Validation of SALTIRSOIL for the calculation of salt composition and electrical conductivity in horticultural soils

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Abstract
A validation exercise of the SALTIRSOIl model developed to predict average major ion content, pH and electrical conductivity in soils under risk of salinisation, has been carried out in two irrigated horticultural subplots cropped to water melon and pepper . Calculated values were compared with depth-averaged measurements made in saturated pastes from soil samples taken at three soil depths during the growing season of 2008. SALTIRSOIL predicts reasonably well ion composition, pH and electrical conductivity of saturation extracts in these studied horticultural soils irrigated by surface systems. Nevertheless, in order to carry out a more complete validation, more plots and crop species are necessary.

Key Words
Soil salinisation, ion composition, agricultural modelling, irrigation, SALTIRSOIL model

Introduction
Coastal alluvial soils for horticultural crops under surface irrigation systems in the Valencian Community (Eastern Spain) are under risk of salinisation due to several factors such as intense evapotranspiration, scarcity and loss of quality of the irrigation water, over-irrigation, water-logging, misuse of fertilizers and management practices. At the same time, irrigated agriculture is also depleting and polluting water supplies in many places. Ideally, it would be desirable to know the concentrations of the individual solutes in the soil water without the intensive soil sampling and laboratory analyses necessary for characterizing the salinity conditions of extensive areas. SALTIRSOIL (Visconti 2009) is a capacity-type, steady-state and chemical equilibrium model developed to predict average major ion content (sodium, calcium, magnesium, chloride, sulphate, etc) in the medium to long term in productive well drained soils.
Our objectives in this study were i) to calculate the composition of the average soil solution in the saturated paste from two furrow irrigated plots cropped to water melon and pepper in an area under risk of salinisation in Mediterranean Spain and ii) to compare the calculated values with those observed.

Methods
Study area and experimental plots
Two experimental subplots were selected in the lower *Palància* river basin in Valencian Community, Mediterranean coast of Spain. Climate is characterised by high evapotranspiration (1000 mm/yr) and low rainfall (less than 500 mm/yr). Soils near the coast are fine-textured and coarser inland. Irrigation in horticultural soils is applied by both surface and drip systems. Irrigation water quality in the area varies from good (1 dS/m) to salty (4 dS/m). The experimental area (1.3 ha) has been cultivated to produce vegetables for many years. It has been monitored since late spring 2007 until early autumn 2008. Soil texture is clay loam (USDA), medium in organic matter and calcium carbonate. During 2008 it was cropped to water melon (subplot 1, 1ha) and pepper (subplot 2, 0.3 ha), and furrow irrigated with salty water (4.2 dS/m) from a nearby well.

Plot sampling and soil analyses
Each experimental subplot was sampled monthly from April until November 2008 at two points, one near the irrigation water inlet (point 1), and another one opposite this in the direction of the water flow (point 2). At each point and date, soil was sampled at three depths: 0-10, 10-30 and 30-60 cm. Eighty-four soil samples were analysed in the saturated paste for main inorganic ion composition, pH and EC_{25}.
Saturated soil-pastes were prepared adding deionised water to the soil according to the method described by Rhoades (1996) with no addition of sodium hexametaphosphate solution in the saturation extract. Soil saturation extracts were analysed for electrical conductivity (EC_{25}), sodium, potassium, calcium, magnesium, sulphate, chloride, nitrate, alkalinity and pH. Determination of EC_{25}, pH, and alkalinity were performed within 2 hours of extract collection. Simultaneously, an aliquot of the soil saturation extract was diluted with

deionised water. Ions were determined by ion chromatography in the diluted extracts filtered through 0.45 µm pore filters to remove particulate material, within 4 days of extract collection. EC_{25} was measured with a Crison microCM 2201 conductivity meter with temperature probe. The pH was measured with a Crison GLP22 pHmeter. Alkalinity was determined by potentiometric titration with sulphuric acid 10 mM standardized every week.

Simulations
Simulations of the soil saturated-extract composition in the experimental plot were carried out with the weather, water, irrigation, crop, soil and chemical information shown in boxes 1 and 2. The information used to calculate the soil solution concentration factor (Visconti 2009) is shown in box 1, and so is in box 2 the information used to calculate the final composition in equilibrium with CO_2, calcite and gypsum.

