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# Effects of Sand Addition to Heavy Saline-Alkali Soil on the Infiltration and Salt Leaching in Hetao Irrigation District, China †

**Qingfeng Miao [1,*], Liying Zhou [1], José Manuel Gonçalves [2,3,*], Isabel Maria Duarte [2,4], Ruiping Li [1] and Haibin Shi [1]**

1 College of Water Conservancy and Civil Engineering, Inner Mongolia Agricultural University, Hohhot 010018, China; zly18447054211@163.com (L.Z.); nmglrp@163.com (R.L.); shb@imau.edu.cn (H.S.)
2 Instituto Politécnico de Coimbra, Escola Superior Agrária, 3045-601 Coimbra, Portugal; iduarte@esac.pt
3 LEAF—Linking Landscape, Environment, Agriculture and Food, Institute of Agronomy, University of Lisbon, 1349-017 Lisboa, Portugal
4 CERNAS—Research Centre for Natural Resources, Environment and Society, 3045-601 Coimbra, Portugal
* Correspondence: imaumqf@imau.edu.cn (Q.M.); jmmg@esac.pt (J.M.G.)
† Presented at the 1st International Electronic Conference on Agronomy, 3–17 May 2021; Available online: https://iecag2021.sciforum.net/.

**Abstract:** Soil salinity is a matter of great economic and environmental implications. In Hetao Irrigation District, soil salinity limits crop productivity affecting about 69% of its total cultivated land due to natural soil salinisation and salt accumulation caused by irrigation. The goal of this study is to contribute to the alleviation of this problem through the technique of adding wind-sand to the top layer of heavy saline-alkali soil, and to evaluate and analyse their effects on the infiltration and salt leaching. The experiment was carried out on a laboratory scale. Clayey soil with 21 g/kg of salts collected at the Ulat Front Banner site was used. Wind-sand was added to the top 30 cm layer of this soil. The infiltration tests were carried out in plastic columns with 9 cm diameter and 45 cm high, loaded with a soil and wind-sand mixture (from 2% to 30% ratio), supplied by a constant hydraulic head. Soil water samples were collected for 15 days for quantification of the soil salt leaching. A significant increase of the infiltration rate was observed in the first infiltration hour, rising from 1 to 9 mm/h, in response to the addition of 8% and 30% of sandy particles, respectively. The effects of wind-sand in salt leaching were relevant in the top 20 cm layer. After 7 days of infiltration there was a decrease in the salt content in soils with 4%, 8%, and 30% of sand particles added, of 35%, 55%, and 95%, respectively, in relation to the control. In conclusion, the practice of adding sandy particles to the topsoil is a soil melioration method that allows a positive impact on soil infiltration and salt leaching. An addition of 8% of sand seems to be a good choice, as it favours an increase in salt leaching of about 55% after 7 days. These results are encouraging and appeal to field studies to assess the impact on a field-scale system, and the effects of this soil melioration on irrigation, drainage, and agronomic aspects.

**Keywords:** soil infiltration; salt leaching; soil drainage; heavy saline-alkali soil; sand mixing; water–salt transport; Hetao Irrigation District



**Citation:** Miao, Q.; Zhou, L.; Gonçalves, J.M.; Duarte, I.M.; Li, R.; Shi, H. Effects of Sand Addition to Heavy Saline-Alkali Soil on the Infiltration and Salt Leaching in Hetao Irrigation District, China. *Biol. Life Sci. Forum* **2021**, *3*, 33. https://doi.org/10.3390/IECAG2021-10156

Academic Editor: Cornelia Rumpel

Published: 19 May 2021



## 1. Introduction

Salinity is a common problem in irrigated agriculture, causing the loss of fertile soil and consequently the reduction of land productivity. When the accumulated soil salinity exceeds the threshold of salt tolerance of a given crop, leaching is required to maintain the soil salinity below that limit to avoid yield losses. Efficient leaching requires a good soil permeability, an irrigation system that applies the water uniformly in the field, and an adequate soil drainage system [1]. There are several techniques to cope with this problem, particularly in arid and semi-arid regions.

