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If Sand Interlayer Acts Better than Straw Interlayer for Saline Soil Amelioration? A Three-Year Field Experiment

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Abstract: An addition of straw interlayer in the 0.40 m soil depth could effectively reduce salt accumulation in the surface soils by regulating water fluxes, thus mitigating the salt stress to the crop growth and development. However, the positive effects of straw interlayer were weakened with straw decomposition, and whether we could use sand (an indecomposable substance) instead of straw for saline soil amelioration still needs further investigation. Therefore, a three-year field experiment was established with straw and sand interlayers, as well as with no interlayer as a control. Straw interlayer demonstrated an increase of 4.85~13.10% of water content, while the sand interlayer increased 12.41~16.48% of water content in the soil layer of 0–0.40 m depth comparing to the control. Salt contents were lowered by 10.69~17.01% in the same soil layer of the straw interlayer and lowered by 7.00~7.59% in the sand interlayer treatment after irrigation. Data also shows that irrigation significantly increased water content and lowered salt accumulation in the soil plough layer, thus increasing the sunflower emergence rate of 10.49~13.54% in the straw interlayer treatment and 12.53~14.78% in the sand interlayer treatment, respectively. Both the straw interlayer and sand interlayer treatments effectively reduced the evaporation of groundwater and established a beneficial plough layer with a lower salt accumulation throughout the sunflower growth period. At harvesting stage, the evaporation fluxes of salt in the straw interlayer and sand interlayer treatments were significantly lower than that in the control treatment. Lower salt accumulation conferred a beneficial promotion for the growth of sunflower, while the grain yields in the straw interlayer treatment were increased by 8.67% in 2018, 11.00% in 2019 and 17.37% in 2020 compared to the no-interlayer soil, respectively. However, the low water content in the soil layer of 0–0.40 m depth in the sand interlayer treatment inhibited the growth of sunflower, resulting in a significant decrease in the seed yields. It is worth noting that the precipitation effectively alleviated water stress on the sunflower at the middle and late growth stage in the sand interlayer treatment. This study suggests that a maize straw burial of 0.05 m thickness at a depth of 0.40 m soil layer could be used as an effective tillage practice that could improve the distribution of water and salt in saline soils.

Keywords: saline soils; straw interlayer; sand interlayer; soil water content; soil salinity

Citation: Liu, N.; Feng, W.; Zhang, H.; Chang, F.; Wang, J.; Li, Y.; Pang, H. If Sand Interlayer Acts Better than Straw Interlayer for Saline Soil Amelioration? A Three-Year Field Experiment. *Sustainability* **2023**, *15*, 4931. https://doi.org/10.3390/su15064931

Academic Editor: Luciano Cavani

Received: 20 January 2023
Revised: 7 March 2023
Accepted: 7 March 2023
Published: 10 March 2023

1. Introduction

Soil salinization has been an abiotic stressful factor limiting plant growth and development in agricultural production systems [1], and a large portion of saline soils are not fully utilized because of excessive salt accumulation on the soil surface [2]. Particularly, special geographical and climatic characteristics in regions with soil salinization frequently lead to an occurrence of salinization in the arable lands, thereby accumulating more salt on the soil surface and greatly affecting the plant emergence rates and growth. For example, as an important base producing grain and oil in China, the Hetao plains of the Inner Mongolia region have been playing a positive regulatory role in supplying food and oil. However, soil salinization seriously restricts the agricultural sustainable development in this region.

For alleviating the salt stress to the crops, more farmers have been attempting to drain out excessive salt in the soil by flooding irrigation in the local area, but flooding irrigation usually rises the groundwater level, thus resulting in a shortage of available water resources; therefore, flooding irrigation practices cannot be widely applied [3]. Statistics show that the irrigation area under saline–alkali cultivated land is about 394,000 ha, accounting for 68.65% of the total cultivated area [4]. Therefore, both reasonable irrigation and drainage are of great importance for reducing the water evaporation and the salt accumulation in soil, thereby establishing a healthy crop growth environment [5,6].

A layered structure is a very typical soil characteristic in natural soils; the transport of water and salt in layered soil is completely different from that in homogeneous soil [7]. A study showed that layered soil demonstrated an obvious difference in the pore structure, suction and conductivity of water at the layered interface compared to homogeneous soil [8]. Usually, the capillary barrier at the interface decreases the permeability of water, thus increasing the holding capacity of water in the upper soil [9]. As reported previously, the layered structure of soil increases the level of the capillary water in soil, while the capillary water enters into the clayey soil layer in sandy soil [10]. Li et al. (2004) reported that the clay interlayer in light loam soil could significantly raise the transport speed of capillary water compared to light loam soil without an interlayer [11]. These studies suggest that a layered structure could alter the movement profile of water and solute potentials in soil.

Burying an interlayer has been confirmed to demonstrate a positive effect on the water and salt management in soil, but the movement profiles of water and salt in soil are affected by the material and thickness of the interlayer, as well as burying location. For example, a sand interlayer changes the water infiltration, while water holding capacity in the upper soil would be increased by the sand interlayer with a certain thickness; an increasing interlayer depth increased the infiltration rate at an early stage and then demonstrated a decrease in the infiltration rate [12]. The interlayer mainly inhibits the evaporation of soil water, and the maximum inhibition rate of water evaporation was more than 70% when soil was added by burying a sand interlayer at a depth of 0.35–0.40 m [13]. As an important organic fertilizer from the harvesting residues, crop straw not only improves the physical-chemical properties of soil, but also regulates the movement of soil water and salt in soil. A previous study indicated that burying the crop straw as a layer at a depth of 0.20 m in soil could retard the water infiltration, thus restraining the evaporation of water in the deep layer of soil and improving water use efficiency as well as soil fertility [14]. Burying plastic mulch with straw in the soil layer at a depth of 0.40 m reduced salt contents in the 0–0.40 m soil plough layer and lowered the accumulation of salt in the environmental soil throughout the sunflower growth period [15]. Another report showed that burying the straw with a thickness of 0.07 m obviously relieved salt stress damage because the leaching flux of the salt was significantly increased; burying the straw with a thickness of 0.07 m demonstrated an increase of 105% in leaching fluxes of salt compared to when burying a thickness of 0.03 m, and the increase in salt leaching fluxes was 84% compared to when burying a thickness of 0.05 m [5].