Box 1. Input information to calculate soil solution composition

Weather from Benavites station:
- ❖ Rainfall of 501 mm/yr
- ❖ Reference evapotranspiration of 1022 mm/yr calculated according to Penman-Monteith (Allen *et al.* 1998)

Irrigation
- ❖ Programme:

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
mm	0	0	0	80	0	30	23	92	123	0	0	0
days	0	0	0	1	0	1	1	4	6	0	0	0

- ❖ Water quality:

EC_{25}	Na	K	Ca	Mg	Cl	NO_3	SO_4	Alk	pH
4.23	14.7	0.3	8.0	6.8	24.8	4.1	6.4	3.8	7.95

All ions in mmol/L, Alk in meq/L and EC_{25} in dS/m

Crop:
- ❖ Species: subplot 1 water melon (*Citrullus lanatus* L.) with cabbage foot, and subplot 2 pepper (*Capsicum annuum* L.)
- ❖ Basal crop coefficients (Allen *et al.* 1998):
  - ➢ Water melon

Stage	initial	development	mid season	late season
Duration / days	32	45	45	31
Crop coefficient	0.15	0.55	0.95	0.83

  - ➢ Pepper

Stage	initial	development	mid season	late season
Duration / days	34	34	35	30
Crop coefficient	0.15	0.63	1.10	0.80

- ❖ Growing season: water melon from 26th April till 6th September, and pepper from 14th May till 3rd September
- ❖ Maximum shaded soil: 47% water melon and 42% pepper
- ❖ Maximum rooting depth: 60 cm
- ❖ Water extraction pattern: 40-30-20-10

Soil:
- ❖ Physical properties
  - ➢ Stone percentage: < 5%
  - ➢ Texture (USDA): 35-43 and 33-38 clay-sand in point 1 and 2 respectively
- ❖ Chemical properties
  - ➢ Equivalent calcium carbonate: 14%
  - ➢ Gypsum: < 0.5%
  - ➢ SOM: ~ 3% in the 10 surface cm

Drainage:
- ❖ Pipeline 60 cm deep with a 9 m spacing

During the growing season, three irrigation water samples were taken and analysed with the same methods used for the soil extracts.
Texture, soil organic matter and equivalent calcium carbonate were determined according to the Spanish Ministry of Agriculture official methods (MAPA 1994).

A weighted average soil saturation-extract composition was calculated for each of the two points using equation 1 where P is the average value of the property and $P_{0\text{-}10}$ is its value in the sample from the 0-10 soil layer and so is $P_{10\text{-}30}$ from the 10-30 layer, etc.

$P = (P_{0\text{-}10} + 2\, P_{10\text{-}30} + 3\, P_{30\text{-}60})/6 \quad (1)$

Water contents at saturation and field capacity were calculated with pedotransfer functions developed for agricultural soils of Valencian Community (Visconti 2009).

Box 2. Input information to the chemical equilibrium calculation

Chemical equilibrium constants:

- Ion association constants: Lindsay (1979)
- Calcite solubility product (pKs): 8,29.
- Gypsum solubility product (pKs): 4,62.

CO_2 partial pressure in equilibrium with the solution in the soil saturated paste after 4 hours: $9.5\ 10^{-4}$ atm

Results

Subplot 1 water melon

The soil composition of the saturation extract in points 1 and 2 calculated with SALTIRSOIL (Sim1-1 and Sim1-2 respectively) was compared to the corresponding measured compositions (Figure 1). The calculated values of electrical conductivity in the saturation extract (EC_{se}) in point 1 (3.24 dS/m) and point 2 (3.29 dS/m) differed only in 0.05 meq/L. This is a negligible difference, as the only important input variable different between both points is the sand fraction, which is an order of magnitude less important than the electrical conductivity of the irrigation water (EC_{iw}) on EC_{se} calculation as we know from the Sensibility Analysis (Visconti 2009). For the two points, the measured EC_{se} are 5.17 and 3.51 dS/m, respectively. The EC_{se} point is observed under the 1:1 line in Sim1-1 (left scatter plot), and on the 1:1 line in Sim1-2 (centre scatter plot). The error in the calculation of EC_{se} in Sim1-1 is because the errors in the calculation of chloride, sodium, calcium, magnesium and sulphate, which are, in this order, the most abundant ions in the irrigation water. These ions make up the major portion of salts in the irrigation water, and in the soil solution also, and then dominate the calculated value of electrical conductivity.

