—
Total	183.477	11	—	—	—	—
Depth: 20 cm						
Between groups (parcels)	83.3292	3	27.7764	1.75828	0.23261	4.06618
Within groups (parcels)	126.38	8	15.7975	—	—	—
Total	209.709	11	—	—	—	—
January						
Depth: 10 cm						
Between groups (parcels)	16.6825	3	5.56083	1.27811	0.34592	4.06618
Within groups (parcels)	34.8067	8	4.35083	—	—	—
Total	51.4892	11	—	—	—	—
Depth: 20 cm						
Between groups (parcels)	12.35	3	4.11667	1.21975	0.36375	4.06618
Within groups (parcels)	27	8	3.375	—	—	—
Total	39.35	11	—	—	—	—

At 20-cm depth, the highest EC value was 25.0 μs/cm and the lowest was 11.3 μs/cm in September and January, respectively.

Therefore, and according to the USDA, there was a situation of slight salinization in September (by the end of the growing season) which evolved into a situation of no salinization 4 months later in this parcel.

During the period of 4 months after the last fertigation procedures, the EC evolved from 368% of the value of control parcel's EC (in September) to 120% of its value (in January) due to natural remediation.

EC of Parcel B: Low Salinity (1 mS/cm)

At 10-cm depth, the highest and lowest EC values were 20.8 and 12.0 μs/cm in September and January, respectively. At 20-cm depth, the highest EC value was 22.8 μs/cm and the lowest was 9.2 μs/cm in September and January, respectively.

Therefore, and according to the USDA, there was a situation of no salinization through the entire experimental period in this parcel.

During the period of 4 months after the last fertigation procedures, the EC evolved from 170% of the value of the control parcel's EC (in September) to 112% of its value (in January) due to natural remediation.

EC of Parcel C: No Fertigation

At 10-cm depth, the highest and lowest EC values were 24.9 and 9.7 μs/cm in September and January, respectively. At 20-cm depth, the highest EC value was 14.5 μs/cm and the lowest was 9.4 μs/cm in September and January, respectively.

As expected, and according to the USDA, there was a situation of no salinization through the entire experimental period in this parcel.

During the period of 4 months after the last fertigation procedures, the EC evolved in this case from 212% of the value of the control parcel's EC (in September) to 91% of its value (in January) due to natural remediation.

EC of Parcel D: Control Parcel (No Treatment)

At 10-cm depth, the highest and lowest EC values were 11.7 and 10.7 μs/cm in September and January, respectively. At 20-cm depth, the highest EC value was 11.8 μs/cm and the lowest was 8.6 μs/cm in September and January, respectively.

As expected, and according to the USDA, there was a situation of no salinization through the entire experimental period in this parcel.

Water-Stable Aggregates

The measurements of WSA indicate that, by the end of the experimental period, both parcels A and C had higher values of water soil aggregate stability than the control parcel, which is a soil improvement in these parcels. In parcel B, this improvement was

