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Research on Different Irrigation Water Effect on Soda Alkaline Soil and Horizontal Drainage Water Salinity-alkalinity

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The effect of tube-well water and river water irrigation on soda alkaline soil and horizontal drainage water salinity-alkalinity was studied. Through soil column simulated experiment, the influence of the tube-well water and river water irrigation on soda alkaline soil and horizontal drainage water salinity-alkalinity was studied. The salinity indexes of surface drainage water in puddling period, the rules of salt ions change of surface drainage water, and the soil electrical conductivity changes in prime field period and the change of soil salinity indexes after a growing season were analyzed. The results showed that, there was no significant different of irrigation water on salinity-alkalinity index for the first surface drainage water in puddling period. But the EC, Na^+, Ca^{2+}+Mg^{2+} and total alkalinity of CK 1 was significant higher than CK 2 for the second drainage water. Irrigation water quality has not significant influence on the soil EC, but desulfurization gypsum could significantly reduce EC value of 0 to 10 cm soil layer. After one rice growth period, the T1 with pH and EC value was significantly less than T2 in 20-40 cm soil layer, but there no significant different on the top layer. Therefore, the tube-well water was choosing at the puddling period, so as to increase the surface flushing effect. With the corresponding, the river water was choosing at the prime field period to prevent soil secondary salinization.

1. Introduction

Agricultural irrigation was an important factor to achieve sustained high yield of agriculture and the irrigation water quality was closely related to the soil salinization, especially in arid and semi-arid areas. Salinity in irrigation water accumulates in the root zone of the soil profile continuously, and had interactions with soil absorbent complex, which lead to soil salinization and alkalization. The western part of Jilin province is located in arid areas; the average annual rainfall in the region is only 400 mm, while the average annual evaporation of 1008 mm, less precipitation, evaporation, water scarcity, a serious shortage of water areas. Baicheng City, Zhenlai County is located in the arid area of Jilin province, is the main grain-producing areas, but also the national commodity grain base. In order to ensure the national food security, to meet the needs of water for food production and domestic water use, to alleviate the over-exploitation of groundwater, to repair and improve farmland soil. In 2012, Jilin province started to construct a project, the use of Nenjiang rich water resources to solve the serious water shortages in the region. The area is located in the hinterland of the Songnen Plain in western China. The soil is typical soda-saline soil, mainly content are carbonates and bicarbonates (Li et al., 2007), with high exchangeable sodium content (ESP) and low infiltration rate (Liu and Han, 2008, Chi and Wang, 2010). The use of power plants to do the dust desulfurization waste (Qiligeer, 2012) not only can improve the soda-alkali soil, and is rich in plant essential trace elements (Li et al., 2003), Desulfurization gypsum (FGD) is a kind of chemical which was modifier widely used in modified soda - saline soil (Qiligeer, 2012; Wang et al., 2011; Zhang et al, 2007). The main component of the FGD is $CaSO_4 \cdot 2H_2O$ and $CaSO_4 \cdot H_2O$ mixture, Na ions in the soil could be replaced out, reducing the alkalinity of the soil. At the same time, if shallow underground gentle salty water in this area can be used properly. First, the permeability of soda saline soil could be enhanced for the salt to create a prerequisite for leaching; and second, to achieve the purpose of washing salt; third, to substitution of sodium base; fourth, play a role in irrigation, will not cause soil salinization and alkalization (Li, 2002). Before 2012, Baicheng area rice planting mainly adopted well

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water irrigation. After the project is completed, as the Nenjiang River water pulled in that the Baicheng are agricultural irrigation water can be ensured. To this end, to carry out the soil column simulation test about the well water and river water irrigation on desulphurization gypsum improved soil. The effects of two kinds of irrigation water on the horizontal drainage quality and soil of soda-alkali soil paddy field were compared with each other so as to provide theoretical basis for the irrigation management system of western paddy field.