Although either sand or straw interlayer plays a regulatory role in promoting salt leakage and inhibiting water evaporation in soil, most studies are mainly focused on the transport profiles of water and salt of the same interlayer-mediated material [5,16,17]. There are few studies that investigate the effects of an inorganic material (sand) interlayer, and whether organic and inorganic barriers have different effects on the transport of water and salt under soil saline stress remains unknown. We hypothesized that the decomposition of organic straw materials and the stability of inorganic sand possibly confer a different regulatory role in controlling the water and salt in soil salinization, particularly in the sustainability and controlling of salt and water. In order to test the hypotheses, a field-comparable experiment lasting three years was performed by using maize straw and sand materials. The objectives of this study were to (i) evaluate the effects of straw and sand on controlling the transport of water and salt under the same soil salinization environment and (ii) to provide a sand interlayer reference in selecting the optimum interlayer material in soils with high salinization.

2. Materials and Methods

2.1. Experimental Site

Experimental site was located in Wuyuan county of Inner Mongolia belonging to the hinterland of Eurasia, a typical continental arid-climate region (108°18′ E, 41°02′ N). The mean annual temperature is 8.1 °C and the effective accumulative temperature of more than 10 °C surpasses 3360 °C. Annual precipitation is mainly concentrated in summer and autumn, and the precipitation between June and September was 152.4 mm in 2018, 57.0 mm in 2019, and 173.2 mm in 2020, respectively (Figure 1). The average evaporation of water reaches 11 times that of the annual precipitation. A three-year field experiment was conducted from 2018 to 2020. The local soil is sandy, silty loam with a mean salt content of 4 g kg^{-1}, classified under Argosols (FAO classification). Basic soil properties from the soil layer of 0–0.60 m are shown in Table 1. The SOC and TN were analyzed by the $K_2Cr_2O_7$ oxidation–reduction titration and the semi-micro Kjeldahl methods, respectively [18]. Alkali hydrolyzale nitrogen was obtained by the alkaline hydrolysis diffusion method. Available phosphorus was extracted with 0.5 mol L^{-1} $NaHCO_3$ and analyzed by the Mo-Sb colorimetric method with a spectrophotometer (UV2550, Shimadzu, Japan). Available potassium content in the soil was determined by CH_3COONH_4 extraction method and measured with a flame photometer (M-410; Cole-Parmer, Chicago, IL, USA). The soil pH was determined at a soil: water ratio of 1:5 with a pH meter (FE20, Mettler-Toledo, OH, USA).

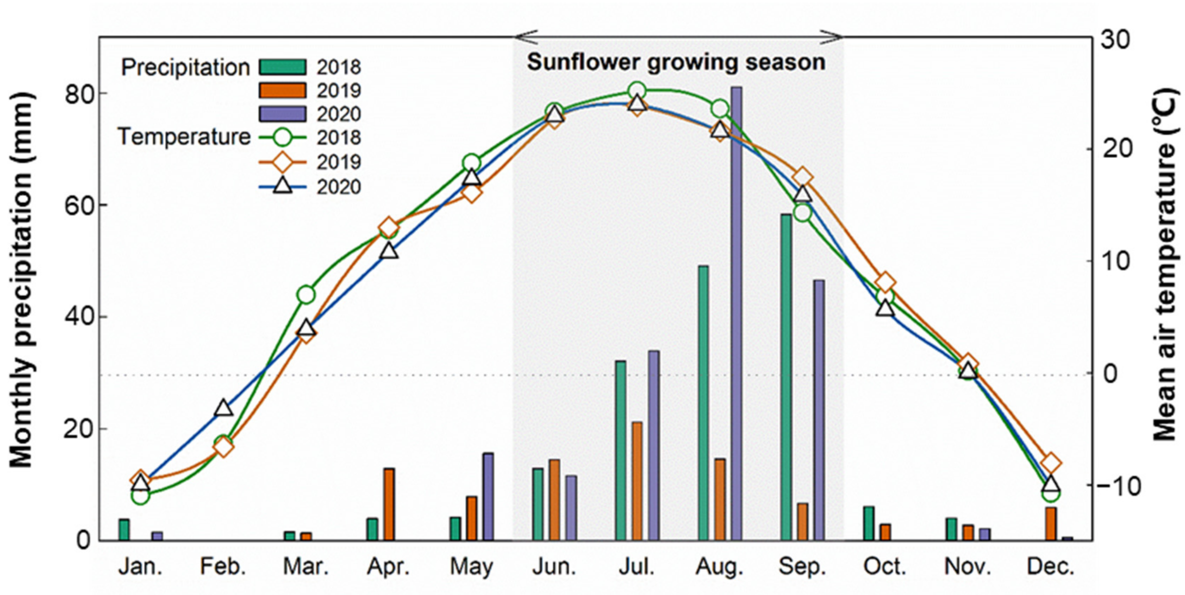

Figure 1. Monthly precipitation (vertical bars) and mean air temperature (solid curve) in the three experimental years. The dotted lines were shown as 0 °C.

Table 1. Soil basic properties before the experiment in the 0–0.60 m soil depth.

