Comparative investigation on soil salinity leaching under subsurface drainage and ditch drainage in Xinjiang arid region

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Abstract: This study was carried out to explore the effects of leaching salinity under subsurface drainage and mulched drip irrigation on saline and alkaline land from the year 2012 to 2014 in Xinjiang Region of China. Three sampled points were both set up in the subsurface drainage and ditch drainage areas. Soil samples were obtained at varied depths. Through observing the underground water table under each sampled point and measuring the electrical conductivity (EC) of the soil extracts, the following results were obtained: (1) after draining, the underground water table ranged from 1.6 m to 2.2 m in the ditch drainage area, and ranged from 1.5 m to 2.2 m in the subsurface drainage area. Thus, both irrigations could control underground water table below 1.5 m which is deeper than the main water-absorbing layers of crop root systems; (2) for subsurface drainage, the closer to the pipe, the better to leach salinity; decreased from the initial 13.54-22.95 g/kg to 8.20-11.47 g/kg; (3) compared with the amounts in 2012, soil total salt at each sampling point at depths of 0-200 cm in subsurface drainage area decreased by 42.99%, 36.84% and 24.41% respectively in 2014; and in ditch drainage area decreased by 46.85%, 38.12% and 30.80% respectively in 2014. The results showed both ditch and subsurface drainage could leach salinity effectively.

Keywords: mulched drip irrigation, soil salinity, subsurface drainage, ditch drainage

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1 Introduction

Northwest areas of China, especially Xinjiang Region, play an important role in the agriculture of China. But these areas have scarce rainfall and strong evaporation. As a result, there is salt accumulation on the surface soil. Soil salinization has restricted agricultural production and affected the stability and sustainable development of the oasis ecological environment, especially in arid and semi-arid areas[1-3]. With varying degrees of salinization, the cultivated area of Xinjiang is about 122.88×10^4 hm², accounting for about 30.19% of the whole cultivated area in Xinjiang[4].

Many studies have shown that mulched drip irrigation, as a new micro-irrigation approach incorporating surface drip irrigation method and film mulching technique, enables a high yield of crops on saline soil, so it has been applied widely[5-8]. However, it is still a kind of partial irrigation and only can form a root salt desalination zone under the effect of a drop emitter, thus crops can normally

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facilitated. With root water absorption and evaporation, the salinity below the root zone is bound to increase and the second year's cultivation could cause salt redistribution[8]. Additionally, with the continued use of mulched drip irrigation from year to year, some studies have indicated that the soil salinity of uncovered land and farmland increased. Mou et al.[9] analyzed the salinity changes in cotton field with different irrigation years in four different growing period and found that with the drip irrigation time extension, soil salt content would increase; Zhang et al.[10] done a 3-year experiment in an arid area in Xinjiang and found the salt accumulatesin the inter-film zone at the end of growth period. Zhang et al.[11] carried out a study that found mulched drip irrigation provides less irrigation than conventional drip irrigation but causes more salt accumulation in the topsoil; Li et al.[12] analyzed the spatial and temporal change of salinity in long-term drip irrigation under the film and found an increase in surface soil salinity. Since 1990s, mulched drip irrigation has been promoted and applied in Xinjiang, the drainage system was discarded gradually. As a result, soil salinity has never been carried out of the soil. Therefore, if irrigation measures are unreasonable, it will easily lead to secondary soil salinization[6].

Subsurface drainage, as a scientifically effective measure for controlling the underground water table and reclaiming saline land[13-15], has several advantages such as: (1) convenient for mechanical labor in fields; (2) saving much land and improving land utilization rate. Subsurface drainage follows the law of salt movement that salt comes with water and is taken away by water, and through subsurface pipe, it could drain excess water off to achieve soil desalination. Thus, theoretically, it is an effective way to leach salinity on mulched drip irrigation farmland. Currently, few studies have showed that subsurface drainage has significant effects on control of farmland groundwater table, the governance of waterlogging, the exclusion of salt, and the improvement of crop yields. For example, Liu et al.[16] simulated the changes of water table depth in coastal saline land with subsurface drainage systems and discovered that subsurface drainage systems obviously reduced the occurrence of waterlogging in coastal saline land, even under the condition of heavy rainfall; Mastrocicco et al.[17] carried out a study that focused on the distribution of major anions and inorganic N species and found that subsurface drainage systems were effective in ameliorating soil properties even in agricultural field consisting of low permeability materials with naturally high content of organic matterand salinity, and that they can induce changes in redox conditions responsible for the large differences in N speciation found in soil profiles; Liu et al.[18] researched the shallow subsurface drainage in Xinjiang and discovered that shallow drainage systems could leach salinity from soil with water. In addition, combined with drip irrigation system, shallow subsurface drainage systems could effectively manage saline-alkaline land.