Soda saline soil infiltration performance is very poor; the saturated soil hydraulic conductivities of different soil layers were between 0.52 and 1.09 $mm \cdot d^{-1}$, which were almost impervious to water. Therefore, the leaching effect of precipitation on soil salinity is very weak, especially when the surface soil is saturated; the leaching effect of this salt is almost stopped. In addition, the alkalization layer produced by soda-salinization actually acted as an impermeable layer throughout the soil profile, not only making the descending current difficult to produce, but also almost completely blocking the downward channel of the water flow (especially gravity water) downward movement of surface salt (Li et al., 2007; Sivakumar et al., 2015; Suvanjan et al., 2016).

2. Materials and methods

2.1 Soil

Soil samples of salt-affected soil were collected from 0 to 20 cm depth at a degraded grassland area near the Da'an Sodic Land Experimental Station (N45°35′58″–N45°36′28″, E123°50′27″–123°51′31″) operated by the Chinese Academy of Sciences in Songnen Plain, northeast China. Approximately 500 kg of soil samples was collected. These samples were air-dried and passed through a 1-cm sieve. The soil basic characteristics including salinity, sodicity, pH, sand, silt and clay content were measured (Sand content 30.12%, Silt content 54.98%, Clay content 14.90%, Bulk density 1.35 $g \cdot cm^{-3}$, pH(1:5) 10.58, EC(1:5) 2.63 $dS \cdot m^{-1}$, SAR $(mmol_c \cdot L^{-1})^{1/2}$, Soluble Na^+ 25. 10 $mmol_c \cdot L^{-1}$, Ca^{2+} +$Mg^{2+}$$mmol_c \cdot L^{-1}$, Exchangeable Na, K, Ca, Mg, 119.10, 3.28, 167.90, 13.00$mmol_c \cdot L^{-1}$ respectively, ESP 39.30%). The soil was severely affected by salts of carbonate or bicarbonate that result in the high pH values of the 1:5 suspensions. The texture is sandy and clayey with poor permeability for the unstable structure of the soil related to the high percentage of the exchangeable sodium, hereby could consider the soil as the sandy clayey loam seriously affected by the salt of sodium carbonate with high pH, mild content of salts, collapsed soil structure and poor permeability for water (Chi and Wang, 2010). For the high value of the pH we could say it is alkali for the farming consultation issues link to the sodicification, in this very case we prefer the definition of alkaline sodic for the soil we work with.

2.2 Treatments

Desulfurization gypsum (DG) used in this study was produced as a waste of the Datang thermal power plant in Changchun, China, containing 981.23 $g \cdot kg^{-1}$ $CaSO_4 \cdot 2H_2O$ and 11.42 $g \cdot kg^{-1}$ $CaSO_4 \cdot H_2O$ with particle size <0.5 mm. Heavy metal contents were all below the ecological index of arsenic, cadmium, lead, chromium and mercury for fertilizer standards in China (GB/T 23349, 2009).

Four treatments, replicated five times, were arranged in randomized soil columns; the treatments were: T1 (alkali-sodic soil desulfurized gypsum applied at the rate of 100% gypsum requirement (30t/ha)and irrigated with tube-well water), T2 (alkali-sodic soil desulfurized gypsum applied at the rate of 100% gypsum requirement (30t/ha)and irrigated with river water), CK1 (alkali-sodic soil irrigated with tube-well water) and CK2 (alkali-sodic soil irrigated with river water)The amount of desulfurized gypsum used to achieve the fraction of gypsum requirement (GR) was calculated by a modified method (Oster and Frenkel, 1980), where:

$$GR(mol_c\ kg^{-1}) = 1.25 \times CEC \times (ESP_i - ESP_f) \times 10^{-4}$$

Where CEC ($mmol_c \cdot kg^{-1}$), ESP_i (%) and ESP_f (%) are soil cation exchange capacity, original exchangeable sodium percentage and target exchangeable sodium percentage, respectively. The application of desulfurized gypsum was at a rate of 100% GR with the value of ESP_f of 5.00.

2.3 Preparation of soil columns

Soil columns were made of PVC cylinders with 28cm inner diameter and 50 cm height. 20 kilogram of soil was packed into each column to a height of 38cm. The desulfurization gypsum was mixed well-distributed with the soil before packing into the upper soil columns to a height of 10 cm. The bottoms of the columns were closed, and the tops of the buckets were open to the atmosphere.