Soil Depth (m)	BD (g cm^{-3})	SOC (g kg^{-1})	TN (g kg^{-1})	AN (mg kg^{-1})	AP (mg kg^{-1})	AK (mg kg^{-1})	TS (g kg^{-1})	pH
0–0.20	1.45	6.50	0.88	35.50	6.25	168.17	6.78	8.68
0.20–0.40	1.50	5.20	0.71	33.25	4.40	126.83	4.59	8.36
0.40–0.60	1.48	3.31	0.56	29.5	3.04	109.24	3.23	8.32

Note: BD, bulk density; SOC, soil organic carbon; TN, total nitrogen; AN, alkaline hydrolyzed nitrogen; AP, available phosphorus, AK, available potassium; TS, total salt.

2.2. Experimental Design

The experiment was composed of three treatments: no interlayer treatment (no interlayer), burial of a 0.05 m thick interlayer of maize straw at a depth of 0.40 m (straw interlayer), and burial of a 0.05 m thick layer of sand at a depth of 0.40 m (sand interlayer). In brief, the upper soil of the 0–0.40 m profile was removed and divided by the 0–0.20 m soil layer and the 0.20–0.40 m soil layer using a spade. Then, the maize straw or sand was uniformly placed in the vacant position, and the dug soil was in turn correspondingly refilled into the 0.20 m and 0.40 m soil layers (Figure 2). The experiment was designed by an arrangement of a randomized block with 3 replicates, and the plot area of each treatment was 12 m^2 (3 × 4 m). Water management was performed by local traditional irrigation practice, and the soil was flood-irrigated from Yellow River (salt concentration 0.58 g L^{-1}) at approximately 2250 m^3 ha^{-1} in October and in May every year, respectively. Fertilizer was applied at 133.2 kg ha^{-1} N (urea, 46%), 133.2 kg ha^{-1} P_2O_5 (diammonium phosphate, 18% N and 46% P_2O_5) and 110.4 kg ha^{-1} K (potassium sulphate, 50% K_2O). Seeds were sown at a density of 35,000 plants of per hectare on 6 June, and sunflower was harvested on 23 September manually. Field management was consistent with local traditional practices such as plastic mulching, weeding and spraying insecticides throughout the entire experiment.

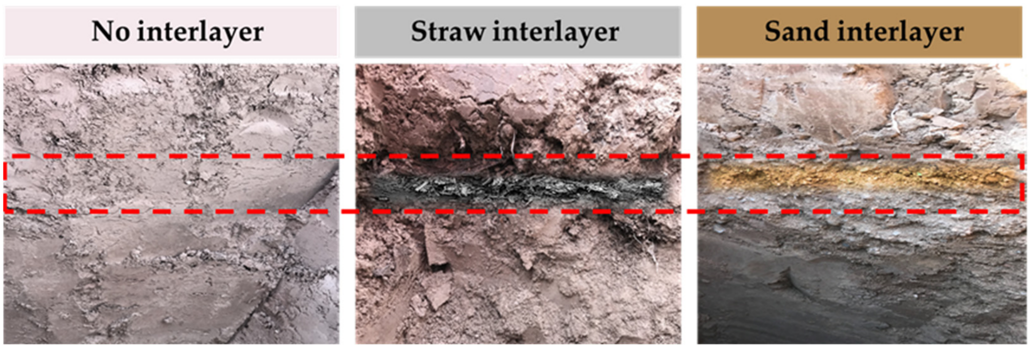

Figure 2. A Schematic diagram of experimental design pattern.

2.3. Sampling and Measurement

Soil samples from the layers corresponding to 0–0.10, 0.10–0.20, 0.20–0.30, 0.30–0.40, 0.40–0.60, 0.60–0.80 and 0.80–1.00 m depths were separately collected before spring irrigation, after irrigation and at harvest stage. Sampling sites were located at the center of two sunflower rows in each plot. After sampling, the sampled empty hole was refilled by using the same texture soil to minimize the effects of sampling on water and salt measurements. All soil samples were immediately oven-dried at 105 °C for 24 h and used for determining the soil water content. The dried soil samples were sieved through a 2 mm mesh and used for the determination of salt contents. Soil salinity was measured from the electrical conductivity of the 1:5 soil water extract. The electrical conductivity of the extract was measured using a DDS-307 conductivity meter (Shanghai TecFront Electronics Co., Ltd., Shanghai, China). Salt content was then inferred from measured electrical conductivity values on a percent basis according to Pang et al. (2010) [19].

The emergence rates of the sunflowers were determined by the seedling number in each plot. All sunflowers' heads were manually harvested and threshed, and fresh seeds were naturally dried under sunlight for 7~10 days and weighed for the determination of the grain yields. Because of travel limitation from COVID-19, partial soil samples were not collected before irrigation, and the emergence rates of the sunflowers were absent for 2020.

2.4. Calculations

Soil salt content was calculated according to a previous method, as shown in Equation (1):

$$y = 3.0111x \tag{1}$$

where y represents the soil salt content (g kg^{-1}) and x indicates the electrical conductivity in the soil extracts (mS cm^{-1}) [19].

Soil desalinization ratio was calculated by Equation (2):

$$S_{DR} = \frac{S_B - S_A}{S_B} \times 100\% \tag{2}$$

where S_{DR} is the soil desalinization ratio (%), S_B indicates the soil salt content before spring irrigation (g kg^{-1}), and S_A represents the soil salt content after spring irrigation (g kg^{-1}) [5].

Soil back salting ratio was calculated by Equation (3):

$$S_{RR} = \frac{S_H - S_A}{S_A} \times 100\% \tag{3}$$

where SRR indicates the soil back salting ratio (%), SH is the soil salt content after harvest (g kg^{-1}), and SA represents the soil salt content after spring irrigation (g kg^{-1}) [20].