Sand application to the root-zone of heavy soils is a technique known to reduce compaction, enhancing drainage and leaching of salts from the soil profile, due to increased infiltration, a consequence of increased effective porosity of soil and moisture conservation [2,3]. Several studies showed that the sand added to the soil surface benefits salt leaching [4,5] and enhances soil aggregate structure and water retention capacity [5–7]. This technique also reduces the evaporation of soil water and the accumulation of salt on the surface [2], therefore having the potential to increase water use and crop yield, particularly under severely saline-alkali conditions. Other studies using sand mixed with other materials, such as gypsum, isolite, and brick grit, have been published [2–4].

Hetao is in Inner Mongolia, China, in the upper reaches of the Yellow River, with an irrigation area of about 676,000 ha. About 69% of the total cultivated land area is severely affected by soil salinisation, seriously restricting the sustainable development of Hetao agriculture [8]. To cope with this problem, several measures to favour soil salt leaching have been implemented. Conventional measures, such as underground drainage and soil tillage improvement, favour the growing environment of crops [1]. Recently, other measures have been adopted in saline-alkali soil, such as mulching, aiming to control soil evaporation or the soil burial of straw or manure, to favour the melioration of soil ecological conditions [9]. Deep tillage is used to improve the physical and chemical properties of soil [10], thus favouring deep percolation. Salt leaching is also used, although the leaching time is much longer for the heavily saline-alkali soils. Precise land levelling is a usual practice for surface irrigation that also has a beneficial effect on surface drainage and effectiveness of soil salt leaching [11].

To deal with the increasing pressure for soil and water productivity in this region, easy-to-manage and cost-effective solutions to reduce the effects of soil salinity are needed. From this perspective, the objectives of this study were outlined, envisaging the extensive use of this technique. The main goals were to analyse and quantify the influence of sand particles incorporated into a heavy saline-alkali soil, namely on the soil infiltration rate and soil salt leaching over time.

## 2. Materials and Methods

The experiment was carried out in October 2019, in the Soil Laboratory of the Inner Mongolia Agricultural University, in Hohhot. It was conducted on a laboratory scale, using the one-dimensional vertical constant water head method.

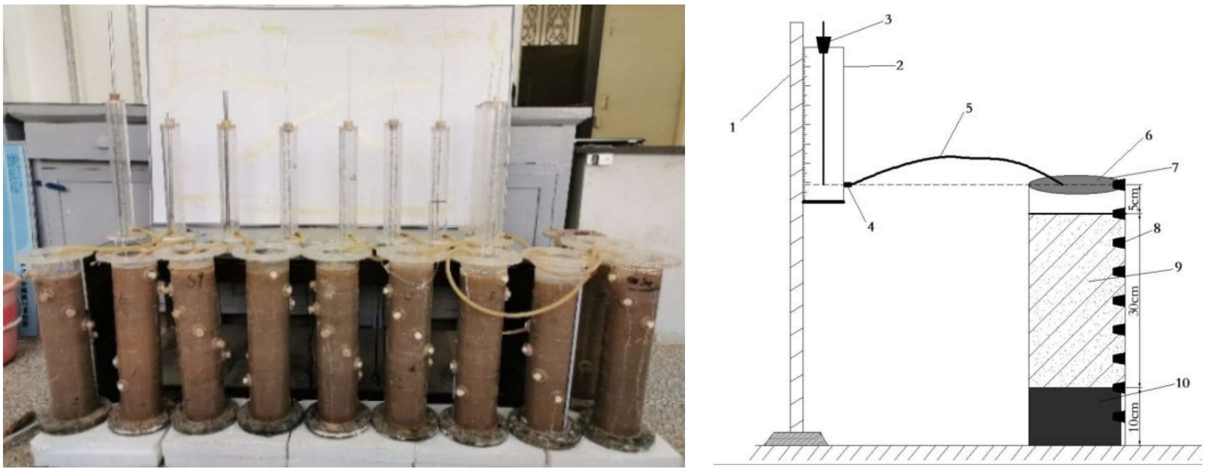
The soil used in the experiment was collected from the 0–40 cm soil layer in the Xishanzui Farm, Ulat Front Banner, upstream of Hetao (Longitude: E 108°37′; Latitude: N 40°45′; Altitude 1118 m), with the physical properties presented in Table 1. The wind-sand selected for this experiment had a volume composition of 96.7% of sand, 2.95% of silt, and 0.34% of clay, with a salt content of 1.89 g/kg.