2.4 Irrigation water analysis

Canal water from the Daan irrigation District of Nen River in west part of Jilin Province was applied to irrigation soil columns (Table 1). Tube-well water is the groundwater from Quaternary sediments in Da'an Sodic Land Experimental Station. To assess water quality, some chemical compounds were measured and they are shown in Table 1. According to the FAO irrigation water quality standards, the tube-well water classified as mild to moderate hazard levels, river water was not affected.

Table 1: Analysis of tube-well water and river water used for irrigation

Charact-eristic	pH	EC ($dS \cdot m^{-1}$)	$CO_3^{2-}+HCO_3^-$ ($mmol_c \cdot L^{-1}$)	SO_4^{2-} ($mmol_c \cdot L^{-1}$)	$Ca^{2+}+Mg^{2+}$ ($mmol_c \cdot L^{-1}$)	Na^+ ($mmol_c \cdot L^{-1}$)	K^+ ($mmol_c \cdot L^{-1}$)	RSC ($mmol_c \cdot L^{-1}$)	SAR [$(mmol_c \cdot L^{-1})^{1/2}$]
Tube-well water	7.52	1.07	10.05	5.15	5.34	2.04	1.67	9	3.78
River water	7.82	0.19	2.32	0.23	1.03	0.24	0.69	1.92	0.34

RSC, residual sodium carbonate. SAR, sodium adsorption ratio.

2.5 Drainage water analysis

After the transplanting of rice, 10 days drainage at one time of ponding water in surface of soil columns, which was outflow by siphonage. After the water was drainaged from the soil surface, an additional 1L of water was added. All the soil columns were irrigation and drainage at the same time. The surface drainage water was collected in plastic bottles for analysis.

Recorded the irrigation and removal soil surface ponding water volume. These samples were analyzed for pH, EC, soluble Na^+, $Ca^{2+}+Mg^{2+}$, K^+, $CO_3^{2-}+HCO_3^-$, SO_4^{2-}, SAR, RSC, Total alkalinity and removal sodium (TNa_F). The total alkalinity was the sum of carbonate and bicarbonate ions. The removal sodium (TNa_F) was calculated as (Staff, 1954):

$$Plotsize = 3.14 \times 0.14m \times 0.14m \times 10^{-4} = 0.62 \times 10^{-4} ha$$

$$TNa_F\,(t/ha) = Na^+ (mmolc/L) \times 23 \times V_F\,(L per plot) / 0.62 \times 10^{-5}$$

The SAR [($mmol_c \cdot L^{-1}$)1/2] of drainage water was calculated by the formula (Staff, 1954):

$$\mathrm{SAR} = Na^+ / \sqrt{(Ca^{2+} + Mg^{2+})/2}$$

The formula for RSC ($mmol_c \cdot L^{-1}$)of 1:5 soil to water extracts (RSC1:5) calculation is:

$$RSC = (HCO_3^- + CO_3^{2-}) - (Ca^{2+} + Mg^{2+})$$

2.6 Soil chemical properties analysis

After the rice growth period, soil samples from 0-10, 10-20 and 20-40 cm layers were collected. All soil samples were air dried and passed through the 2-mm sieve and analyzed for pH, EC, soluble K^+, Na^+ , Ca^{2+} $+Mg^{2+}$, HCO_3^- and CO_3^{2-}, using1:5 soil to water extracts.

The 1:5 soil to water extracts were prepared by adding 150 mL distilled water to 30 g soil in a 250 mL beakers, stirring to mix well with a glass rod, then using buchner funnel vacuum suction filtration, and collected liquid of suction flask. The EC of 1:5 soil to water extracts (EC1:5) was determined by DDS-307 conductivity meter (Shanghai Precision Scientific Instrument Co., Ltd), soluble Ca +Mg by titration with standard verse Nate solution, Na and K by flame photometrical, HCO_3^- and CO_3^{2-} by titration with standard H_2SO_4 and extra gale K, Na, Ca and Mg by atomic absorption.

2.7 Statistical data analysis

All data obtained were the average of five replicas. Statistical analysis on one-way variance analysis (ANOVA) was performed using SPSS 12.0. When significance at a 0.05 level was indicated, means were separated by a Least Significant Difference (Duncan) Procedure.