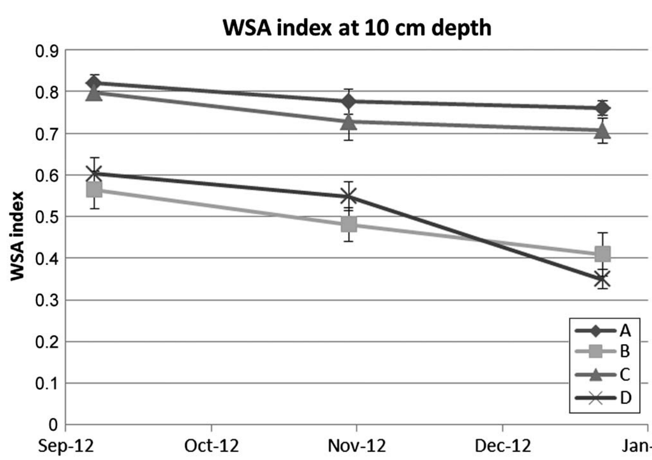

Fig. 6. Evolution of WSA averages in the four parcels at 10-cm depth

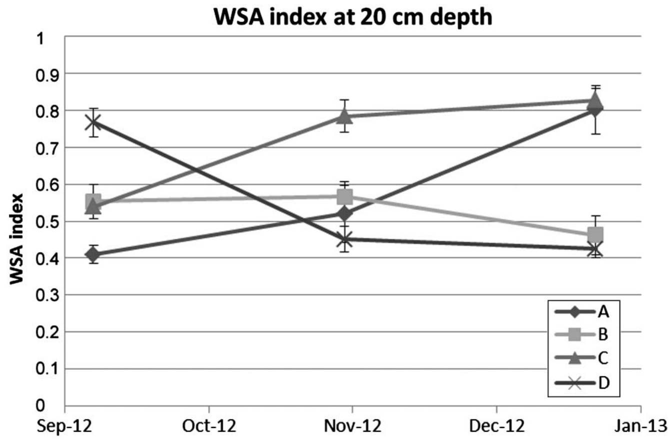

Fig. 7. Evolution of WSA averages in the four parcels at 20-cm depth

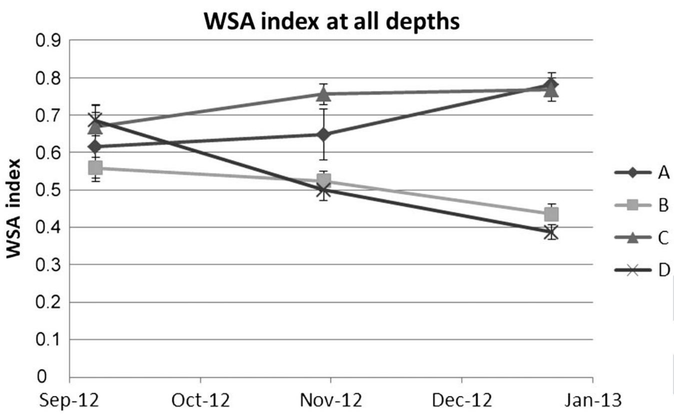

Fig. 8. Evolution of WSA averages of both layers in the four parcels

not as significant as in parcels A and C. Parcels A and C behave collectively as well as parcel B and the control parcel, which suggests that the random effect of the site prevails and there is no effect of fertigation. Nevertheless, the water aggregate stability index of parcels A, B, and C was never lower than the control parcel since November, and there was a clear improvement in parcels A and C (Figs. 6–8). ANOVA (Table 3) also shows significant differences between the applied treatments.

Water-stable aggregates increased with salinity; this was compatible with what was stated by Shindi et al. (2011) and Saad et al. (2011): that high-salinity treatment has resulted in the highest WSA.

For both parcels B (conventional salinity treatment) and D (no treatment), WSA decreased at both depths from September to January, and therefore the WSA variation from salt transference between soil layers was not as evident as in the treatments for A and C (Figs. 6–8).

Bullock et al. 1988 and Lehrsch et al. 1991 have indicated that aggregate stability decreases with increasing soil water content at the time of freezing (layers 10 and 20 cm have been frost several times during the experimental season). Therefore, lower values of WSA in samples collected during winter are not a strange result, especially in the control parcel where no other WSA influencing factor has been applied.

Total Dry Matter Production

Even though this article is not particularly focused on the crop behavior as a consequence of fertigation, the crop presence was necessary to produce evapotranspiration, and therefore to allow cycles of irrigation followed by soil water depletion. The crop used was grass, which is near the FAO 56 standard crop for reference ET estimation (lawn field).

The results have shown that the total dry matter (TDM) production for each of the 2-m^2 parcels was as follows: 950, 750, 307, and

Table 3. ANOVA Results—WSA between the Four Experimental Parcels for a 95 Confidence Interval

Source of variation	SS	df	MS	*F*	*P*-value	*F* crit
September						
Depth: 10 cm						
Between groups (parcels)	0.15468	3	0.05156	15.7647	0.00101	4.06618
Within groups (parcels)	0.02616	8	0.00327	—	—	—
Total	0.18085	11	—	—	—	—
Depth: 20 cm						
Between groups (parcels)	0.19692	3	0.06564	25.1763	0.0002	4.06618
Within groups (parcels)	0.02086	8	0.00261	—	—	—
Total	0.21778	11	—	—	—	—
November						
Depth: 10 cm						
Between groups (parcels)	0.17893	3	0.05964	13.9566	0.00152	4.06618
Within groups (parcels)	0.03419	8	0.00427	—	—	—
Total	0.21312	11	—	—	—	—
Depth: 20 cm						
Between groups (parcels)	0.18645	3	0.06215	10.4854	0.00381	4.06618
Within groups (parcels)	0.04742	8	0.00593	—	—	—
Total	0.23387	11	—	—	—	—
January						
Depth: 10 cm						
Between groups (parcels)	0.38667	3	0.12889	37.8525	4.5×10^{-5}	4.06618
Within groups (parcels)	0.02724	8	0.00341	—	—	—
Total	0.41391	11	—	—	—	—
Depth: 20 cm						
Between groups (parcels)	0.41631	3	0.13877	38.9721	4×10^{-5}	4.06618
Within groups (parcels)	0.02849	8	0.00356	—	—	—
Total	0.4448	11	—	—	—	—

160 g in parcels A, B, C, and D, respectively. Note that these results might have been much different if a more EC-sensitive crop had been used instead of the lawn. In this particularly case (crop and experiment) where excess salinization was not a limiting factor, more saline water resulted in higher dry matter production.

Conclusion

Both methods for assessing the EC evolution have shown no significant differences between the EC values at the end of the experiments; the higher fluctuations of EC readings were observed between the irrigation cycles, and those fluctuations are connected to the EC relation to volumetric water content as shown in Eq. (2).

