Volume 84(1). Published September, 01, 2021
www.jnsciences.org
E-ISSN 2286-5314

Modelling by Hydrus-1D of Salt Dynamics and Feasibility of Water Blending

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Abstract – Water blending is one of the most common strategies to improve the overall water supply and water quality.

The Hydrus-1D model has been applied in the following treatments:

-Full blending between saline water (1 g/l or 3 g/l or 5 g/l) and distilled water before water supply,

-An alternating supply between saline water (1 g/l or 3 g/l or 5 g/l) and distilled water with the same proportions (50% of saline water and 50% of distilled water), i.e. every day (T50-50), either day by day (T1d-1d), or two days by two days (T2d-2d).

The same daily amount of blended water was supplied in all cases. Two time-cycle in modelling were considered, the first 48 hours of crops cycle and a complete crop season wish is about 90 days. Based on Hydrus-1D modelling, the interval between the desalinated water and saline water intake must be reduced. The longer the interval between salt water inflow and freshwater inflow, the higher the observed salinity peak is. The highest salinity was observed successively in the cases of T2d-2d, followed by T1d-1d and then by T50-50. Full blending leads to the lowest salinity, it is the recommended treatment. These results are in concordance with field trials. Saline water and desalinated water blending is less profitable than fresh water in the case of moderately saline-sensitive crops such lettuce due to high desalinated water cost.

Keywords: water blending feasibility, irrigation scheduling with blended water, Hydrus 1-D, soil profiles salinities

Introduction

Tunisia's water resources present a high salinity; deep and shallow aquifers having a salinity of less than 1.5 g/l, represent respectively only 20% and 8% of underground water resources (Mammou, 1993). Low crops yield decrease is observed; tomato yield is generally less than 50 tons/ha while it reaches more than 100 tons/ha when freshwater is available. The yield of irrigated dates in Tunisia is about 10% of the yield observed in Egypt when freshwater is used. The use of desalinated water for irrigation in the case of high added value crops and/or crops intended for export begins to expand in recent years worldwide but desalination cost is high. In Tunisia, it's about 0.5 US $/m^3$ while currently, irrigation water cost is about only 0.05 US $/m^3$. To allow the expansion of the use of desalinated water, a blending is imperative in the aim to increase the overall water supply and reduce costs. Desalinated and no-conventional water blending is usually done by farmers to improve the final water quality after the farmers' survey (Monterrey-Viña et al., 2020). Daghari et al (2014) show the importance of a cross-application for sustainable development, including Water-Energy-Food nexus concepts. The water blending of different water sources with better quality is recommended for sustainable irrigation after Maestre-Valero et al. (2019). The use of freshwater during the crop's sensitive phases and saline water during the non-sensitive phases is recommended by Daghari et al. (2021)

By water blending, soil degradation can be reduced and the qualities of irrigation water can be improved (Maestre-Valero et al., 2020a). In the case of water blending, field experimentations show that the interval between the desalinated and the saline water intake must be reduced; the longer the interval between saltwater inflow and freshwater inflow, the higher the observed salinity peak and the higher yield decrease (Daghari et al., 2020a). Blended aquifer saline water and freshwater obtained by reverse osmosis have been used for more than twenty years for the irrigation of cherry tomato mainly for export in the Gabès region in Tunisia (SUNLUCAR project). Both sources are available continuously, so a simultaneous dilution through the irrigation network is done.

In the Cap Bon area, northeast Tunisia when seawater intrusion and aquifer overexploitation were observed, a full blending between surface freshwater (1 g/l) transferred from the northwest region (using a 100 km open channel) and aquifer salty water (more than 5 g/l) is done throughout the irrigated perimeter in large reinforced concrete at a farm level or by injection of fresh water in wells. Wells deep is about 20 m, (Daghari, 2016). Using concrete tanks and/or the injection of freshwater into wells and its pumping generate additional costs for farmers. When water blending takes place on a large (regional) scale, the concentration of mixed water is imposed on the farmers. On the other hand, when the blending is done at the farm level, it has the advantage that the farmers can vary the salinity of the blended water and adapt it to the sensitive salinity of each crop. The method of soil diluting by applying intermittent supply between fresh and saline water constitutes an advantageous practice for the farmers (Kanzari et al., 2020) especially in the case of solar desalination use. Desalinated water production varies and can't be done continuously depending on the solar radiation variation, (Chouaib and Chaibi, 2014) therefore, a full blending is impossible. Tunisia has significant solar potentials (an irradiance of more than 2000 kWh/m^2 while the world average is 1200 kWh/m^2). The introduction of wastewater and desalinated water for irrigation is emerging in Tunisia (Mhiri 2018; Dhahbi 2016). The wastewater sector accounts for 25% of the global energy demand in the global water sector after (Di Cicco et al., 2019). The case of full water blending of salt water and distilled water will be modelized by Hydrus-1D (Šimůnek, 2005) as a complement to field trials which focused on cyclic irrigation of lettuce crop (Daghari et al., 2020a) in the aim to determine how to schedule irrigation in the presence of saline water and variable freshwater amounts. The production of desalinated water is very variable during the day. Lettuce crop occupies an important place in Tunisian culinary tradition and it is highly recommended by medicine as an element that helps digestion. On the other hand, Tunisian exports evolved from 100 tons to 5360 tons between 2004/2005 and 2013/2014. Lettuce production jumps from 14000 tons to 75000 tons between 2000 and 2014.