3. Result and discussion

3.1 Salinity and alkalinity index of drainage water

The salinity and alkalinity index of first drainage water was shown in Table 2. There was no significant difference ($P < 0.05$) in pH and $Ca^{2+}+Mg^{2+}$ ions concentration between four treatments, but there were significant different of EC, Na^+ and total alkalinity between T1, T2 and CK 1, CK 2. Different water irrigation on soda-alkali soil showed no significant effect on drainage water salinity and alkalinity index, whether plus desulfurized gypsum.

The salinity and alkalinity index in T1 and CK1 treatments were significant differences, but there was no significant difference in T1 and T2 of the second drainage water. Except pH and SAR, there was significant difference between CK1 and CK2 treatments. The results of variance analysis showed that different irrigation water had no significant influence on the salinization index of the first drainage water quality. However, there were significant changes ($P < 0.05$) of salinity and alkalinity index in CK1 and 2 in the second drainage water.

The pH, EC, Na^+, Ca^{2+} + Mg^{2+} and total alkalinity of soda-alkali soil drainage in well-water irrigation were significantly higher than those in river irrigation treatment, but there was significant difference between the T1 and T2 treatments. The results showed that gentle salty water has a high salt content and more Ca^{2+} and Mg^{2+} ions, so it is used to leaching soda saline soil to achieve the purpose of washing salt.

Table 2: Salinity and alkalinity index of drainage water

	Treatments	pH	EC (mS·cm^{-1})	Na^+	Ca^{2+}+Mg^{2+}	Total alkalinity	SAR
	T1	9.45±0.38 a	7.87±2.91 a	76.59±27.64 a	5.13±1.47 a	6.60±2.15 b	47.47±10.51ab
First	T2	9.57±0.34 a	8.25±0.43 a	80.43±3.87 a	3.8±0.80 a	4.58±1.47 b	59.65±9.01 a
drainage	CK1	9.67±0.23 a	5.56±0.55 b	54.49±5.42 b	3.8±1.70 a	21.15±2.22 a	41.19±6.57 b
	CK2	9.29±0.16 a	5.04±0.90 b	49.42±8.77 b	3.05±0.53 a	20.65±3.41 a	39.91±3.92 b
	T1	8.69± 0.10 b	8.18±0.96 a	80.14±9.37 a	5.68±1.24 a	10.78±1.29 c	47.88±4.73 a
Second	T2	8.83±0.54 ab	8.13±0.69 a	79.63±6.78 a	4.93±0.92 ab	4.65±0.33 c	50.98±2.01 a
drainage	CK1	9.31±0.15 a	6.29±0.99 b	61.67±9.73 b	3.75±0.82 b	27.60±6.50 a	45.22±4.98 a
	CK2	9.17±0.26 ab	4.76±0.39 c	46.67±3.81 c	1.65±0.84 c	20.73±5.12 b	55.25±15.37 a

a, b represents 0.05 significance level

3.2 Changes of salinity and alkalinity index

The pH, EC, SAR, Total alkalinity, RSC and TNa_F of drainage water have the same tendencies of T1 and T2, CK1 and CK2 treatments, as shown in Figure 1. The pH values changing tend of amelioration treatments (T1 and T2) and CK treatments (CK1 and CK2) were consistent. Throughout the growth period of rice, four kinds of drainage treatment levels of pH fluctuated from 8.4 to 9.9. There were fluctuations of EC and SAR in CK1 andCK2 treatments, and T1, T2 reached a steady state after the fourth drainage, the EC, SAR value basically does not change, even if the change is very small amplitude, EC value was fluctuated from1.1 to 1.5, 0.32 to 0.67 (mS•cm^{-1}), SAR from 6.1to 12.4, 2.6 to 4.6, respectively, in T1 andT2 treatments.

The trend of sodium ion content in all treatments was basically the same; however, the content of total sodium ions in the modified drainage gypsum was significantly lower than that in the control. The higher the residual sodium carbonate value, the more carbonate and bicarbonate discharged from the horizontal drainage water, the more favourable soil desalination improved to grow rice.