The results on the water aggregates stability test have shown some improvement in parcels A (fertigation with high salinity) and C (simple irrigation with no nutrition) during the whole experimental period. In both parcels (A and C), an improvement first at the upper layers and later at the lower layers was clear. Parcels B and D followed the same trend with very similar values at the end of the experimental period, but were less stable than the previous parcels (A and C). None of the three treatments reported a lower value of WSA than the control parcel by the end of the experimental period.

There has been no evidence of soil degradation in any of the parameters where this study was focused (salinization and aggregate stability). In the short term, within the time lapse of one growing season, fertigation has improved WSA and had no significant influence on soil EC in the experimental edaphoclimatic conditions.

Acknowledgments

This study was partly supported by research grant no. MSM6046070901 sustainable agriculture, quality of agricultural products, sustainable use of natural and landscape resources of the Czech University of Life Sciences in Prague, financed by the Ministry of Education, Youth and Sports of the Czech Republic. The authors would like to thank Rute Paredes (ruteparedes@gmail.com) for the English review of this work.

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Queries

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3. "Decision Support System-Fertigation Simulator" was changed to lowercase (decision support system-fertigation simulator). Change ok? Or is this a proper or product name?

4. "... electrical conductivity (EC) of the soil solution; aqueous extracts of soil" was edited as "... electrical conductivity (EC) of the soil solution (aqueous extracts of soil)." Change ok? Or should it be "... electrical conductivity (EC) of the soil solution on aqueous extracts of soil"?

5. Is "Ωm" correct as is (in "... measurement of the bulk electrical resistivity (ER, Ωm) ...")? Or should it be MΩ (megaohms)?

6. Should "ECa" be displayed as "EC_a," similar to EC_b and EC_w? Please clarify throughout.

7. Can "dS m^−1" be edited as "dS . m^−1" or "dS/m^−1"?

8. The citation Rhoades et al. (1999) is not present in the References list. Please provide the full details for Rhoades et al. (1999), and we will insert it in the References list and link it to this citation.

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13. "... and to land use management" was edited as "... and by land use management." Change ok?

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21. Please define "a.s.l." (in "... Czech University of Life Sciences Prague located at 50°8′N and 14°23′E, 286 m a.s.l.").

22. Please define DM ("top soil with 2.5% DM").

23. Can the unit "cm.min^-1" be edited as "cm/min^-1" or "cm · min^-1"? Please clarify for this and similar units throughout.

24. Ok to change "plough sole" to "plow sole" (in "The total porosity varies between 0.40 (plough sole) . . . ")?

25. "in three different moments" was changed to " at three different times" in " . . . at three different times after the growing season (September, November, and January) . . . " Change ok?

26. "Parcel A: Submitted to fertigation . . . " was edited as "Parcel A was submitted to fertigation . . . " Change ok?

27. "Parcel B: Submitted to fertigation . . . " was edited as "Parcel B was submitted to fertigation . . . " Change ok?

28. "Parcel C: Submitted to conventional irrigation . . . " was edited as "Parcel C was submitted to conventional irrigation . . . " Change ok?

29. "Parcel D: No treatment . . . " was edited as "Parcel D received no treatment . . . " Change ok?

30. "Food and Agriculture Organization of the United Nations" was added as the definition for FAO. Please confirm this is correct.

31. The citation (Allen et al. 2012) mentioned in this sentence is not present in the References list. Please provide the full details for (Allen et al. 2012), and we will insert it in the References list and link it to this citation.

32. Is 5TE an abbreviation? If so, please define (in " . . . resorting to 6 5TE sensors installed . . . ").

33. Is ECH_2O a product? Please provide the manufacturer name and location.

34. Is "Decagon equation (2012)" a reference citation? If so, please provide the reference.

35. Please provide the manufacturer name and location for TightVNC.

36. Can "2 g of sodium hexametaphosphate/L" be edited as "2 g/L of sodium hexametaphosphate"?

37. Please clarify "(-)" in "where WSA = the index of water-stable aggregates (-) . . . "

38. "in three different moments" was changed to "at three different times" in " . . . at three different times during the experimental period . . . " Change ok?

39. " . . . and in three different moments . . . " was edited as " . . . and at three different times . . . " Change ok?

40. Please spell out "F crit" in Tables 2 and 3.

41. In Tables 2 and 3, please define SS, df, and MS.

42. " . . . this was compatible with what was stated by Shindi et al. (2011), Saad et al. (2011), high salinity treatment . . . " was edited as " . . . this was compatible with what was stated by Shindi et al. (2011) and Saad et al. (2011): that high salinity treatment . . . " Change ok?

43. Please provide a reference for Shindi et al. 2011.

44. Please clarify "have been frost" in " . . . layers 10 and 20 cm have been frost several times . . . ." Can this be edited as "have experienced frost"?

45. Are "sustainable agriculture, quality of agricultural products, sustainable use of natural and landscape resources" the names of programs, or grants? If they are formal names, they should be changed to uppercase.

46. FAO was spelled out as "Food and Agriculture Organization" in the Allen et al. 1998, Ayers and Westcot 1985, and Brower et al. 1985 references, and Roma was changed to Rome. Please confirm these changes are correct.

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