Since mulched drip irrigation belongs to partial irrigation, the water cannot penetrate the soil deeply, which means that saturated drainage in farmland could not be achieved theoretically. However, saturated drainage may happen because of some special conditions in Xinjiang, such as (1) the melting water of snow cover causes the short-term saturation of soil in the spring sowing time; (2) a large amount of irrigation is needed during period of emergence, and thus soil water saturation happens in a short period of time; (3) after the peak of autumn irrigation, in order to flush soil salt and increase irrigation quota properly, soil water saturation can happen in a short amount of time; (4) an intentional increase of the irrigation quota during the crop growth period can cause soil saturation and deep seepage.

As mentioned above, the long-term mulched drip irrigation can cause the rise of groundwater table, secondary soil salinization and other new agricultural eco-environmental problems; however, the use of drainage can leach soil salinity from salinized land. Hence, taking advantages of the current fact, there are large amounts of farmland with mulched drip irrigation in Xinjiang. But in order to build ditch drainage project, a great deal of farmland is used, that is not economical. In addition, it was not conducive for field mechanical operation. In this study, one saline-alkaline farmland under mulched drip irrigationin Xinjiang arid region was chosen. And from the view of drainage, the specific aim of this article is to do some comparative investigations on soil salinity leaching under subsurface drainage and ditch drainage from the year 2012 to 2014. The results of this study could guide the treatment of saline-alkaline land using subsurface drainage.

2 Materials and method

2.1 Experimental site

The experimental site is located at the north of the Tian Shan Mountains or the southern margin of Junggar Basin, belongs to Xinjiang Region in northwestern China (44°37′-44°48′N, 85°27′-85°41′E, see Figure 1). The field experiment was conducted from the year 2012 to 2014 in a cotton filed with 0.768 hm^2 area. The experimental areas are characterized by a typical inland desert climate with strong evaporation of approximately 1826.2 mm and rarely mean annual precipitation of approximately 141.8 mm. The light and heat resources are abundant with annual total sunshine 2861.6 hand average frost-free period 166 days. Spring and autumn are short while summer and winter are long, besides, there is a large temperature difference between day and night. Within the last 30 years, the extreme maximum temperature is 43.1ºC in summer but extreme minimum temperature is –42.3ºC in winter.

The experimental site is flat and the soil characteristics of the experimental site are shown in Table 1. Irrigation water comes from reservoir and has a low amount of mineralization (approximately 0.4 g/L); thus, it has little influence on soil salinity. The general situations of planting crops in experimental area are shown in Table 2. The experimental irrigation period starts gradually in May, the consumption of irrigation water reaches peak levels in July and August, and the use of irrigation water stops in September. The irrigation schedule is shown in Table 3.

