XVII th World Congress of the International Commission of Agricultural and Biosystems Engineering (CIGR)

Hosted by the Canadian Society for Bioengineering (CSBE/SCGAB)
Québec City, Canada June 13-17, 2010

CHEMICAL CHARACTERISTICS AND ITS IRRIGATION EFFECT OF DRAINAGE WATER IN DITCHES, YINBEI IRRIGATION DISTRICTS, NINGXIA

WANG SHAOLI[1], XU DI[1], YANG JIANGUO[2], FANG SHUXING[3]

[1]W. SHAOLI, X. DI, China Institute of Water resources and Hydropower Research, Beijing 100048, China, shaoliw@iwhr.com.
[2]Y. JIANGUO, Institute of Agricultural Resources and Environment, Ningxia Academy of Agriculture and Forestry Sciences, Yinchuan 750002, China.
[3] F. SHUXING, Hydrology bureau of Ningxia, Yinchuan 750004, China.

CSBE100080 – Presented at ASABE's 9th International Drainage Symposium (IDS)

ABSTRACT Taking five drainage reuse sites in Yinbei irrigation districts, Ningxia for example, this paper analyzed the chemical characteristics of drainage water in ditches, saline-alkaline hazard and its impact of drainage reuse on soil. The result showed that the hydro-chemical type of drainage water is CNa at Nuanquan farm and ClNa at other four pilots. Every alkaline index in the drainage water was obviously smaller during the middle-late irrigation than those during the early irrigation. Except Qianjin Farm, the saline-alkaline hazard of drainage reuse for irrigation was relatively slight. The dominant soluble salt in the soil was the Chloride-sulfate bearing sodium and calcium. The soil texture had an obvious impact on soil saline-alkaline after irrigation. Salt was not easy to accumulate the lightly textured soils, such as sandy loam. In the area where the rice was planted for a long term, the groundwater level was higher and the better choice was to adopt the paddy-upland rotation system in order to maintain the effect of soil improvement. Adopting rotation systems with anti-saline crops, soil flushing with fresh water, paddy-upland rotation and so on would play an important role in controlling soil water-salt and improving the soil. The effects of drainage reuse for irrigation were good.

Keywords: Drainage reuse for irrigation; Mineralization; Saline-alkaline; Chemical characteristics

INTRODUCTION The shortage of irrigation water is a common problem facing the world. In areas deficient of water, the drainage as a necessary complement to irrigation is an important strategy *for crop growth and became* the main way for resolving contradiction between supply and demand of water resources （Tanji et al.，2002）. The research showed that the use of drainage water for irrigation is not only to reuse the nutrients such as nitrogen and phosphorus in the drainage water, but also to protect the quality of receiving waters for downstream uses and to protect the regional environment and ecology (Giveson et al.,1996; William et al., 2003; Qadir et al., 2004) .

Drainage water is normally of inferior quality compared to the original irrigation water. Especially the drainage water is enriched in dissolved mineral salts. Influenced by artificial activities and geographic location, the concentration of dissolved salts is different from area to area. The research practices in arid areas showed that the brackish drainage reuse for irrigation could not cause soil degradation in short term, but adequate attention needs to be paid to proper irrigation and management measures to minimize long-term harmful effects on crop production, soil productivity and water quality.

Ningxia Irrigation district is situated in inland basin of Northwest China where there is less rainfall and more evaporation, and the Yellow River is the main water supply source. In recent years, with the limitation of water diversion of the Yellow River and sustainable i*ncrease of* water demand, the irrigation water use was in short supply situation. Especially in Yinbei irrigation district in the lower reach of Ningxia irrigation district, there have been *increasingly* severe *water* shortages some places were short of fresh water during irrigation period, whereas other places had no fresh water, the demand which the drainage water is reused for irrigation has been increasing. And for the Yinbei irrigation district with high water table and heavy soil salinization, if lacking the essential measures, the long-term drainage water reuse not only causes the declining of the yield and quality of c*rop, and degradation of soil and water environment, but also aggravates the secondary salinization of soil.*

Taking Yinbei irrigation district as an example, this paper analyzed the chemical characteristics of water in ditches, saline-alkaline hazard and its impact of drainage water reuse on soil, evaluated scientifically the hazard of drainage water reuse for irrigation and proposed the scientific evidence for safety utilization of drainage water.