**Table 1.** Physical characteristics of the soil used in the experiment.

| Soil Layer (cm) | Particle Composition (%) | | | Texture | Bulk Density ($g\cdot cm^{-3}$) | Field Capacity ($cm^3\cdot cm^{-3}$) | Saturation Capacity ($cm^3\cdot cm^{-3}$) | Salinity Content ($g\cdot kg^{-1}$) |
|---|---|---|---|---|---|---|---|---|
| | Sand | Silt | Clay | | | | | |
| 0–20 | 26.33 | 60.50 | 13.17 | silty loam | 1.51 | 0.24 | 38 | 23.60 |
| 20–40 | 32.32 | 45.39 | 22.29 | silty loam | 1.49 | 0.25 | 39 | 18.43 |

Data obtained in the Soil Laboratory of the Inner Mongolia Agricultural University, Hohhot.

The experimental treatments included different ratios (x, %) of wind-sand added to the original soil, identified by "Tx". Nine treatments were considered: T0, the null treatment with the original soil, and T4, T8, T12, T16, T20, T24, T28, and T30, with three repetitions each. The soil samples were mixed with wind-sand in the 0–30 cm top layer and the columns were loaded with these mixtures. The soil layer of 30–40 cm was not modified. The infiltration process was carried out in plastic columns (Figure 1), with an internal diameter of 9 cm, 45 cm height, and a porous bottom with filter paper to block the soil particles. These columns were equipped with eight sampling holes, spaced 5 cm apart, to allow the sampling of soil water during the experimental process, in order to determine the water and salt migration in the soil column. The soil column was covered with plastic film to prevent evaporation. Distilled water was added to the columns at a constant hydrostatic pressure of 5 cm for 15 days.




(**a**) (**b**)

**Figure 1.** View of the experimental device to assess the infiltration and salt leaching. (**a**) Photograph of the disposal of soil columns; (**b**) a column scheme. Legend: 1. bracket, 2. Marten site bottle, 3. level index, 4. valve, 5. hose, 6. plastic film, 7. column top, 8. sampling hole, 9. soil sample with added sand, 10. original soil.

Soil water samples were collected from the sampling holes of the soil column after 3, 7, 11, and 15 days. Their electrical conductivity (EC, dS/m) was measured at 25 °C and then the corresponding salt content (SC, g/kg) was calculated using Equation (1) [12,13]. This relationship between EC and SC was determined using linear regression from experimental data collected in Hetao, based on several sources, and commonly used in practice in this region [13].

$$SC = 3.471\ EC + 0.015 \quad (1)$$

## 3. Results

### *3.1. Effects of Added Sand on Soil Infiltration*

The results revealed that the wind-sand added to the soil had a significant effect on soil infiltration (Figure 2), with an increase in soil permeability in response to the growing amounts of sand. The cumulative infiltration relative to T0, for example, after 60 min of infiltration time, was 2, 4, 9, 26 mm higher for treatments T4, T8, T16, and T30, respectively. After 300 min of infiltration time, this increase was 4, 6, 14, and 47 mm.

The variation of the infiltration rate over time (Table 2) showed a direct effect of the amount of the added sand, particularly during the first 60 min. The differences become negligible at 300 min of infiltration time, from T4 to T16. These dynamics of soil infiltration rate over infiltration time revealed that at 30 min from the beginning of infiltration the treatments T8, T16, and T30 have a higher infiltration rate than T0 (with a relative rate increase of 13%, 33%, and 100%, respectively). Considering an infiltration time of 60 min, these increases were 9%, 18%, and 82%, respectively. In turn, at 300 min, T8 and T16 were equal to T0, and T30 was 60% higher than T0. These results allowed to conclude that the major effect of added sand occurs during the first time phase of the infiltration process. This information should be taken into consideration for irrigation scheduling plans, where more frequent irrigation events could explore a higher cumulative seasonal infiltration.