Unfortunately, lettuce becomes rare and with small size almost inedible and the price multiplies at least by three during all the dry periods of June-July-August and September, jumping from 0.03 to 0.1 US $/ piece between the wet season and dry summer. Once the rains resume in October, the quality of the lettuce improves significantly and the price decreases. Salt and fresh water blending can constitute a way to overcome these shortcomings of production in quantity and quality. Malash et al. (2008) recommend the blending of saline and non-saline water for irrigation as this will increase the overall supply of irrigation water and permit the introduction of new saline sensitive crops. The feasibility of irrigation with blended water in the case of lettuce crops deserves to be analyzed especially as freshwater is rare in Tunisia.

Our objectives are (i) whether, in the presence of saltwater and varying amounts of freshwater, splitting the dose of distilled water into several supplies is advantageous over a single supply in a single dose, (ii) check if the Hydrus -1D model can constitute a reliable tool for modelling the evolution of salinity under irrigated crops given the heaviness of the experiments and their repetition and (iii) evaluate the feasibility of using blended water for irrigating lettuce, especially that global water and energy demand will increase due to rapid population growth, climate change and water quality deterioration (Shadi et al., 2020).

Materials and methods

The Hydrus-1D model was used in the case of irrigation with blended waters (distilled water and saline water). The same boundaries and initial conditions observed in field trials were used. For the upper boundary conditions, evapotranspiration was taken equal to 4.3 mm/day, calculated by the CropWat model corresponding to the driest month (May). The daily dose of irrigation was taken equal to the evapotranspiration with the aim to keep the soil water stock constant. Irrigation was done manually in a form of 1D-rain.

For the lower limit, Hydrus offers several possibilities (free drainage, zero flow, horizontal drains ...) which depend on the specificity of the parcel. In our case, the lower limit condition to use is free drainage as the pots have holes underneath but we did not notice any significant water loss.

Initial soil salinity was taken equal to the soil salinity measured in situ (2 g/l). The initial water content was 20%. For all simulations, 50% of saltwater has a salinity of 1 g/l or 3 g/l or 5 g/l and the rest (50%) is in distilled water.

Modelling by Hydrus-1D concerned the 2 situations:

- a full blending with the same proportion of 50% of saltwater (1 g/l or 3 g/l or 5 g/l) and 50% of distilled water, i.e., respective average salinities of the blended irrigation water of 0.5 g/l, 1.5 g/l and 2.5 g/l.

- Irrigation with saltwater in the morning and irrigation with the same amount of distilled water in the afternoon each day corresponding to the treatment $T_{50\text{-}50}$

- Irrigation with saltwater on the first day and irrigation with the same amount of distilled water on the second day corresponding to $T_{1d\text{-}1d}$ treatment.

- Irrigation with saltwater on the first two successive days and irrigation with the same amount of distilled water on the last two successive days corresponding to $T_{2d\text{-}2d}$ treatment for the case 1g/l only. For 3 g/l and 5 g/l, the growth of the lettuce was very poor at field level.

The following equation (Maas and Hoffman, 1977), (Ayers and Westcot, 1985) is applied to calculate relative yield (Y_r) when saline water is used:

$Y_r = 100 – b (EC_s - a)$ (1)

where b = the curve slope expressed in percent per dS/m (equal to 13), a = the salinity threshold expressed in dS/m (equal to 1.3) for lettuce, (Maas and Hoffman, 1977).