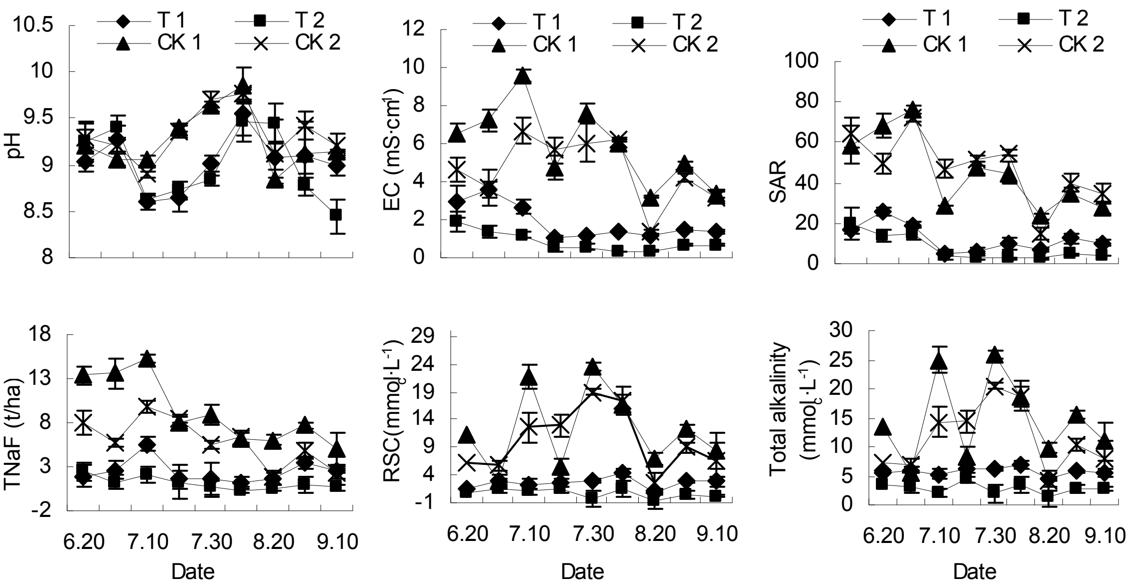

Figure 1: Changes of salinity and alkalinity index

3.3 EC value at 0-10, 10-20cm soil depth

After 1 and 3 months irrigation by different water, the T1 and T2, the Control 1 and Control 2 have no obvious difference on EC ($P > 0.05$), as shown in Figure 2. The EC value of 0-10 and 10-20 cm soil depth showed a decreasing tendency as the increase of time. The EC value of T 1 and T 2 was significant different with Control 1 and Control 2. After irrigation three month by two different waters, the EC of 0-10, 10-20cm soil depth was no significant different between T 1 and T 2, Control 1 and Control 2, but there have significant decrease of T 1 and T 2, compared with Control 1 and Control 2. Three months later, T1 than Control 1, T2than Control 2 smaller than 167.8%, 140.4% at 0-10cm soil depth, 83.9% and 56.7% at 10-20cm soil depth, respectively. After 8 times of horizontal flushing, the decrease of EC in 10 ~ 20cm soil layer of CK1 and CK2 was lower. The results of analysis of variance showed that irrigation water quality had no significant effect on soil EC, but the improvement of the desulphurization gypsum could significantly reduce the EC of plow layer soil.