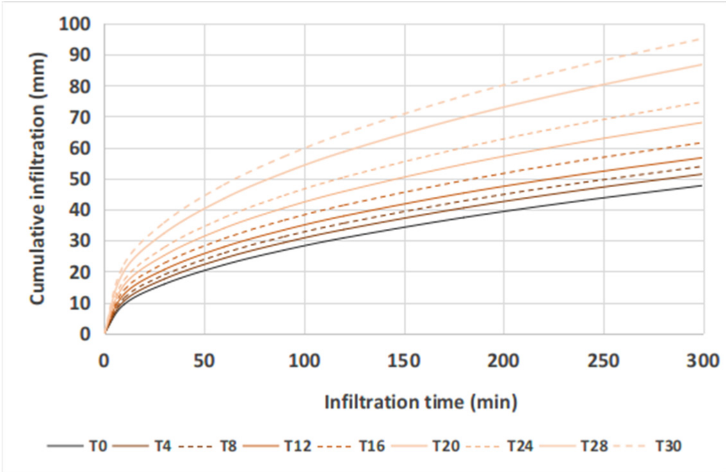



**Figure 2.** Cumulative infiltration curves, per treatment. Treatment, Tx, where "x" represents the percentage of wind-sand added to the soil.

**Table 2.** Infiltration rates (mm/h) over time, per treatment.

| Time (min) | T0 | T4 | T8 | T12 | T16 | T20 | T24 | T28 | T30 |
|---|---|---|---|---|---|---|---|---|---|
| 10 | 27 | 29 | 31 | 33 | 37 | 41 | 45 | 52 | 57 |
| 30 | 15 | 16 | 17 | 18 | 20 | 22 | 24 | 28 | 30 |
| 60 | 11 | 11 | 12 | 12 | 13 | 15 | 16 | 19 | 20 |
| 180 | 6 | 6 | 6 | 7 | 7 | 8 | 9 | 10 | 11 |
| 300 | 5 | 5 | 5 | 5 | 5 | 6 | 6 | 7 | 8 |

Treatment, Tx, where "x" represents the percentage of wind-sand added to the soil.

## *3.2. Effects of Added Sand on Salt Leaching*

The results of the soil salt leaching (Figure 3) revealed that the process of downward salt migration occurred particularly during the first 3–7 days, and the temporary accumulation of salts in the deeper layers. This draws attention to the sensitivity of the irrigation leaching process that should be intensive enough to allow most of the leaching below the soil root zone. Treatments T16 and T30 showed a higher efficiency of salt leaching below the 30 cm soil depth than the other treatments (Figure 3).

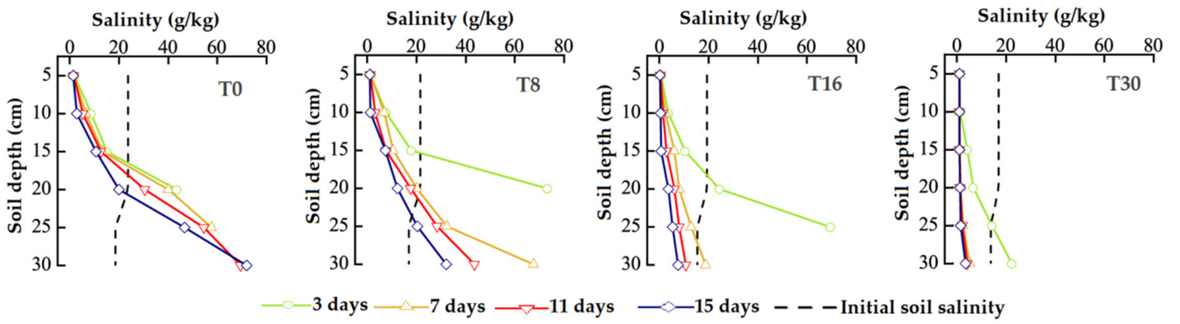



**Figure 3.** Dynamic distribution of soil water salinity content, during 15 days of leaching, of T0, T8, T16, and T30 treatments. Treatment, Tx, where "x" represents the percentage of wind-sand added to the soil.