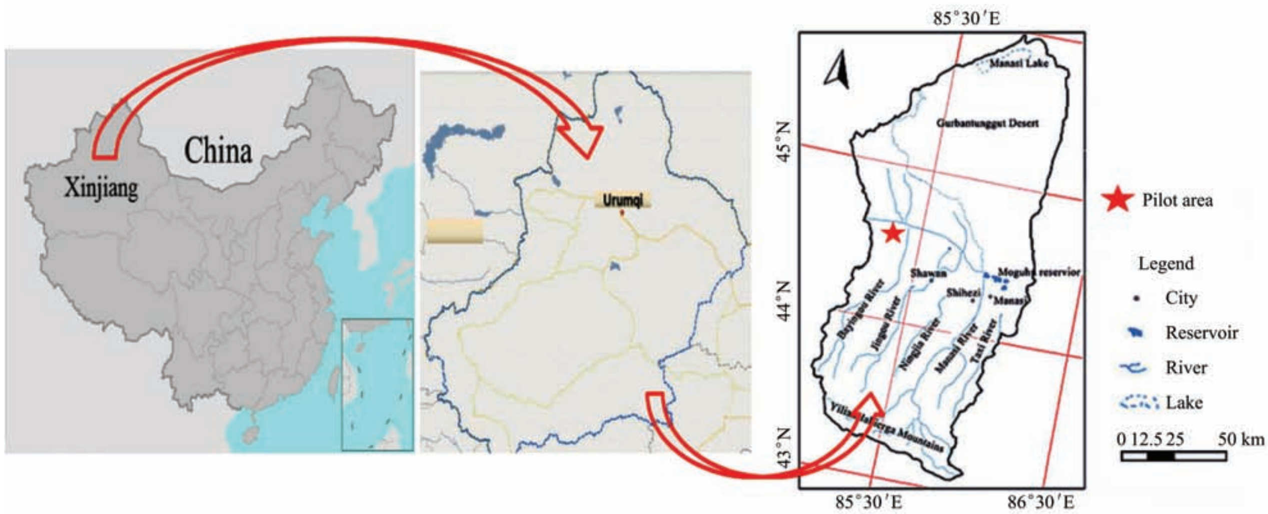


Figure 1 Geographic location of study site

Table 1 Soil characteristics of the experimental site

Depth /cm	Bulk density /g·cm^{-3}	Field capacity (Fc)/%	Wilting point (Pw)/%	Saturation /%
0-50	1.30	25.04	13.3	41.1
50-100	1.32	25.52	14.1	41.6
100-150	1.34	26.23	14.8	42.1
150-200	1.37	26.52	15.1	42.3

Note: Soil texture was also sandy loam.

Table 2 General situation of planting crops in experimental zone

Year	Planting Corps	Sowing Time	Harvest Period	Yield /kg·hm^{-2}	Irrigation quota/mm
2012	Alfalfa	Apr 20	Sep 10	13340	747.3
2013	Cotton	Apr 28	Sep 20	3600	750.7
2014	Cotton	Apr 26	Sep 23	4170	751.2

Table 3 Irrigation schedule for experimental zone

Irrigation time		Early May	Mid May	Mid June	Late June	Early July	Mid July	Late July	Mid Aug	Late Aug	Total
Irrigation quota/mm	2012	120	50.7	79.5	82.6	78.6	86.4	95.6	82.1	71.8	747.3
	2013	121.1	50.3	78.9	83.1	79.3	88	96.6	83.1	70.1	750.7
	2014	122.1	49.9	80.1	83.4	79.1	87.5	95.3	81.6	72.2	751.2

2.2 Subsurface drainage and ditch drainage system

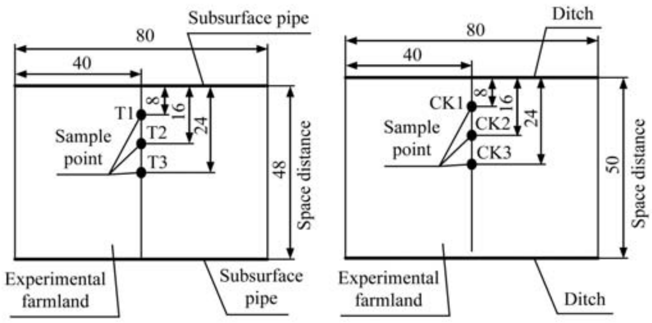
The subsurface drainage and ditch drainage systems were installed in the pilot area. Seepage pipe with perforated corrugated pipes (10 cm in diameter, encircled by sand filter 20 cm thick and produced by a company of Zibo Shandong Province, China) was laid down by an excavator. According to the empirical formula induced by Science China Institute of Water Resources and Hydropower Research and Jiangsu Water Conservancy Science Research Institute, the subsurface pipe was laid in a vertical direction with experiment area at overall length of 80 m, depth of 2.2 m, spacing of 48 m, and design slope ratio of 3‰ (see Figure 3). In contrast, the ditch drainage system was also laid at depth of 2.2 m, spacing of 50 m, and design slope ratio of 3‰. In order to stay the ditch drainage unobstructed and achieve the original design width and slope requirement, the ditch drainage system was cleaned artificially every 2 years. The discharged water of ditch and subsurface drainage was transported to downstream desert. The design parameters of drainage engineering are shown in Table 4.

Table 4 Design parameters for drainage engineering

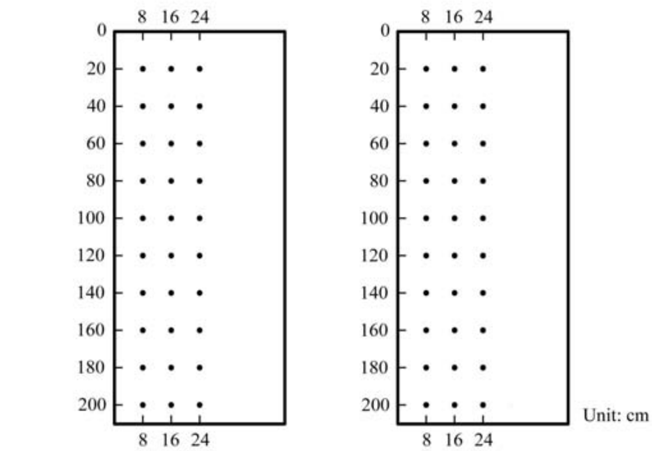
Subsurface pipe		Ditch	
Buried depth/m	2.2	Buried depth/m	2.2
Space distance/m	48	Space distance/m	50
Diameter of pipe/m	0.1	Width of ditch/m	2.5