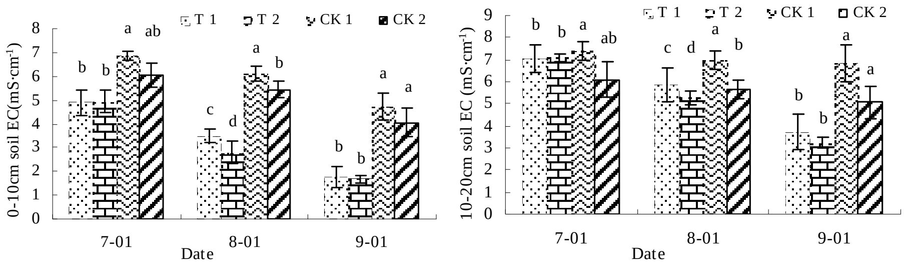

Figure 2: *EC value at 0-10, 10-20cm soil depth*

3.4 Changes of soil salinity and alkalinity

At the end of irrigation, the soil salinity index of different soil layers was analyzed, as shown in Table 3. The SAR of T 1 increased with the increase of soil depth, and the SAR of CK1 in 0 ~ 20 cm soil layer was higher than 30, the result indicated that the soil treated with desulphurized gypsum after a rice growing season, Na + was no downward migration. The highest SAR was in 10 ~ 20cm soil layer of T 2 treatment. The control group (CK 1 and CK 2) had the same trend. The soil pH, EC and SAR of CK 1 were significantly lower than those of T1 in 0-10 cm soil layer, but the treatment of different irrigation water had no significant effect on the salinization index. There was no significant difference in the pH value of the four treatments in the 10-20 cm soil layer. The EC of the modified group (T1 and T2) was significantly lower than that of the control group (CK1 and CK2). The order of the SAR from small to large was: T 1 < CK 2 < T 2 < CK 1. In the 20-40 cm soil layer, the T 1 treatment pH and EC value were significantly less than T2, but the SAR was the oppositechange tendency. The results showed that part soil salinity which was discharged by desulphurized gypsum was drainage by horizontal flushing and desulphurized gypsum improved the permeability of sodic soil, so that a part of salt was infiltrated into the deep soil layer with water vertically. The combination between alternate water management with furrow irrigation method produced the lowest yield.

Table 3: Changes of soil salinity and alkalinity after irrigation with water of different qualities for one year

Depth (cm)	Treatments	pH	$EC_{1:5}$(mS·cm^{-1})	$SAR_{1:5}$ ((mmol$_c$·L^{-1})$^{1/2}$)
0 ~ 10	T 1	9.5 b	6.53b	20.6c
	T 2	9.8 ab	6.53b	11.0d
	CK 1	10.5 a	14.14a	39.6a
	CK 2	10.4 ab	11.97a	28.4b
10 ~ 20	T 1	10.0 a	7.62b	23.0d
	T 2	10.1 a	7.62b	31.1b
	CK 1	10.5 a	14.14a	39.7a
	CK 2	10.5 a	13.06a	26.1c
20 ~ 40	T 1	9.8 b	13.06a	26.3 b
	T 2	10.2 a	10.88b	23.8 c
	CK 1	10.2 a	14.14a	28.5 a
	CK 2	9.6 b	15.23a	23.6 c

4. Conclusions

The different irrigation water quality had no significant effect on the salinization index of the horizontal drainage water quality of the first stirred slurry. But there was significant difference between the two treatments, the pH, EC, Na^+, Ca^{2+} + Mg^{2+} and total alkalinity of surface drainage which was irrigated well-water were significantly higher than those in river irrigation treatment. SAR of irrigation water is an important index to measure the degree of alkalization of soil caused by water. SAR was often used as an important parameter to indicate the content of sodium in irrigation water or soil solution (Chhabra, 1996; Abrol, 1974; Li and Li, 1998). The SAR value of well water is 3.78 (mmol$_c$ ·L^{-1}) $^{1/2}$, which is significantly larger than that of river water 0.34 (mmol$_c$·L^{-1}) $^{1/2}$. Because the well water belongs to shallow saline gentle salty water, the SAR of drainage water was lower than that of river water irrigation. In the Honda period, the saline- sodic index of the treatment level was changed regularly, and the effect of irrigation water quality on the drainage quality and soil conductivity was not significant. The results showed that irrigation water quality had no significant effect on salt content and ion distribution of unmodified soil. Well water (shallow underground gentle salty water) on the soil leaching effect was better than the river, which was combined with Li's et al. findings (Li, 2002). However, Liu and others study results showed that improper gentle salty water irrigation lead to increased soil pH and salt content, resulting to soil salt accumulation (Liu et al, 2015). Therefore, in the paddy period, we chose the well water irrigation to increase the level of salt washing effect, which will help the salt level exclusion; in the Honda period, river water irrigation was chose to prevent secondary soil salinization.

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