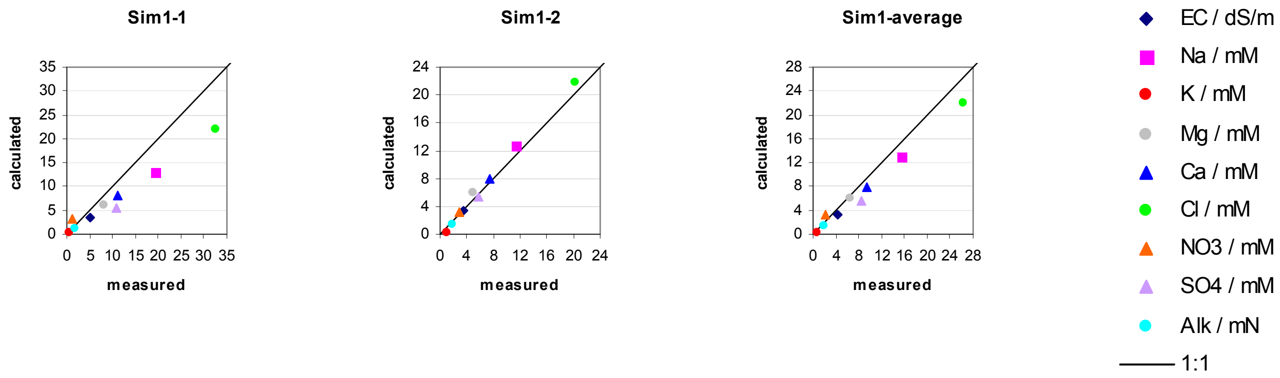

Figure 1. Scatter plots of predicted versus measured values in subplot 1

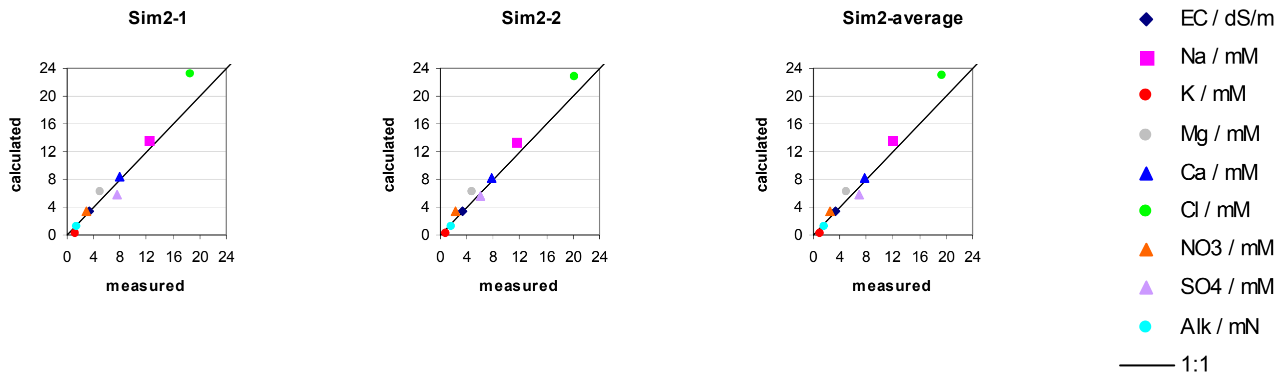

Figure 2. Scatter plots of predicted versus measured values in subplot 2

An alkalinity (Alk) of 1.30 meq/L was calculated in Sim1-1 and Sim1-2. This value is 26% lower than the alkalinity measured in point 1 (1.75 meq/L), and 31% lower than the measured alkalinity in point 2 (1.89 meq/L). The pH values calculated in the saturated pastes from both points were 7.84 and 7.85, thus very close to the measured values of 7.72 in both points.

Subplot 2 pepper

The soil composition saturation extract in points 1 and 2 calculated with SALTIRSOIL (Sim2-1 and Sim2-2 respectively) and comparison to the observed values are shown in Figure 2. The calculated values in Sim2-1 (3.48 dS/m) and Sim2-2 (3.43 dS/m) do not differ. For points 1 and 2, the measured EC_{se} are, respectively, 3.43 and 3.32 dS/m. Both EC_{se} points are located on the 1:1 lines, thus indicating that simulated and measured EC_{se} are very similar for both points. An alkalinity (Alk) of 1.29 meq/L was calculated in both points. This value is 14% lower than the alkalinity measured in point 1 (1.50 meq/L), and 22% lower than the measured alkalinity in point 2 (1.65 meq/L). The calculated pH values were 7.84 in both points, again very close to the observed values of 7.75 and 7.78 in points 1 and 2, respectively.

Discussion

Simulated and measured values for pH, EC, Alkalinity, and main inorganic ions in the saturation extracts are quite similar in subplot 2, but not in subplot 1. In general, surface irrigation systems lack of homogeneity in water application, and this heterogeneity increases with the size of the plot since amount and availability of water is lower as we get further from the inlet. On the other hand, Mediterranean soils are quite heterogeneous in nature and, particularly, those of alluvial origin under conventional horticultural practices that require removal of antecedent crop residues, ploughing etc. Then, irrigation plots are better characterized by spatial averages than by single point values. This statement particularly holds for the 1ha subplot 1. In fact, we observed differences in texture, drainage, actual amount of water available for crops and productivity depending on the relative position respect to the water inlet. Then, mean values in subplot 1 were calculated (Sim1-average). The mean measured electrical conductivity in subplot 1 is 4.34 dS/m and the mean calculated is 3.32 dS/m. In figure 1 (right scatter plot) we can observe that mean measured values are closer to those calculated than single values (centre and left scatter plots). Concerning to salt composition it is worthy to note that chloride seems to be over-predicted compared to other salts. A comparison of simulated and calculated values in more plots will be needed in order to ascertain whether this fact is due to a systematic error.

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Conclusion

SALTIRSOIL seems to predict accurately ion composition and electrical conductivity of saturation extracts in horticultural soils under surface irrigation systems. Nevertheless, in order to carry out a more complete validation, more irrigated plots and crops are necessary.

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