2.3 Data collection

For the subsurface pipe and ditch were symmetrically distributed in the soil profile, we set up three sampled points (T1, T2, and T3) on subsurface drainage area. The horizontal distances of each point from the subsurface pipe are 8 m, 16 m, and 24 m, respectively (see Figure 2). In contrast, three sample points (CK1, CK2, and CK3) were also been set up on ditch drainage area (see Figure 2a). Considering the physiology of crop irrigation cycle, soil samples were collected six times (June 9 and October 4 in 2012; May 28, July 30 and September 20 in 2013; October 30 in 2014) during from the year 2012 to 2014. Soil samples were obtained with an auger and packed using aluminum cans for laboratory analysis. The samples were obtained at varied depths (0-20 cm, 20-40 cm, 40-60 cm, 60-80 cm, 80-100 cm, 100-120 cm, 140-160 cm, 160-180 cm, 180-200 cm depth beneath ground surface); a total of 270 soil samples (see Figure 2b) were obtained. Soil electrical conductivity (EC) is a popular criterion to define soil salinity[19,20], and can be used to calculate total dissolved salt (TDS)[21-23]. Soil samples were crushed and passed through a 2 mm sieve after natural drying. Then the EC was measured in the paste extracts with soil/water ration of 1:5 (weight) by a conductivity meter (FG3-ELK, METTLER TOLEDO, Switzerland). In order to convert EC to TDS, the relationship between them was determined through laboratory experiments with 45 soil samples collected from the experiment fields. The TDS of soil sample was defined by summing up the dominant cations (Na^+, K^+, Ca^{2+}, Mg^{2+}) and anions (Cl^-, SO_4^{2-}, HCO_3^-, CO_3^{2-}) of 1:5 soil water extract. The linear regression between TDS (g/kg) and EC (mS/cm) is shown in Figure 4.



a. Distribution of sampling points for subsurface drainage



b. Distribution of sampling points for ditch drainage

Figure 2 Schematic diagram of sampling points (a) and distribution of sampling points (b) for Subsurface drainage and ditch drainage

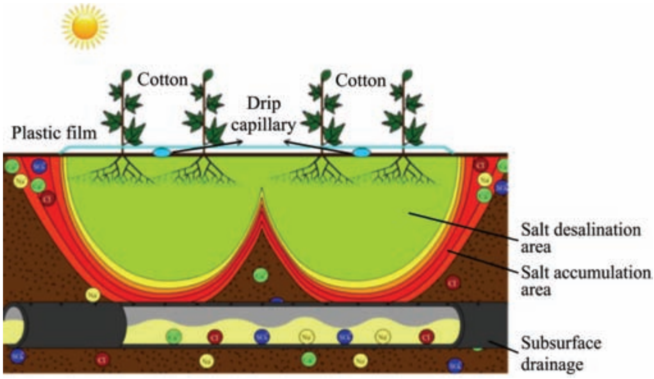


Figure 3 Schematic diagram of subsurface drainage

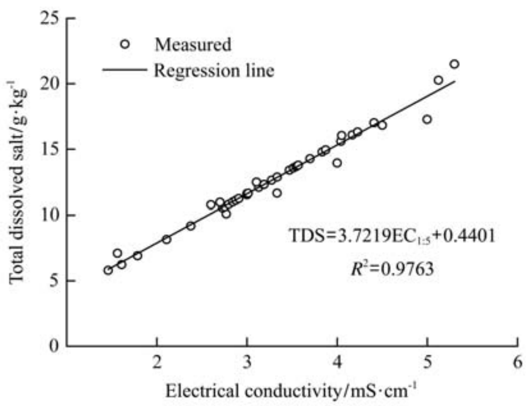


Figure 4 Linear relationship between total dissolved salt (TDS) and electrical conductivity ($EC_{1:5}$)

2.4 Statistical analysis

Origin 8.5 software was used for basic statistical analysis of soil salinity. Excel 2010 software was used to calculate soil desalination rate.