Stratification ratio of salt was calculated by Equation (4):

$$SR = \frac{S_{0\text{–}0.40\text{m}}}{S_{0.40\text{–}1.00\text{m}}} \tag{4}$$

where SR is the stratification ratio of salt, while S0–0.40 m indicates the salt content in the soil layer at 0–0.40 m depth (g kg^{-1}), and S0.40–1.00 m represents the salt content in the soil layer at 0.40–1.00 m depth (g kg^{-1}) [5].

Soil salt storage was calculated by Equation (5):

$$SS = A \times D \times H \times y \times 10^{-3} \tag{5}$$

where SS represents the soil salt storage (g), A is the area of the plot (cm2), D indicates the soil bulk density (g cm^{-3}), H is the soil layer thickness (m), and y indicates the soil salt content of the soil layer (g kg^{-1}) [5].

The leaching flux of salt in the soil layer at 0–0.40 m was calculated by Equation (6):

$$FL = \frac{SSB - SSA}{A \times \Delta t} \tag{6}$$

where FL means the leaching flux of salt in the soil layer at 0–0.40 m (g m^{-2} d^{-1}), SSB is the soil salt storage before spring irrigation (g), SSA indicates the soil salt content storage after spring irrigation (g), A represents the plot area (m^2), and Δt indicates the interval days between pre-irrigation and post-irrigation (days) [5].

Evaporation flux of salt in the soil layer at 0–0.40 m was calculated by Equation (7):

$$FE = \frac{SSH - SSA}{A \times \Delta t} \tag{7}$$

where FE indicates the salt evaporation flux in the soil layer at 0–40 cm (g m^{-2} d^{-1}), SSH is the soil salt content storage after harvest (g), SSA represents the soil salt content storage after spring irrigation (g), A means the plot area (m^2), and Δt means the experienced days from the end of spring irrigation to the harvest (days) [5].

2.5. Data Analysis

All datasets were tested for normality and homogeneity before analysis. A nonparametric test (Kruskal–Wallis) was used when either data normality (Shapiro–Wilk test), symmetry (coefficient of symmetry between −1.96 and 1.96) or the equality of error variances (Levene's test) were not confirmed in each dataset. A two-way ANOVA was performed for measured parameters that considered the year and interlayer treatments in combination with Fisher's least significant difference (LSD) test at a significance level of $p < 0.05$. The data were analyzed using Excel 2016 and SPASS 21.0 software (IBM SPASS Software Inc., Armonk, NY, USA). The figures representing the soil water content and salt content in the soil layer profile of 0–1.00 m were presented using Sigmaplot 14.0 software (Systat Software Inc., San Jose, CA, USA).

3. Results

3.1. Both Sand Interlayer and Straw Interlayer Beneficially Altered the Distribution of Soil Water

The data shows that both the sand interlayer and straw interlayer treatments significantly increased the water content in the soil layer at either the 0–0.10 m, 0.10–0.20 m or 0.20–0.30 m depth after irrigation compared to the no-interlayer treatment in both 2018 and 2019 ($p < 0.05$) (Figure 3). Compared with no interlayer, the average water content in the soil layer at 0–0.40 m in the straw interlayer treatment increased by 9.87% in 2018, 4.85% in 2019, and 13.10% in 2020, and was increased in the sand interlayer treatment by 14.23% in 2018, 12.41% in 2019, and 16.78% in 2020 after irrigation, respectively ($p < 0.05$). However, the average water content in the soil layer at 0.40–1.00 m from the no-interlayer soil was significantly higher than that from the straw interlayer and sand interlayer treatments after irrigation throughout the experiment period. At the harvesting stage, the water storage in the soil layer at 0–0.40 m in the no-interlayer soil increased by 13.70% in 2018, 27.35% in 2019 and 7.29% in 2020 compared to the straw interlayer treatment, respectively, while compared to the sand interlayer, the water storage in the soil layer at 0–0.40 m in the no-interlayer soil was increased by 20.63% in 2018, 60.15% in 2019 and 27.01% in 2020, respectively ($p < 0.05$). However, for the water content in the soil layer at the 0.40–1.00 m depth, the straw interlayer treatment demonstrated the highest value in 2018 and 2019 at the harvesting stage.