MATERIALS AND METHODS Five drainage water reuse sites in Yinbei irrigation districts, Ningxia were chosen as seen in Fig.1, they are Nuanquan farm in Helan county, Qianjin farm in Pingluo county, Longhu in Dawukou, Yanzidun and Fifth drainage ditch in Huinong county. The water samples in ditches were collected separately in May, June and July of irrigation period in 2008, and analyzed for hydrogen ion concentration (pH), water mineralization, and principal solute constituents (sodium (Na^+), calcium (Ca^{2+}), magnesium(Mg^{2+}), potassium (K^+), chloride (Cl^-), sulphate (SO_4^{2-}), bicarbonate (HCO_3^-), carbonate (CO_3^{2-})) at soil-water chemical laboratory , Ningxia Academy of Agriculture and Forestry Sciences. Taking into account the main factors influencing local water environment, the water samples were also analyzed for NH_4 COD and heavy metals (Pb As and Cr). At each site, two plots were chosen, and after crop harvest the soil samples from 0-30cm depth were taken and analyzed for pH, EC, principal solute constituents, organic matter and heavy metals (Pb As and Cr). Na^+ and K^+ were determined by Flame Photometry. Ca^{2+} and Mg^{2+} were analyzed by EDTA Complexometry. Cl^- was estimated by Titration with AgNO3. CO_3^{2-} and HCO_3^- were estimated by Double Indicator Method. SO_4^{2-} was analyzed by Ion-Exchange Method. Pb, As and Cr in soils were determined respectively by Acid Digestion–Atomic Absorption Spectrometry, Water Bath–Atomic Fluorescence Spectrometry and Acid Digestion–Flame Atomic Absorption *Spectrometry. The soil organic matter was analyzed by P*otassium Dichromate Capacity Method.

The chemical compositions of water in ditches were analyzed, and the drainage water was classified by O.A.Aleken method (Chen, 1987). The saline hazard of drainage water reuse for irrigation was evaluated using chloride concentration in milligram per litre (mg/l) and salinity index in millimoles per litre (mmol/l). The salinity index (Xu et al., 2000) was expressed in S, if $Na^+>Cl^-+2SO_4^{2-}$, $S=Cl^-+2SO_4^{2-}$, if $Na^+<Cl^-+2SO_4^{2-}$, $S=Cl^-$. The alkaline hazard of drainage water reuse for irrigation was analyzed using sodium adsorption ratio (SAR), soluble sodium percentage (SSP), sodium dianion ratio (SDR), residual sodium carbonate (RSC). All ions were in mmol/l unless otherwise indicated. Mineralization (M) and harmful coefficient (K) in gram per litre were used to analyze the comprehensive hazard of drainage water reuse, in which K=12.4M+SAR. Combined with the soil quality monitoring at each site, the impacts of drainage water reuse on soil environment were evaluated.

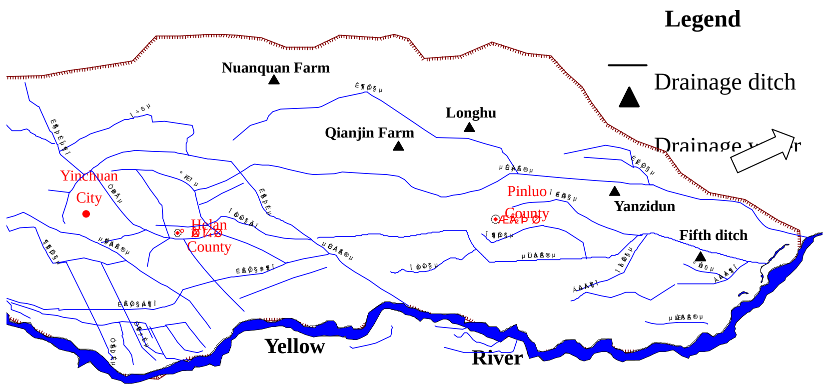
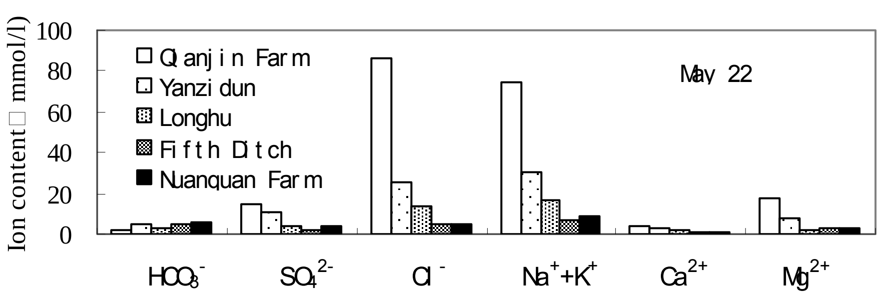