The total salt content in the soil of 0-200 cm depth beneath ground surface was calculated as:

$$y = \int_0^x f(x)\mathrm{d}x$$

where, $f(x)$ is the function of soil depth (m) and salt content (g); x is soil salt content at varied depths, g; y is thetotal salt content in the soil of 0-200 cm depth, g.

$$f(x) = \gamma\theta \cdot V$$

where, γ is the depth of soil bulk density, kg/m^3; θ is the depth of TDS, g/kg; V is the depth of soil volume, m^3.

For convenience of calculation and analysis, let the value of soil volume of each 20 cm depth be equal to a cubic in this article, so,

$$V = d^3 = 0.2^3 = 0.008\ (\mathrm{m}^3)$$

The ratio of soil desalinization was calculated as

$$R_{des} = (S_i - S_j) / S_i \times 100\%$$

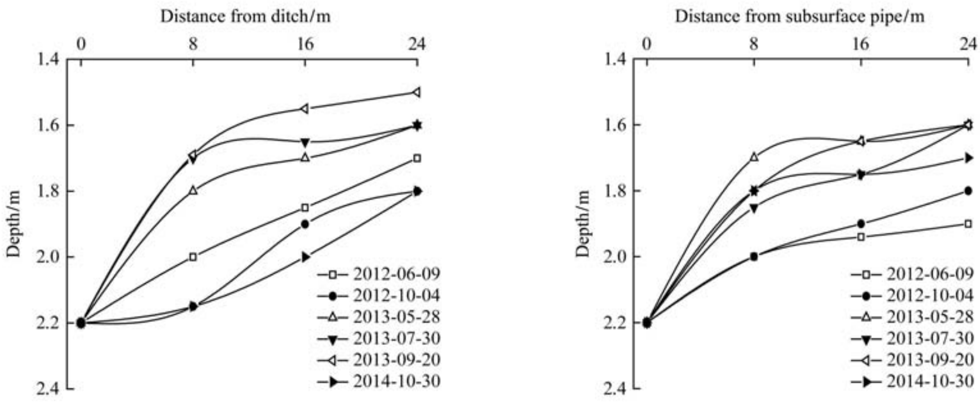
where, R_{des} is ratio of soil desalinization; S_i is the salinity of soil samples before subsurface drainage or ditch drainage; S_j is the salinity of soil samples after subsurface drainage or ditch drainage.

3 Results and discussion

3.1 Effect of ditch and subsurface drainage on groundwater table

The effects of ditch and subsurface drainage on the depth of groundwater are shown in Figure 5. Due to the alternating actions of irrigation and evaporation, fluctuations occurred in the groundwater table; however, in both cases, the groundwater table and the distance to the subsurface pipe (or ditch) are inversely related, as the distance to the drainage pipe or ditch decreased, the groundwater table increased. As a relatively high hydraulic head remains near the drain, resulting in low hydraulic gradients from the midsection (i.e., interior area between two drains) to the drain[24]. Irrigation happens from May to September each year, during irrigation period, the effect of subsurface drainage was less than ditch's. This is because the soil reached partial saturation and the porosity of subsurface pipes was low, as a result, the water confluence of the subsurface drainage was smaller when compared with the ditch drainage. After irrigation (or so, in October), precipitated water depth at each point for subsurface drainage was greater. In terms of soil, drip irrigation and precipitation have some similarities. This was consistent with previous studies[25] that after the precipitation, the relationship between the groundwater table and the discharge of drainage were significant positive correlation. Additionally, it was observed that the underground water seepage slope in the subsurface drainage area was slightly smaller when compared with that of the ditch drainage area. This is because subsurface drainage is influenced by the spacing distance and buried depth[26].

These results of statistical analysis showed that both subsurface drainage and ditch drainage could play an effective role in the control of underground water table. After draining, the underground water table ranged from 1.6 m to 2.2 m in the ditch drainage area, and ranged from 1.5 m to 2.2 m in the subsurface drainage area.