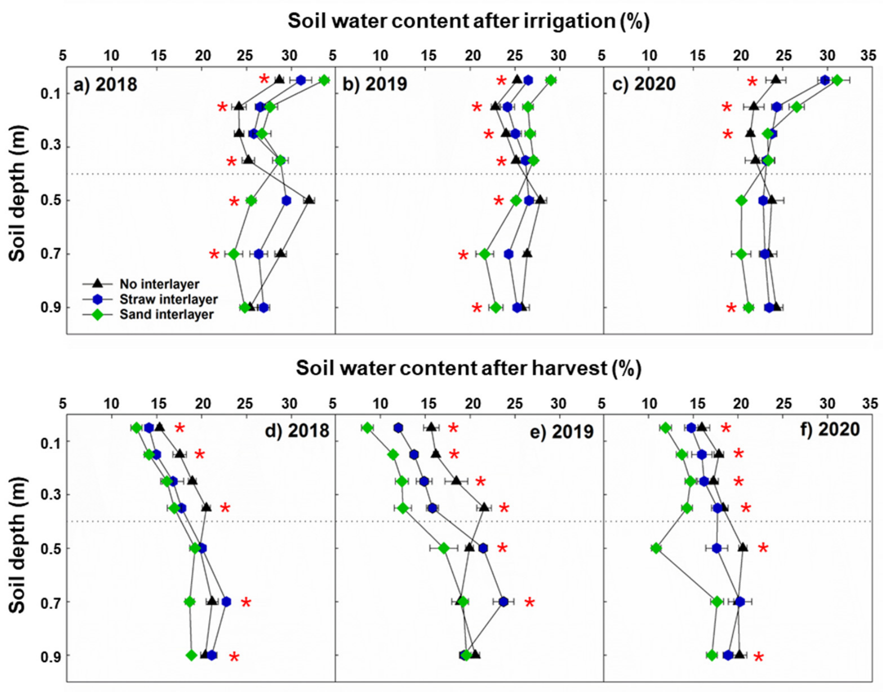

Figure 3. Soil water content in the 1.00 m soil depth before sowing (**a**–**c**) and after harvest (**d**–**f**) under no interlayer, straw interlayer, and sand interlayer from 2018 to 2020. Note: one irrigation was applied for salt leaching before sowing and no irrigation during sunflower growing season. Values are means ± standard errors (n = 3). * $p < 0.05$.

3.2. Straw Interlayer Effectively Lowered the Accumulation of Salt in Upper Soil Layers of Soil

To confirm whether the interlayer affected the salt distribution, the accumulation of salt was measured throughout the soil profile after irrigation and harvesting. The data show that the no-interlayer soil demonstrated the highest salt content in the soil layer at 0–1.00 m depth ($p < 0.05$) (Figure 4). Measurements show that the salt content in the soil layer at 0–0.60 m depth with the straw interlayer treatment was significantly decreased in 2018, lowered in the soil layer at 0–0.40 m depth in 2019, and decreased in the soil layer at 0–0.10 m depth in 2020 compared to the no-interlayer treatment, respectively ($p < 0.05$). Compared with the no-interlayer soil, the average salt content in the soil layer at 0–0.40 m depth in the straw interlayer treatment decreased by 17.01% in 2018, 15.49% in 2019 and 10.69% in 2020, and lowered in the sand interlayer treatment by 7.10% in 2018, 7.00% in 2019 and 7.59% in 2020 after irrigation, respectively ($p < 0.05$). At the harvesting stage, the average salt content in the soil layer at 0–0.40 m depth in the no-interlayer soil increased by 27.93% in 2018, 21.56% in 2019 and 29.02% in 2020 compared to the straw interlayer treatment, and lowered by 19.48% in 2018, 17.76% in 2019 and 18.58% in 2020 compared to the sand interlayer treatment, respectively ($p < 0.05$).

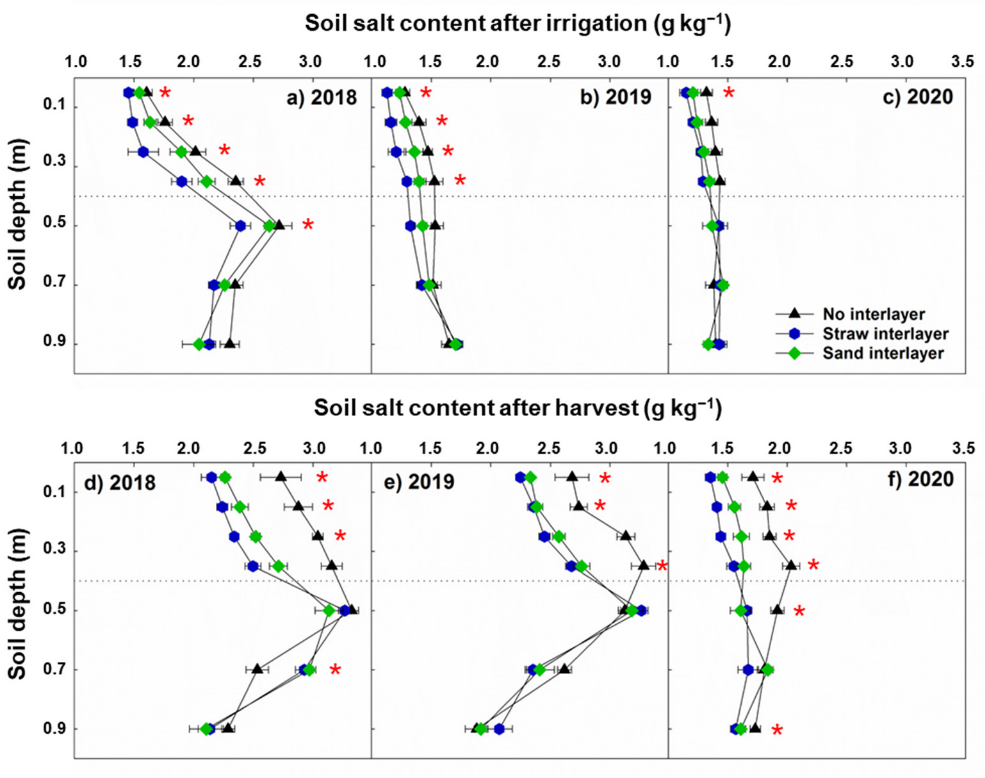

Figure 4. Soil salt content in the 1.00 m soil depth before sowing (**a**–**c**) and after harvest (**d**–**f**) under no interlayer, straw interlayer, and sand interlayer in the three years. Note: one irrigation was applied for salt leaching before sowing and no irrigation during sunflower growing season. Values are means ± standard errors (n = 3). * $p < 0.05$.

The S_{DR} in the 0–0.40 m soil depth showed great variation in different years (Table S1). The straw interlayer significantly increased the soil desalinization ratio (S_{DR}) in the soil layer at 0–0.40 m depth compared to the no-interlayer soil and sand interlayer in 2018 ($p < 0.05$), but no significant difference in the S_{DR} was observed between the treatments in 2019 ($p < 0.05$, Table 2). The data shows that the no-interlayer soil had the highest soil back salting ratio (S_{RR}) throughout the experiment. In particular, the S_{RR} with the sand interlayer treatment reached the lowest value in both 2018 and 2019, while the S_{RR} with the straw interlayer treatment was significantly lower than that in the no-interlayer soil in 2020 ($p < 0.05$).