For the 20 cm top layer of soil, after 15 days of leaching (Figure 4), the salt content was reduced in all treatments, and those reduction rates were variable over time. For treatments T12–30 this rate was higher during the first 3 days, while in the other treatments the leaching rate was almost uniform over time. On the other hand, the initial salt content, compared with T0, was reduced due to the direct effect of the mixing with sand with a very low salt content.

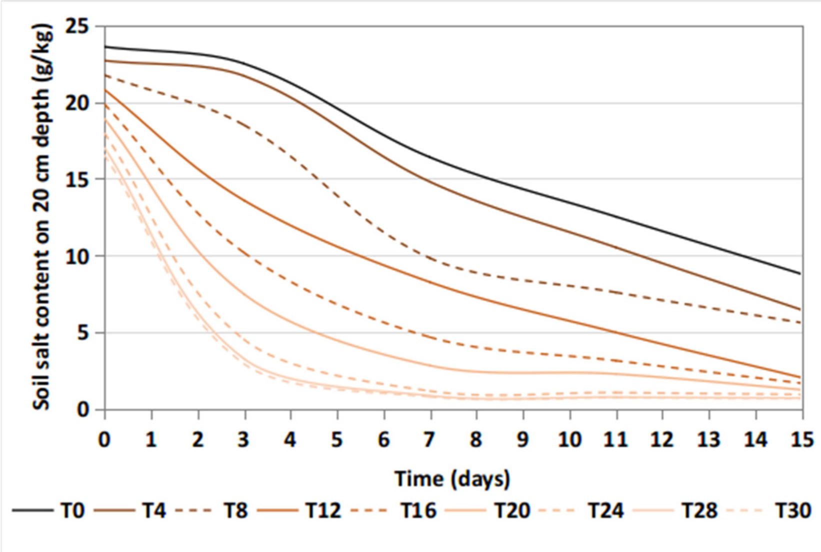



**Figure 4.** Soil salt content of the top 20 cm layer per treatment during leaching time. Treatment, Tx, where "x" represents the percentage of wind-sand added to the soil.

Three indicators were used to assess the relative effects of added wind-sand on the infiltration and salt leaching, compared with T0, on the rate and cumulative infiltration after 5 h, and the salt leaching of the 20 cm top layer for 7 days (Figure 5). These indicators are sensitive and have a direct relationship with the amount of sand added to the soil. Focusing on the effect of salt leaching, as the main target of this soil amelioration process, it showed that, even in the lower intensive treatments, T4, T8, and T12, it implied significant salt leaching increases of 35%, 55%, and 60%, respectively.

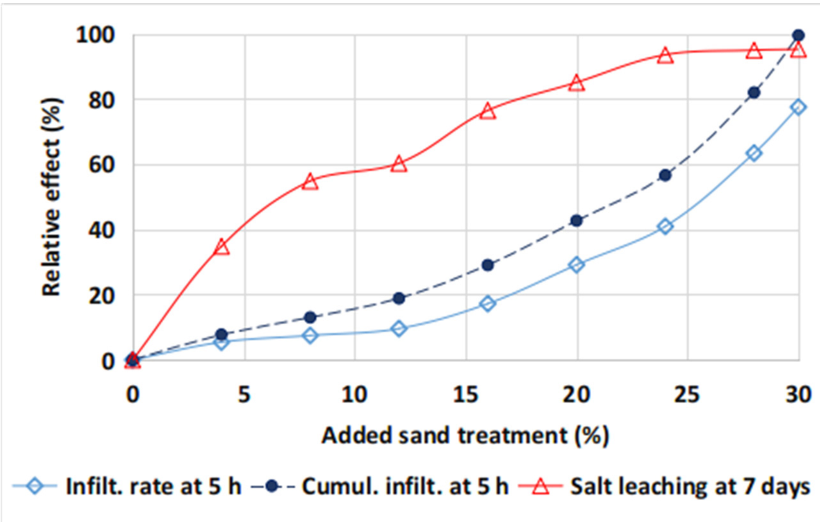



**Figure 5.** Relative effects of added sand on the infiltration rate, cumulative infiltration at five hours, and salt leaching at seven days.