Figure 1 Layout of ditches and location of five drainage water reuse sites in Yinbei irrigation district

RESULTS AND DISCUSSION

Chemical Characteristics of water in ditches The pH values of the water in ditches were generally 7.22–8.45 and varied in a relatively steady state. The water quality was on the weak alkaline, and not more than the upper limit value 8.5 required by irrigation water quality standard (NSPRC ,2005). The pH was the higher and larger than 8.0 during the beginning of irrigation. With the large area of irrigation, the return water of irrigation entered into drainage ditches so that the water in ditches was relatively desalted and pH of water in ditches decreased to some extent.



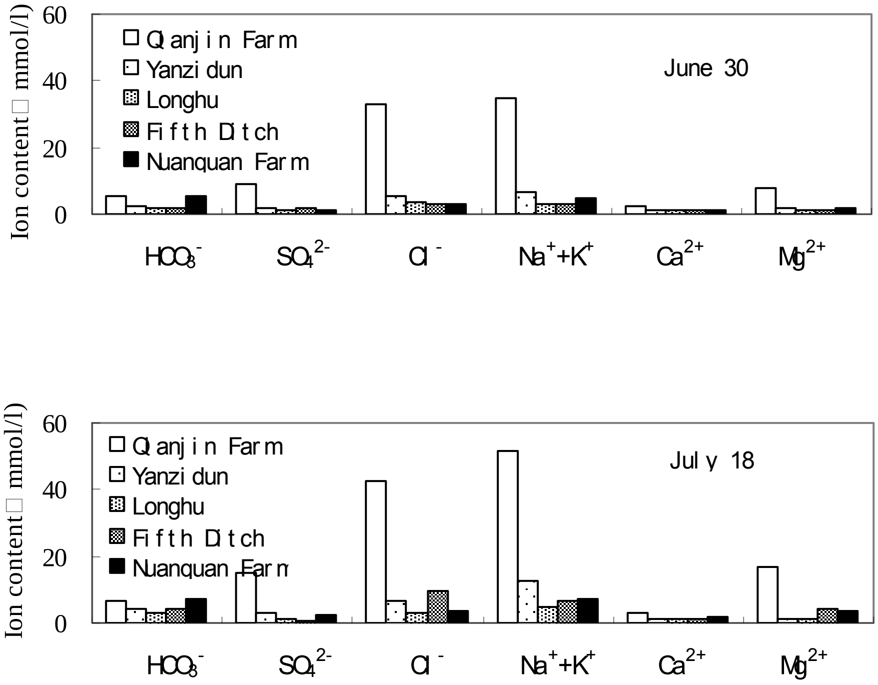


Figure 2 Ion composition and concentration of water in ditches during the different period of irrigation

There were few CO_3^{2-} in the drainage water, and CO_3^{2-} could not be found during the middle and later period of irrigation. K^+ concentrations were far less than Na^+. Figure 2 presented only the variation of 6 major ions in the drainage water (Na^+□Ca^{2+}□Mg^{2+}□HCO_3^-□SO_4^{2-}□Cl^-) at each site, and K^+ was incorporated with Na^+. It can be seen that the drainage water was characterized by high Na^+ and Cl^- concentration, and this might be attributed to the enriched soil salts leached into groundwater and drained into ditches. Na^+ and Cl^- concentration at Qianjin Farm was obviously higher than that at other sites, and the reuse of drainage water might bring more NaCl salts into soil. During the middle and later period of irrigation, Na^+ and Cl^- concentration decreased at each site, particularly at Qianjin Farm, Yanzidun and Longhu. Mg^{2+} concentration was equivalent to Ca^{2+} at Longhu and higher than Ca^{2+} at other sites, whereas Mg^{2+} concentration at Qianjin Farm was obviously higher than that at other sites.

The analysis results for major ions showed that the dominant anion was HCO_3^- at Nuanquan Farm and Cl^- at other sites, the dominant cation was Na^+ at each site. In the ion composition based on Aleken's classification, the drainage water was bicarbonate-sodium type water (C^{Na}) at Nuanquan Farm, chloride-sodium type water □Cl^{Na}□at other sites, in which the drainage water was on low mineralization at Nuanquan Farm, and poor at Qianjin Farm.