Table 2. Soil desalinization ratio after irrigation (S_{DR}) and re-salinization ratio after harvest (S_{RR}) in the 0–0.40 m soil depth under no interlayer, straw interlayer, and sand interlayer treatments.

Index	Year	Interlayer		
		No	Straw	Sand
S_{DR} (%)	2018	65.56 ± 0.61 [b]	71.41 ± 0.82 [a]	68.00 ± 1.03 [b]
	2019	66.39 ± 1.11 [a]	64.63 ± 1.13 [a]	64.16 ± 0.97 [a]
	2020	—	—	—
S_{RR} (%)	2018	52.62 ± 2.57 [a]	43.91 ± 2.18 [b]	37.68 ± 2.42 [b]
	2019	108.71 ± 7.69 [a]	103.13 ± 5.05 [a]	90.61 ± 6.27 [a]
	2020	35.04 ± 6.12 [a]	16.88 ± 1.16 [b]	23.01 ± 2.46 [ab]

Note: No, no interlayer; Straw, straw burial layer at 0.40 m depth; Sand, sand burial layer at 0.40 m depth. All data were presented by means ± standard errors (n = 3), and different lowercase letters within a row of the same year indicate significant difference at $p < 0.05$.

3.3. Straw Interlayer Treatment Showed the Best Stratification Ratio of Salt in Soil

The stratification ratio of the salt content before irrigation, after irrigation and after harvesting were all influenced by the interlayer treatments (Table S1). Three treatments had no significant differences in the stratification ratio (SR) of the salt content in the soil layer at 0–0.40 m and 0.40–1.00 m without irrigation in 2018, as shown in Table 3 ($p < 0.05$), although the straw interlayer revealed the lowest SR. Meanwhile, the SR of the soil salt content in either straw interlayer or sand interlayer treatment was lower than that in the no-interlayer treatment before irrigation in 2019 ($p < 0.05$). However, the SR of the soil salt content in the straw interlayer treatment was significantly lower than that in the no-interlayer soil after irrigation in 2020 ($p < 0.05$). At the harvesting stage, the SR of the soil salt content in the no-interlayer soil was significantly increased compared to the straw interlayer and sand interlayer ($p < 0.05$).

Table 3. Stratification ratio (SR) of salt content in the soil layer at 0–0.40 m and 0.40–1.00 m under no interlayer, straw interlayer and sand interlayer treatments from 2018 to 2020.

Time	Year	Stratification Ratio (%)		
		No	Straw	Sand
Before irrigation	2018	1.31 ± 0.007 [a]	1.31 ± 0.007 [a]	1.31 ± 0.007 [a]
	2019	1.60 ± 0.051 [a]	1.23 ± 0.025 [b]	1.32 ± 0.020 [b]
	2020	—	—	—
After irrigation	2018	0.79 ± 0.010 [a]	0.72 ± 0.013 [a]	0.78 ± 0.030 [a]
	2019	0.91 ± 0.025 [a]	0.81 ± 0.014 [a]	0.86 ± 0.048 [a]
	2020	0.98 ± 0.036 [a]	0.86 ± 0.027 [b]	0.93 ± 0.015 [ab]
After harvesting	2018	1.09 ± 0.044 [a]	0.83 ± 0.012 [b]	0.90 ± 0.026 [b]
	2019	1.17 ± 0.035 [a]	0.95 ± 0.023 [b]	1.00 ± 0.004 [b]
	2020	1.02 ± 0.021 [a]	0.88 ± 0.018 [b]	0.95 ± 0.031 [ab]

Note: No, no interlayer; Straw, straw burial layer at 0.40 m depth; Sand, sand burial layer at 0.40 m depth. All data were presented by means ± standard errors (n = 3), and different lowercase letters within a row of the same year indicate significant difference at $p < 0.05$.

3.4. Straw Interlayer Treatment Effectively Lowered the Soil Salt Flux

The leaching flux and evaporation flux of salt showed great variation in different years (Table S1). The data shows that the straw interlayer treatment significantly increased the leaching flux of salt and demonstrated an increase of 11.30% compared to the no-interlayer soil and an increase of 5.69% compared to the sand interlayer soil in 2018, respectively; meanwhile, the FL with the straw interlayer treatment in 2019 was lowered by 25.24% compared to the no-interlayer soil and lowered by 8.60% compared to the sand interlayer treatment, respectively ($p < 0.05$, Table 4). The measurements also show that the evaporation fluxes of salt (FE) in the soil layer at 0–0.40 m with the straw interlayer treatment decreased by 33.75% in 2018, 23.17% in 2019 and 58.34% in 2020, and decreased in the sand interlayer treatment significantly by 35.51% in 2018, 24.61% in 2019 and 40.62% in 2020 compared to the no-interlayer soil, respectively ($p < 0.05$).

Table 4. Leaching flux and evaporation flux of salt under no interlayer, straw interlayer and sand interlayer treatments from 2018 to 2020.

Index	Year	Interlayer		
		No	**Straw**	**Sand**
FL (g m^{-2} d^{-1})	2018	340.72 ± 4.97 [b]	379.22 ± 3.99 [a]	358.80 ± 6.49 [b]
	2019	226.67 ± 8.49 [a]	169.47 ± 5.68 [b]	185.41 ± 4.48 [b]
	2020	—	—	—
FE (g m^{-2} d^{-1})	2018	22.67 ± 1.31 [a]	15.02 ± 1.40 [b]	14.62 ± 1.47 [b]
	2019	32.63 ± 1.87 [a]	25.07 ± 0.81 [b]	24.60 ± 1.25 [b]
	2020	10.61 ± 1.57 [a]	4.42 ± 0.39 [b]	6.30 ± 0.60 [b]

Note: No, no interlayer; Straw, straw burial layer at 0.40 m depth; Sand, sand burial layer at 0.40 m depth. All data were presented by means ± standard errors (n = 3), and different lowercase letters within a row of the same year indicate significant difference at $p < 0.05$.