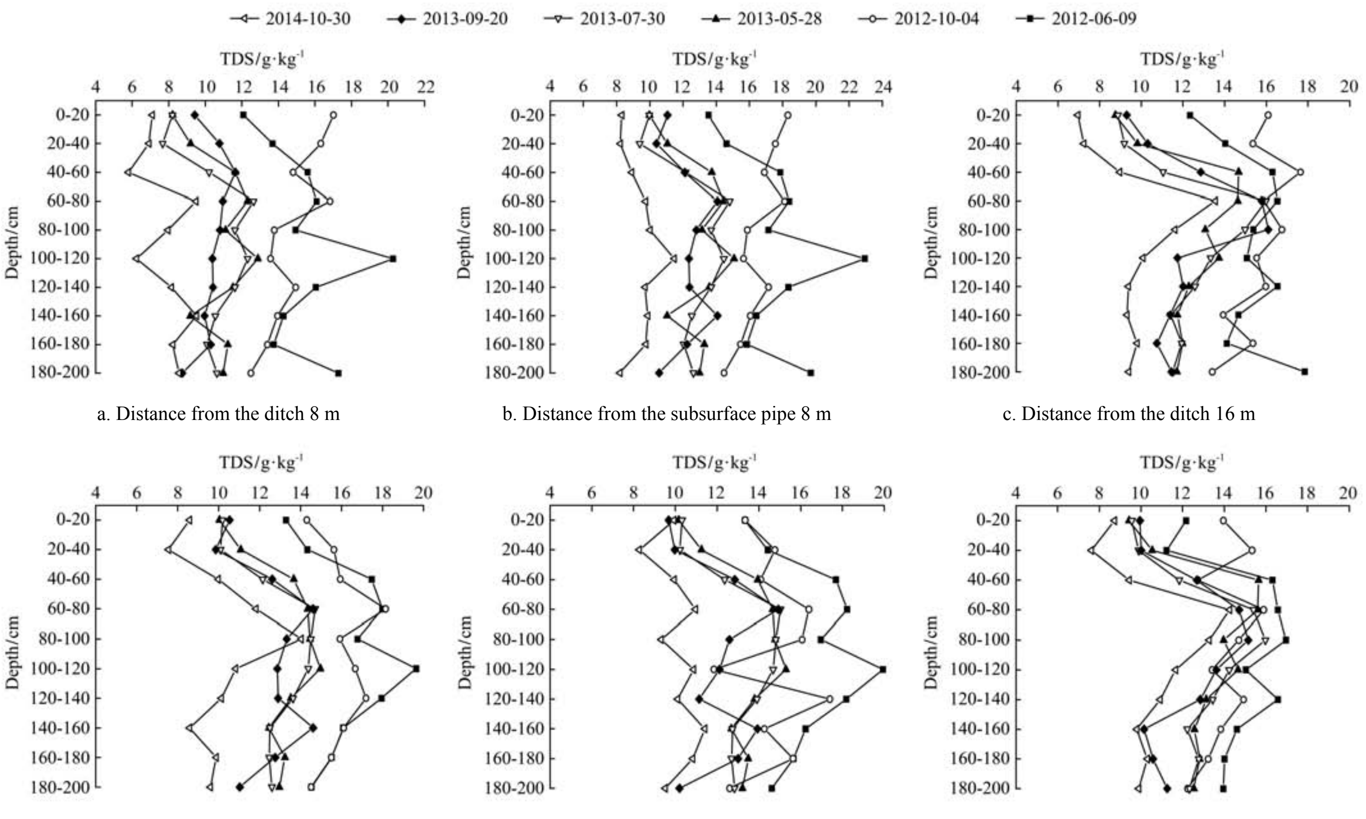


a. Ditch drainage b. Subsurface drainage

Figure 5 Effect of ditch and subsurface drainage on underground water table

3.2 Characteristics of soil salinity variation under ditch and subsurface drainage

The characteristics of soil salinity variation in each sampling period are shown in Figure 6. The results shown in Figure 6 confirm that the soil salinity in different layers follows a decreasing trend after draining. In addition, because that drainage system has been set on mulched drip irrigation farmland, the condition of strong evaporation did not bring about a sharp rise of soil salinity. Since the subsurface drainage system could strictly control the depth of underground water table below the buried pipe and thus prevent the pathway for salinity to go up, as a result, the closer to the subsurface pipe (or ditch), the more stable the change of salinity was. These results are consistent with the findings reported about the closer to the drain, the stronger hydrodynamic condition was, so the movement of water were faster and the effect of soil salinity leaching were more obvious[26,27].



a. Distance from the ditch 8 m b. Distance from the subsurface pipe 8 m c. Distance from the ditch 16 m

d. Distance from the subsurface pipe 16 m e. Distance from the ditch 24 m f. Distance from the subsurface pipe 24 m

Figure 6 Characteristics of soil salinity variation under ditch and subsurface drainage

The results of statistical analysis are as follows: in the sampling point at 8 m, the TDS values in the ditch drainage area decreased from the initial 12.09-20.27 g/kg to 5.80-9.53 g/kg, and the TDS values in the subsurface drainage area decreased from the initial 13.54-22.95 g/kg to 8.20-11.47 g/kg; in the sampling point at 16 m, the