EC_s = the mean electrical conductivity of a saturated paste normally taken from the root zone (dS/m)

In the aim to analyze the feasibility of different water blending ways used to irrigate a lettuce drop, the following parameters will be used:

- value of agricultural products (US $/ha) = Selling price (US $/piece) * number of pieces of lettuce per hectare (2)
- gross margin (US $ /ha) = value of agricultural products (US $/ha) – (production cost (US $/ ha) + water cost (US $/ ha)) (3)

Furthermore with (Daghari et al., 2021):

- number of pieces of lettuce per hectare: 60000
- selling price (0.03 US$/piece during all the rainy season and 0.1 US $/piece during the dry season when lettuce production is done on few areas due to the lack of fresh water); the selling price of the agricultural products considered is the selling price at farm level.
- production cost (1000 US $/ha) are taken according to the Tunisian Ministry of Agriculture database and lettuce producers.

Results and discussion

Soil salinity modelization

The soil salinity evolution will be presented for the first 48 hours of the lettuce cycle and for a complete crop cycle of 90 days. The simulated curves are presented for only the case of 1 g/l so as not to encumber the paper. Initial soil salinity was 2 g/l. This salinity value is very common in Tunisian soils. Salinities of more than 3 g/l were respectively measured (Bani et al., 2020); Salty soils represent more than 30% of tunisian arable lands.

Simulated salinities in the case of a 48-hour cycle with 50% of salt water with a different salinity (1 g/l, 3 g/l and 5 g/l) and 50% of distilled water

For 1 g/l, Soil surface salinity exceeded initial salinity (2 g/l) and reached about 2.6 g/l and 2.8 g/l respectively for $T_{50\text{-}50}$ and $T_{1d\text{-}1d}$ treatment at t = 48 hours; the increase of salinity in the surface layer is due to the drying out of the soil following evapotranspiration (Figure 1).

In the case of cyclical supply between the same amounts of salt water and distilled water, salinities are less than the initial salinity (2 g/l) in the majority part of soil profiles, (Figure 1); average irrigation blended water salinity is 0.5 g/l. The supply of desalinated water lowers the soil profile salinities (green curve) then the salinity increases following evapotranspiration.

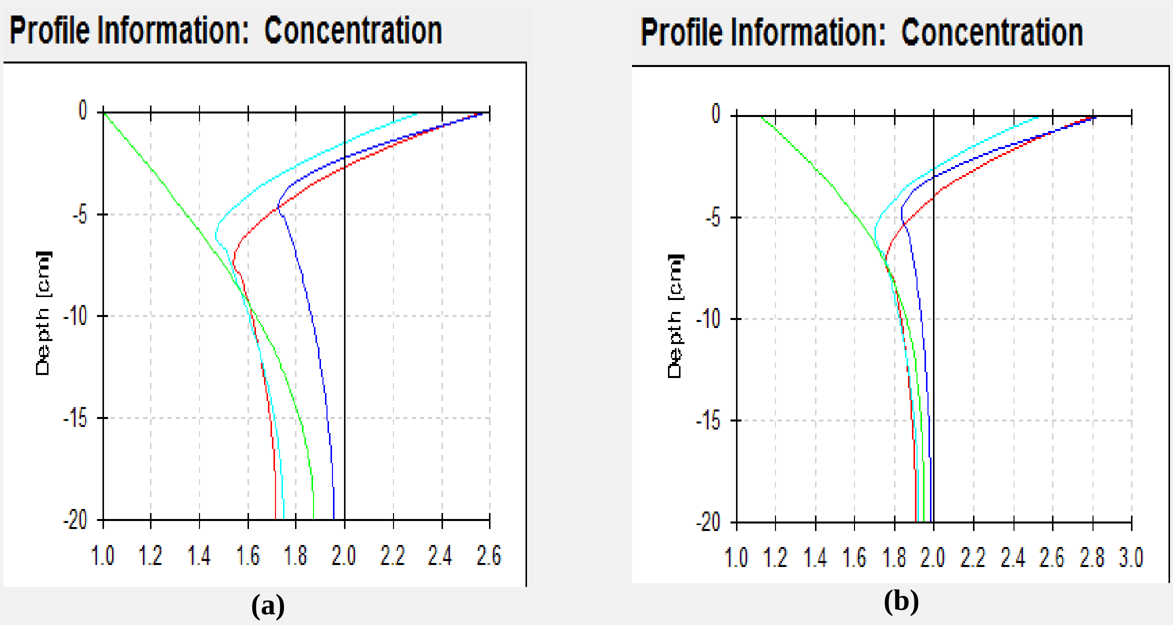

Figure 1: Simulated rootzone soil salinity for a 48-hour cycle with 50% of salt water with a different salinity (1 g/l, 3 g/l and 5 g/l) and 50% of distilled water for different time steps t=12 hours (------), t=24 hours (-------), t=36 hours (-----) and t=48 hours (-----).