3.5. Water and Salt Distribution of Straw Interlayer-Mediated Improved the Sunflower Yield

The data shows that the interlayer treatments significantly affected the emergence rate and seed yield of sunflower (Table S1). Both the straw interlayer and sand interlayer treatments significantly promoted the emergence rate of sunflower and increased the seed yields of sunflower compared to the no-interlayer soil in 2018 and 2019 ($p < 0.05$, Table 5). The seed yields of sunflower from the straw interlayer treatment increased by 18.51% in 2018, 11.00% in 2019 and 17.46% in 2020 comparing to that in the no-interlayer soil, respectively ($p < 0.05$), while the seed yields of sunflower from the sand interlayer treatment were significantly lower than that from the no-interlayer soil in 2019.

Table 5. Emergence rate and grain yields of sunflower under no interlayer, straw interlayer and sand interlayer treatments from 2018 to 2020.

Index	Year	Interlayer		
		No	**Straw**	**Sand**
Emergence rate (%)	2018	74.15 ± 3.11 [b]	84.20 ± 1.63 [a]	85.12 ± 2.90 [a]
	2019	78.82 ± 1.00 [b]	87.09 ± 2.90 [ab]	88.69 ± 2.85 [a]
	2020	—	—	—
Seed yields (t ha^{-1})	2018	2.81 ± 0.10 [b]	3.33 ± 0.04 [a]	2.92 ± 0.07 [b]
	2019	3.85 ± 0.07 [b]	4.27 ± 0.08 [a]	3.48 ± 0.10 [c]
	2020	3.55 ± 0.06 [b]	4.17 ± 0.05 [a]	3.71 ± 0.06 [b]

Note: No, no interlayer; Straw, straw burial layer at 0.40 m depth; Sand, sand burial layer at 0.40 m depth. All data were presented by means ± standard errors (n = 3), and different lowercase letters within a row of the same year indicate significant difference at $p < 0.05$.

4. Discussion

4.1. Different Interlayers Demonstrate Differential Effects on the Water in Soil

Soil water capacity is a crucial factor affecting the crop growth and the evaluation of the amelioration effect of saline soil [5,16]. In this study, both the straw interlayer and sand interlayer significantly increased the water content in the soil layer at 0–0.40 m after spring irrigation but demonstrated a lower soil water content in the soil layer at 0.40–1.00 m, as shown in Figure 3, indicating that either a sand or straw interlayer in soil effectively improved the water holding capacity in the soil plough layer after spring irrigation, which is necessary for the emergence rate of sunflower under a beneficial soil environment. Because the soil interlayer changed the structure of soil and formed a capillary barrier effect in the soil, the capillary barrier system was proven to be an effective factor affecting the movement of water in soil, thus decreasing water permeability [21,22]. Usually, the rapid infiltration of water reduces the water content in the upper soil layer and increases the water content in the bottom soil layer [5]. Yan et al. (2018) reported that different burying materials affect the pore structure and hydraulic conductivity, thus leading to the difference in the hydraulic properties of the interlayer-mediated soil [23]. Granular material generally forms more small pores that have a diameter equal to or less than 1 mm, thus evidently reducing the infiltration due to the presence of the small porosity [23]. Meanwhile, spring irrigation easily accelerates the mixing rate of sand and soil due to the supply of large amounts of water, thus changing the pore structure in the sand interlayer and reducing the porosity [24]. In our study, the sand interlayer treatment significantly lowered the hydraulic conductivity because of the presence of the mixture of sand and soil, as shown in Figure 3, resulting in a higher soil water content in the soil layer at 0–0.40 m depth compared to the straw interlayer treatment. Particularly, both the extension of sunlight and the increase in temperature elevated the evaporation of soil water, thus promoting the upward movement of groundwater. Nevertheless, the existence of an interlayer in the soil could cut off the transport channel of soil capillaries and weakened the evaporation rate of water [17]. Our data indicate that the inhibition effect of the straw interlayer-mediated soil on the evaporation of ground water was gradually weakened because of the continuous decomposition of straw in the soil, but there was no such phenomenon with the sand interlayer treatment. Naturally, the precipitation also affected the capacity of the soil moisture, especially for the sand interlayer treatment. As observed in our study, the rainfall in the 2018 growing season was significantly higher than that in 2019 or 2020, and the soil water content in the soil layer at 0–0.40 m depth with the sand interlayer treatment in this year demonstrated the highest storage of the three years.