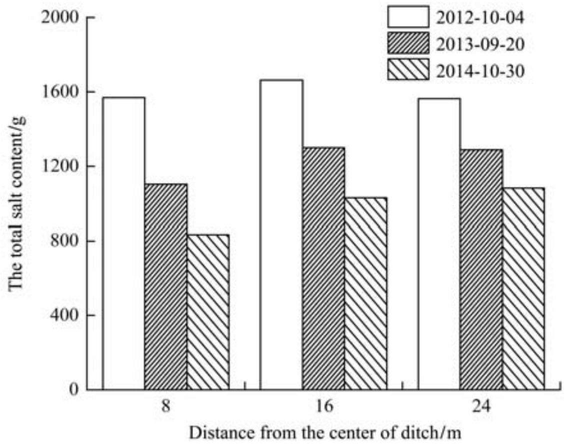
TDS values in the ditch drainage area decreased from the initial 12.34-17.84 g/kg to 6.96-13.55 g/kg, and the TDS values in the subsurface drainage area decreased from the initial 13.29-19.64 g/kg to 7.55-14.04 g/kg; in the sampling point at 24 m, the TDS values in the ditch drainage area decreased from the initial 13.33-19.94 g/kg to 8.28-11.41 g/kg, and the TDS values in the subsurface drainage area decreased from the initial 11.23-16.96 g/kg to 7.62-14.25 g/kg. Therefore, the above results indicated that the closer to the subsurface pipe, the better leaching salinity effect in subsurface drainage area. This is because soil salinity accumulates slowly in the subsurface drainage area, and salinity could be fully dissolved, then returned a high degree of leaching-salinity efficiency. Similar findings were also reported by several authors[10,17,27]. Under the condition of subsurface drainage, as the film mulching could inhibit evaporation, the salt movement in surface soil was mainly influenced by precipitation and salt content decreased most quickly and co-influenced by salt accumulation and precipitation, the decrease rate of salt content in deep soil lagged, soil salinity showed a trend of first increasing and then decreasing.

3.3 Change of total soil salinity

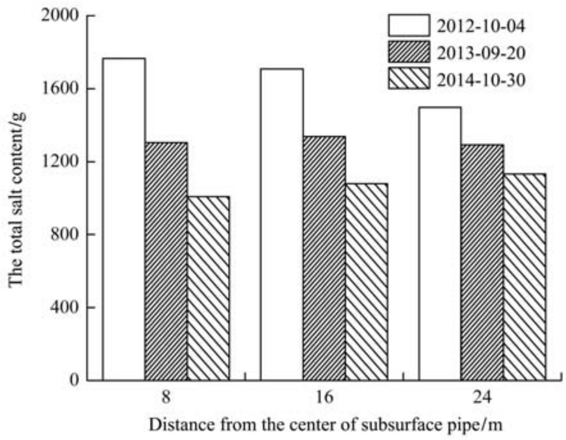
The stratified sampling method was applied in the study area. Regarding 20 cm depth as a unit (total of 10 units), then the total salt content of soil in the depth range of 0-200 cm were calculated. The results of the calculations are shown in Figure 7.

It could be found from Figure 7 that after irrigation (or so, in October), total soil salt was decreasing year by year at the sampling points of 8 m, 16 m, and 24 m away from the subsurface pipe: compared with the total soil salt in 2012, the amount respectively decreased by 26.14%, 21.67% and 13.73% in 2013; compared with the total soil salt in 2012, total soil salt respectively decreased by 42.99%, 36.84% and 24.41% in 2014. Therefore, total soil salt was decreasing year by year with the use of subsurface drainage, the results shows an obvious improvement in saline-alkaline land with mulched drip irrigation and the closer to the subsurface pipe, the greater effect obtained on total soil salt.

Correspondingly, at the sampling points of 8 m, 16 m, and 24 m away from the ditch, total soil salt were also decreasing year by year: compared with the total soil salt in 2012, the amount respectively decreased by 29.64%, 21.91% and 17.67% in 2013; Compared with in 2012, total soil salt in each sampling point decreased by 46.85%, 38.12% and 30.80% in 2014. The results of statistical analysis show that both subsurface drainage and ditch drainage could effectively reduce total soil salt.



a. Ditch Drainage



b. Subsurface drainage

Figure 7 Total salt content of soil in the depth range of 0-200 cm in ditch and subsurface drainage areas