For all salinities, average soil profiles salinity obtained by simulation in the case when irrigations occur one day with salt water and one day with distilled water (T_{1d-1d}) are greater than the salinities recorded when 50% of the water amount was given in the morning and 50% in the afternoon (T_{50-50}) (Table 1). For 1 g/l, average soil profiles salinity decreased from 2 g/l (initial salinity) to 1.51 g/l and 1.95 g/l respectively for T_{50-50} and T_{1d-1d} at t = 48 hours, (Table 1). In the case of 3 g/l, for T_{50-50}, salinity decreases from 2.13 g/l to 1.8 g/l at t=48 hours while it increases continually for T_{1d-1d} treatment, from 2.07 g/l to 2.52 g/l at t = 48 hours (Table 1). For 5 g/l, the maximum reached was 2.41 g/l, against 3.1 g/l respectively for T_{50-50} and T_{1d-1d} at t= 48 hours (Table 1).

Table 1 : Average predicted soil salinities under the treatments T_{50-50} and T_{1d-1d} at 12 hours, 24 hours, 36 hours and 48 hours for different water salinities

Salty water salinity	**1 g/l**		**3 g/l**		**5 g/l**	
Blended water salinity	**0.5 g/l**		**1.5 g/l**		**2.5 g/l**	
Treatment	T_{50-50}	T_{1d-1d}	T_{50-50}	T_{1d-1d}	T_{50-50}	T_{1d-1d}
Inital salinity	2	2	2	2	2	2
Salinity at 12 hours	1.86	1.92	2.13	2.07	2.13	2.23
Salinity at 24 hours	1.80	1.88	1.95	2.16	2.23	2.44
Salinity at 36 hours	1.44	1.81	1.7	2.23	1.94	2.65
Salinity at 48 hours	1.51	1.95	1.8	2.52	2.41	3.10

For the 3 salinities, the advantage of T_{50-50} is clear compared to T_{1d-1d}. The salinities reached (average soil profiles salinities and surface salinities) were less in the case of T_{50-50} compared to T_{1d-1d} for the same amounts of salt added but scheduled differently.
In addition, the final salinity simulated under T_{50-50} with a salinity water of 3 g/l are lower than this obtained with a salinity water of 1 g/l with the T_{1d-1d} treatment. Likewise, the final salinity measured under T_{50-50} with a water of salinity 5 g/l are less than this measured above T_{1d-1d} with a salinity of 3 g/l. Hence the advantage of reducing the irrigation interval if salt water and fresh water are used (Table 1). Ould Ahmed et al (2007) used irrigation water with 2 salinities 0.11 and 2.0 dS/m with two different irrigation intervals (one day and two days). The results showed that the soil salinity increases 7 to 15 times with daily irrigation and 8 to 18 times with the irrigation treatment given every other day.

Simulated salinities in the case of a 90-day complete lettuce cycle with 50% of salt water with a different salinity (1 g/l, 3 g/l and 5 g/l) and 50% of distilled water
It's clear that when a cyclical supply of desalinated water and saline water is done, the lower the interval between the supply of desalinated water and salt water the lower the maximum salinity measured or simulated in the soil (Table 2).

For blended water of a salinity of 0.5 g/l, average soil profiles salinities simulated were 1.54 g/l, 1.99 g/l and 2.77 g/l, respectively for T_{50-50}, T_{1d-1d} and T_{2d-2d} at t = 90 days, (Table 2). In the case of blended water of 1.5 g/l, average soil salinities simulated were 2.61 g/l and 3.23 g/l at t = 90 days, respectively for T_{50-50} and T_{1d-1d}. Average soil profiles salinities recorded were 3.03 g/l for T_{50-50} while this value was 4.06 g/l for T_{1d-1d}, at t = 90 days, with blended water of 2.5 g/l (Table 2).
At field level, lowest measured salinities were observed also generally under the treatment T_{50-50} compared to T_{1d-1d}. They were respectively 1.85 g/l and 2 g/l in the case of blended water of 0.5 g/l, 2.57 g/l and 2.6 g/l for blended water of 1.5 g/l and 4 g/l and 4 g/l for blended water of 2.5 g/l. The better values of agronomic parameters (height, width and number of leaves) were observed under treatment T_{50-50}. In the case of 0.5 g/l, the better width is observed under T_{50-50} with 20 cm. For 1.5 g/l, a decrease in the number of leaves was observed for the treatment T_{1d-1d} in the opposite of T_{50-50}. Even for water blended of 2.5 g/l, the leaves still present only for T_{50-50} (Daghari et al., 2020).