## 4. Discussion and Conclusions

Soil salinity in Hetao Irrigation District has major economic and environmental implications, which is threatening agricultural sustainability. The complexity of dealing with soil salinity is due to the spatial variability of soil characteristics, the relative effectiveness, and sometimes high costs, of the accomplishable solutions. The control of problems in saline alkali soils requires comprehensive hydraulic and agricultural measures, namely the improvement of underground drainage and the adoption of cultivation and techniques to increase soil organic matter content, which alleviates the salinity problem in terms of availability of water for crops and its toxicity effects. The authors' empirical knowledge, based on experiences of local farmers who applied this technique (unpublished data), leads to the conclusion that the sand addition is a specific measure with potential to be applied to relatively limited areas, and especially dedicated to growth of high-yield and horticultural crops.

The effects of this technique on salt leaching have been studied little and are not well known, the published studies having analysed various aspects such as cotton yield, turf grass growth [4], infiltration and evaporation [7], micro-ecological factors [5], and the influence greenhouse gas fluxes [14].

With the aim to contribute to a feasible solution to this problem, this exploratory study investigated the technique of adding wind-sand to the soil top layer. The results obtained appear to be promising, as the addition of wind-sand promoted a significant increasing effect on the infiltration rate (Table 2), especially in the first hour, being, however, incipient from the third or fifth hour onward. The infiltration rate at 1 h is 9%, 18%, and 82% higher for treatments T8, T16, and T30, compared with T0. At 5 h, the rate is equal for T0, T8, and T16, and 30% more for T30. The increase in the soil infiltration characteristics has implications on the irrigation performance, especially for surface systems, also related to the land slope and the size of the plots [15].

To be effective, salt leaching should guarantee the transport of salts to layers of soil deeper than the root absorption zone, e.g., below 60 cm in maize. This problem of salt migration calls attention to the question of assessing the amount of water to be infiltrated, providing, if necessary, an adequate leaching fraction, depending on the local soil salinisation. This issue is correlated with the soil drainage conditions, namely the control of the groundwater level through the subsurface drainage system [16]. The analysis of the effects of added wind-sand treatments on infiltration and salt leaching (Figure 5) leads to the conclusion, in a first approximation, that the T8 treatment (add 8% of sand on top 30 cm) is sufficient, as it favours an increase in leaching of 50%.

The technique of wind-sand addition to heavy saline-alkali soil showed to have a significant potential to improve soil salt leaching by increasing the infiltration rate. The practical implementation of this technique requires a deeper analysis, considering the effects of the following factors at field scale: the sand application cost, the subsurface drainage effectiveness, the management of irrigation leaching fraction, and the impact on the crop yield. The initial expectation is that the use of this technique will be limited to heavier soils and to higher yielding crops, so that the investment in the application of sand and in the improvement of drainage can have an appropriate financial benefit. Although promising, this analysis requires further experimentation in field conditions, to assess impacts on crop productivity and efficiency of soil salinity control. This further experimentation should be followed by the analysis of subsequent problems of salt discharge, accompanied by nutrient loss which, in turn, might lead to environmental problems.

As a final conclusive note, encouraged by the results obtained, further studies on field trials are recommended for treatments T4, T8, and T12, as well as the assessment of their productivity, field-scale drainage system effects, agronomical aspects of soil melioration, and economical impact.

**Supplementary Materials:** The poster presentation can be downloaded at: https://www.mdpi.com/article/10.3390/IECAG2021-10156/s1.

**Author Contributions:** Conceptualisation, H.S., Q.M., J.M.G.; methodology, L.Z., Q.M., R.L.; data analysis, Q.M., R.L., J.M.G., I.M.D.; writing—original draft preparation, L.Z., R.L., Q.M., J.M.G.; writing—review and editing, Q.M., I.M.D. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research was funded by National Natural Science Foundation, grant number 52009056, 51839006, 51539005; Inner Mongolia Natural Science Foundation grant number 2019BS05015, and projects of Inner Mongolia Agricultural University, grant number NDSC2018-11; 2017XQG-4, NDYB2016-23.

**Institutional Review Board Statement:** Not applicable.

**Informed Consent Statement:** Not applicable.

**Data Availability Statement:** Not applicable.

**Conflicts of Interest:** The authors declare no conflict of interest.

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