3.4 Discussion

The results of statistical analysis showed that the soil salinity did not orderly decline while sometimes rose and sometimes fell. Especially in summer (or so from May to July), the change characteristics of soil salinity in the experimental area showed the soil salinity content in the upper layers was lower while in the lower layers was higher. However, by contrast, in autumn (specifically in October), the soil salinity content in the upper layers was higher while in the lower layers was lower. The above conclusions did not completely agree with the research conclusions of several authors. Liu et al.[16] carried out their research on subsurface drainage in the conditions of soil saturation in the coastal saline area. But in this article, the conditions of mulched drip irrigation, arid climate, strong evaporation and artificial irrigation have changed the farmland water cycle. Therefore, in summer, due to more irrigation and function of farmland mulch, the flux of soil salinity declined significantly, and formed a salt-leaching distribution curve (see Figure 6). In contrast, in autumn, due to less irrigation and strong evaporation, formed a salt-returning distribution curve of heavy salinity accumulation in upper soil layers and light salinity content in lower soil layers.

Regarding the effect of salt-leaching through subsurface drainage and ditch drainage, the results of this study showed both subsurface drainage and ditch drainage could effectively leach soil salinity. The conclusion was consistent with previous research results[17,18,28,29]. However, previous studies only researched the laying of subsurface pipe, so far, no discussions about subsurface drainage under the condition of long-term use of mulched drip irrigation have been given. Liu et al.[18] researched the shallow subsurface drainage in Xinjiang and discovered that drainage systems could leach salinity from the field with water, and concluded subsurface drainage and drip irrigation systems could effectively manage saline-alkaline land and increase crop yield; but the effect of long-term use of subsurface drainage was not discussed in their study; Ritzema et al.[14] found subsurface drainage, either by open or pipe drains, was an effective tool to combat waterlogging and salinity, but they carried out study under no condition of mulched drip irrigation. In this article, we chosen one saline-alkaline land under the long-term use of mulched drip irrigation and subsurface drainage, and then observed the effect of salt-leaching for three years (2012-2014). The results showed that the use of subsurface drainage could continuously improve saline-alkaline land with mulched drip irrigation.

As for subsurface drainage, considering cost reduction and installation convenient, corrugated porous pipe instead of traditional ceramic tubing was used this study. However, combining use of subsurface drainage and mulched drip irrigation would lead to other new ecological farmland problems, which need more researches. In addition, the key factors affect the leaching of salinity are the spacing and depth of subsurface pipe. Chen et al.[29] researched subsurface drainage systems with three kinds of spacing in coastal saline soil and discovered that the less space between subsurface drainage systems, the better to control groundwater water table and leach salinity; other similar studies[27,30,31] also discovered that reasonable spacing and depth of subsurface pipe in drainage systems had key functions in leaching salinity, however, if only considering spacing and depth of subsurface pipe, the investment and further maintenance cost will increase[32]. This study only took one standard of spacing and depth (48 m of spacing, 2.2 m of depth) on the experimental area; while various combinations of spacing and depth have been not studied for figuring out the optimal one combination. Therefore, to be a certain degree, the effect of leaching salinity was affected in this study. Aiming at different levels of saline and alkaline land, how to set up a rational irrigation management system for leaching salinity still needs further study.

4 Conclusions

Taking ditch drainage as a contrast, this study used subsurface drainage to leach salinity on a saline and alkaline land with mulched drip irrigation. The effects of ditch and subsurface drainage on underground water table, spatial distribution of soil salinity and the change of total soil salinity were analyzed.

(1) Subsurface drainage and ditch drainage both could play an effective role in the control of underground water table; after draining, the underground water table ranged from 1.6 m to 2.2 m in the ditch drainage area, and ranged from 1.5 m to 2.2 m in the subsurface drainage area. Thus, both could control underground water table below 1.5 m which is deeper than the main water-absorbing layers of crop root systems.

(2) After draining on farmland with mulched drip irrigation, the results obtained are as follows: for subsurface drainage, the closer to the pipe (8 m), the better to leach salinity; decreased from the initial 13.54-

22.95 g/kg to 8.20-11.47 g/kg.

(3) After draining, both subsurface drainage and ditch drainage could effectively reduce total soil salt. Compared with the amounts in 2012, soil total salt at each sampling point (8 m, 16 m, and 24 m) at depths of 0-200 cm in subsurface drainage area respectively decreased by 42.99%, 36.84% and 24.41% in 2014; and in ditch drainage area respectively decreased by 46.85%, 38.12% and 30.80% in 2014.

To sum up, subsurface drainage and ditch drainage both could control underground water table and leach salinity.

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