Table 2: Average predicted and measured soil salinities in the case of T_{50-50} and T_{1d-1d} at 30 days, 60 days and 90 days for different water salinities.

Salty water salinity		**1 g/l**			**3 g/l**		**5 g/l**
Blended water salinity		**0.5 g/l**			**1.5 g/l**		**2.5 g/l**
Treatment	T_{50-50}	T_{1d-1d}	T_{2d-2d}	T_{50-50}	T_{1d-1d}	T_{50-50}	T_{1d-1d}
Initial salinity	2	2	2	2	2	2	2
Simulated salinity at 30 days	1.75	1.98	2.28	2.2	2.24	2.35	2.70
Simulated salinity at 60 days	1.65	1.98	2.46	2.42	2.83	2.70	3.38
Simulated salinity at 90 days	1.54	1.99	2.77	2.61	3.23	3.03	4.06
Measured salinity in pots at 90 days	1.85	2.1	-	2.58	2.63	4.08	4.09

Here too, the T_{50-50} treatment obtained with a blended water of 1.5 g/l salinity leads to lower salinities than those simulated in the case of the T_{2d-2d} treatment with blended water of 0.5 g/l salinity (columns 5 and 4 in Table 2). The advantage of reducing the irrigation interval in the case of blended water is confirmed not only for a 48 hours cycle but also for the all-lettuce cycle.

The lowest yield drops are obtained in the case of T_{50-50}. An early generalized fall was observed in the case of 5 g/l. In the case of moderately saline-sensitive crops such as lettuce (Lactuca sativa L.), irrigate with drainage water whose salinity varies between 4-6 dS / m can lead to yield decrease of 80% (Dinar et al., 1986).
Measured and predicted salinities are in concordance (Table 3, the last two lines). The final simulated salinities in the case of full blended water of 0.5 g/l, 1.5 g/l and 2.5 g/l were respectively 1.4 g/l, 1.76 g/l and 2.21 g/l at t = 90 days. In this case, also we see that full blended water before supply leads to the lowest salinity compared to T_{50-50} and T_{1d-1d}. The advantage of full blending is clear compared to cyclic supply.

Feasibility of water blending in the case of lettuce crops
Desalinated water cost is around 0.5 US$ / m^3 and the cost of irrigation water from the public network is around 0.05 US $/ m^3 in Tunisia.
In our case, the water requirements are 4.3 mm/day for 90 days and if only 50% is given in the form of desalinated water, i.e., a volume of desalinated water needed is 1935 m^3/ha and total cost of required desalinated water is 967.5 US $/ha (= 1935 m^3/ha *0.5 US$/$m^3$). With this blending rate of 50%, the salt water cost is only 96.75 US $/ha.
If only state network salt water is used, saline water cost is 193.5 US$/ha (= 3870 m^3/ha * 0.05 US$/$m^3$).

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Table 3: Net revenues in the case of tretmentsT_{50-50} and T_{1d-1d} at 30 days, 60 days and 90 days for different water salinities.

Salt water salinity (g/l)		**1**		**3**		**5**		**1**
Blended water salinity (g/l)		**0.5**		**1.5**		**2.5**		**1 (no blending)**
Treatment		T_{50-50}	T_{1d-1d}	T_{50-50}	T_{1d-1d}	T_{50-50}	T_{1d-1d}	
Measured salinity in pots at 90 days		1.85	2.1	2.58	2.63	4.09	4.08	2.3
Relative yield (%) (a)		79	74	66	63	44	44	70
Yield (piece/ha) (b) = (a) * 60000		47400	44400	39600	37800	26400	26400	42000
Production cost (US $/ha) (c)				1000				
Desalinated water cost (US $/ha) (d)				1064 (= 967.5 + 96.75)				193.5
Value of agricultural products (US $/ha) (e)	0.03 US $/piece (during the rainy period)	1422	1332	1188	1134	792	792	1260
	0.1US $/piece (during the dry period)	4740	4440	3960	3780	2640	2640	4200
Net revenue (US $/ha) (f) = (e) – ((c) +(d))	0.03 (US $/piece)	-640	-732	-876	-930	-1272	-1272	66.5
	0.1 (US $/piece)	2676	2376	1896	1716	576	576	3006.5