4.2. Different Interlayers Influence the Movement Profile of Salt in Soil

The salt movement in soil is generally very complex and is closely related to the water movement, indicating a regulatory role of water on the salt movement in soil. Previous studies have shown that either a straw burial or sand burial layer plays an important regulatory role in promoting soil desalination and inhibiting the accumulation of salt on the soil surface [14,15], suggesting that these reports are similar to our results. Another report showed that spring irrigation stored sufficient water in the upper soil layer, thereby promoting the salt ion exchanges and accelerating the salt leaching rates in soil [17]. In this study, spring irrigation significantly lowered the soil salt content in the soil layer at 0–0.40 m depth in either the straw interlayer or the sand interlayer treatment compared to the no-interlayer soil, while the soil salt in the soil layer at a 0.40–1.00 m depth demonstrated an opposite accumulation profile compared to that in the soil layer at a 0–0.40 m depth, as shown in Figure 4. Usually, the irrigation water in the upper soil can promote the dissolution of salt ions for a long time, thus lowering the soil water infiltration and blocking the salt leaching rate. Because the water's infiltration and evaporation occurred simultaneously in the field soil, when the evaporation intensity was higher than the infiltration rate, the salt leaching in the soil was inhibited, indicating that the sand interlayer treatment demonstrated higher salt content in the soil layer at a 0–0.40 m compared to the straw interlayer treatment. Since the interlayer could block the channel of soil capillary, both the upward movement of groundwater and the salt accumulation on the surface soil were effectively inhibited [23]. As shown in our results, the no-interlayer soil demonstrated a higher soil salt content, soil back salting rate and FE in the upper soil layer at a 0–0.40 m compared to the straw interlayer and sand interlayer treatment after harvesting; meanwhile, the desalinization ratio and FE in the soil layer at a 0–0.40 m depth in both the straw interlayer and sand interlayer treatments were decreased because of the extension of burial years, suggesting that the regulatory role of the interlayer in blocking the salt leaching was mainly reflected in the first year.

The salt stratification ratio (SR) in the soil layer at 0–0.40 m or 0.40–1.00 m usually reflects the salt distribution in the soil profile and plays a regulatory role in the mediated interlayer on soil desalination in the plough layer. Before spring irrigation, the SR values in all the treatments demonstrated an increase of more than one-fold, but the SR values in all the treatments were maintained at a level of less than one because more salts were leached to the bottom soil layer, particularly for the SR value in the straw interlayer treatment after spring irrigation. Even at the harvesting stage, only the SR value in the straw interlayer treatment did not reach 1, although the SR value increased year by year. This suggests that the straw burial layer could effectively regulate the back salting rates in the plough layer, but the blocking salt effect of the straw burial layer was usually weakened with the decomposition of straw in the soil [5]. In addition, long-term irrigation using the Yellow River (salt concentration 0.58 g L^{-1}) may aggravate soil secondary salinization [25]. The interlayer treatments in our study could act as effective barriers to prevent salt accumulation in the upper soil and alleviate the secondary salinization caused by the irrigation regime.

4.3. Interlayer Effectively Increased the Sunflower Yields

Soil salinity and water shortage usually limit the sunflower growth in saline land. Therefore, effective spring irrigation could provide a good growth environment by supplying water and lowering salt accumulation, thus promoting the emergence of sunflowers by interlayer mediation in either the straw interlayer or the sand interlayer treatment. The water content in the soil layer at a 0–0.40 m depth in these two treatments was significantly lowered, indicating that the interlayer played an important regulatory role in blocking the upward movement of water in soil profile. As previously reported, the sand layer obviously decreases the soil water capacity in the plough layer, thus greatly influencing the sunflower yield [6]. From the sunflower budding to flowering stage, a higher transpiration rate and a stronger soil evaporation intensity inevitably causes adverse effects on sunflower growth, eventually leading to a decrease in sunflower yield [26,27]. Our data show that the no-interlayer soil demonstrated a lower salt content in the soil layer at a 0–0.40 m depth, thus triggering water stress and significantly influencing sunflower growth, especially in 2019. The sand interlayer treatment revealed higher seed yields in both 2018 and 2019, indicating that heavy rainfall is an important factor in alleviating water deficiency during the whole growth period. Although the straw interlayer treatment lowered the soil water content in the soil layer at a 0–0.40 m depth at the late growth stage of sunflower, the available water content and the released nutrients from straw decomposition could meet the requirement for sunflower growth, significantly increasing the seed yields [15,28,29]. In either 2019 or 2020, the changes in meteorological factors exerted on the seed yields of all treatments compared to those in 2018—which were accompanied by the thunderstorm and strong winds on 1 September—and rainfall in this short term reaching 46 mm seriously lodged the sunflowers and decreased the yields in this area. In addition, a straw interlayer is technically practical with the development and popularity of straw deep burial plough, and it is also economically feasible with the yield advantages that result from a beneficial plough layer with a better salt-water environment.

5. Conclusions

The interlayers play an important regulatory role in altering the distribution of water and salt in saline soil. After irrigation, either straw- or sand-burial interlayer treatment provided an environment with more water and less salt for the emergence of sunflower. Straw interlayer treatment obviously demonstrated a lower capacity for water storage in the soil layer at a 0–0.40 m depth compared to the sand interlayer, but it showed more amounts of leached salt after irrigation. Compared with sand-burial interlayer treatment, the straw-burial interlayer established a beneficial plough layer with a better salt water environment in the later stage of sunflower growth. This study suggests that the straw-burial layer is an effective management practice for saline environment amelioration and provides an important reference for applying interlayer material in saline soil.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su15064931/s1, Table S1. Analysis of variance for soil desalinization (S_{DR}) and back salting ratio (S_{RR}), stratification ratio of salt content before irrigation (SR^a), after irrigation (SR^b) and after harvesting (SR^c), Leaching flux (FL) and evaporation flux (FE) of salt, as well as emergence rate and seeds yields under no interlayer, straw interlayer, and sand interlayer treatments from 2018 to 2020.

Author Contributions: Conceptualization, methodology, software, and writing—review and editing, N.L. and W.F.; formal analysis, visualization, and software, H.Z. and F.C.; investigation, J.W. and Y.L.; project administration, funding acquisition, supervision, H.P. All authors have read and agreed to the published version of the manuscript.

Funding: This research was supported by the National Natural Science Foundation of China (32172126), the National Key Research and Development Program of China (2022YFD1500304) and the Agricultural Science and Technology Innovation Program (CAAS-ZDRW202202).

Acknowledgments: We are grateful for the constructive comments for this manuscript from the anonymous reviews and editors.

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

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