If desalinated water is used in the proportion of 50% and when the selling price of lettuce is 0.03 US $/piece, the gross margin is negative (Table 3, penultimate line). A low or negative income of - 172 US $/ha was observed when mixed fresh water and desalted seawater were used to irrigate mandarins during Oct-2017 to Sept-2018, (Maestre-Valero et al., 2020b). When the price jumps to 0.1 US $/piece, the gross margin is positive. The use of desalinated water can be justified in regions lacking fresh water and especially since these high prices are encountered in summer when an important solar radiation potential is available in Tunisia. But the use of good quality water (1 g/l) is more interesting and results in a gross margin of 3006.5 US $/ha while it’s less for all cases of blended water given the high cost of desalination, (Table 3, last row). During the rainy period, farmers often didn’t irrigate lettuce and all their water needs can be met by rainfall, and family labor is often used to reduce production costs. Even a low lettuce selling price (0.03 US $/piece) can result in a positive gross margin, especially since lettuce does not require much care and is of short growing season.

Desalinated water and salt water blending is of little interest in the case of moderately saline-sensitive crops such lettuce. The use of saline water (1 g/l) has a gross margin greater than that observed in the case of blended water with 0.5 g/l, desalinated water cost is very high.

When water salinity increases, relative yield decreases. In the case of blended water of 2.5 g/l, relative yield is less than 45% (Table3). Drainage water with salinity in the 4-6 dS/m (4.06 to 5.93 dS/m) range have little utility unless 80% of yield potential is allowed in the case of moderately saline-sensitive crops such as lettuce (Lactuca sativa L.), (Dinar et al., 1986). Water blending is not profitable in all cases; when well water and blended water were used for irrigation of Buxus and Pistacia, similar growth was observed (Gori et al., 2008).

Conclusion

In the case of water blending, the interval between the desalinated and the saline water intake must be reduced. This assertion is confirmed by field experiment and by Hydrus-1D modelization. Indeed, the treatment T_{50-50} always resulted in the lowest salinity peaks compared to the treatment T_{1d-1d} and the treatment T_{2d-2d}. The better values of agronomic parameters (hight, width and number of leaves) were observed under treatment T_{50-50}.

For 1 g/l and for a 48-hour cycle, the soil salinity irrigated with blended water did not exceed 1.51 g/l for T_{50-50} versus 1.95 g/l for T_{1d-1d}. Even for a 90-day cycle, an average salinity of 1.54 g/l was simulated for T_{50-50} versus 1.99 g/l for T_{1d-1d}. In the case of T_{2d-2d} treatment, the salinity obtained by Hydrus 1-D for a 90-day cycle is 2.77 g/l, which is superior to salinities obtained under T_{1d-1d} and T_{50-50} with irrigation water salinity of 1g/l.

For a 48-hour cycle, the soil salinity did not exceed 2.13 g/l for T_{50-50} versus 2.52 g/l for T_{1d-1d} for the case of 3 g/l. For this salinity, an average soil profiles salinity of 2.61 g/l was measured for T_{50-50} versus 3.23 g/l for T_{1d-1d} for a 90-day cycle.

In the case of irrigation water with a salinity of 5 g/l, the soil salinity did not exceed 2.41 g/l for T_{50-50} versus 3.1 g/l for T_{1d-1d} for a 48-hour cycle when blended water is used. Even for a 90-day cycle, an average salinity of 3.03 g/l was measured for T_{50-50} versus 4.06 g/l for T_{1d-1d}.

The interval between the saline water and desalted water supply is an important factor in decreasing salinity in the soil. It's imperative to reduce the maximum possible the interval separating a first supply of salt water and a second supply of fresh water.

For treatments T_{50-50} and T_{1d-1d}, the values found in the field experiments and the values modelled by Hydrus 1-D are almost equal for a complete cycle of 90 days. Hydrus-1D can be considered as useful tool to predict soil profiles salinity.

In the case of moderately saline-sensitive crops such lettuce, irrigate with desalinated water is not recommended only when fresh water is lacking.

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