Mineralization in the drainage water indicates total concentration of soluble salts, and its change reflects the variation and distribution of chemical ion concentration. And mineralization is also an index to be measured easily in the field, so the variation of ions can be analyzed through the mineralization index. The analysis results for major ions and mineralization in the drainage water showed that the mineralization was significantly related to Ca^{2+}□Mg^{2+}□SO_4^{2-}□Cl^- respectively □r =0.937~0.997, P<0.001□, relatively weak related to HCO_3^-. With the increase of mineralization, Na^+, Ca^{2+}, Mg^{2+}, SO_4^{2-}, Cl^- concentration increased, in which Cl^- concentration increased obviously than Na^+ and SO_4^{2-}, Ca^{2+} and Mg^{2+} had less increase. So, with the increase of mineralization, the disaster of Cl^- and Na^+ to soil saline-alkaline might increase, and Cl^- concentration should be a major factor influencing the mineralization.

Saline hazard of the drainage reuse for irrigation Saline hazard of the drainage reuse for irrigation are mainly NaCl and Na_2SO_4 salts brought into the soil by irrigation water, and could be evaluated by ions concentration and salinity. Due to less SO_4^{2-} in the drainage water, Cl^- was considered as major ion. During the drainage reuse for irrigation, Cl^- concentration at Qianjin farm was the highest, and 3.3 to 8.7 times of the upper limit value 350mg/l required by irrigation water quality standard. The reason might be that the water at sampling point was at the static and less exchange state, and the capability of the pollutants diluted and purified was much weakened. So, the reuse of drainage water at Qianjin farm might cause the soil salinization. For other 4 sites, except Yanzidun and Longhu where Cl^- concentration was 2.6 times and 1.3 times respectively of those listed in the irrigation water quality standard during the beginning of irrigation, Cl^- concentration was generally 0.3 ~ 0.9 times during other period, the reuse of drainage water at these sites might have less salinization hazard to soil. The salinity index also displayed the similar phenomena, that is, the salinity of drainage water at Qianjin farm was the highest between 34.6 and 74 mmol/l, and the salinization hazard of drainage reuse was also high, the next was Yanzidun and Longhu respectively with salinity 30 and 16.2 mmol/l during the beginning of irrigation. During the middle and later period of irrigation, the salinity in the drainage water was generally smaller than 10 mmol/l except Qianjin farm, and the salinization hazard of drainage reuse was small. In sum, the salinization index in drainage water during the middle and later period of irrigation was obviously smaller than that during the beginning of irrigation.

Alkali hazard of the drainage reuse for irrigation When the high-concentration Na^+ in the irrigation water enters into the soil and adsorbed by soil colloids, it is possible to arose the soil secondary alkalinization and degradation, and affect the soil permeability and crop production. Except pH and ion concentration, the combination ratio among ion concentration in the irrigation water is the major index which indicates the soil alkalinization or not, in which SAR, SSP, SDR and RSC indexes are frequently used. The alkalinization index at each site was showed in table 1.

Table 1 Alkalization index of drainage water

Location	SAR($(mmol/l)^{1/2}$)			SSP(%)			SDR			RSC(mmol/l)		
	22-May	30-Jun	18-Jul	22-May	30-Jun	18-Jul	22-May	30-Jun	18-Jul	22-May	30-Jun	18-Jul
Fifth ditch	3.5	1.9	2.7	47.2	38.3	36.6	0.9	0.6	0.6	-2.5	-3.1	-6.8
Nuanquan Farm	3.8	2.8	2.9	46.5	44.2	37.8	0.9	0.8	0.6	-3.8	-0.8	-4.1
Longhu	8.2	1.9	3.0	67.4	37.7	49.0	2.1	0.6	1.0	-4.0	-3.1	-1.5
Yanzidun	9.1	3.9	7.8	58.0	53.4	70.8	1.4	1.1	2.4	-16.3	-3.0	-1.0
Qianjin Farm	15.9	10.8	11.4	63.0	62.8	56.0	1.7	1.7	1.3	-41.4	-15.2	-33.5

It can be seen that the drainage water at Fifth ditch and Nuanquan farm belongs to low-Na water (SAR<7, SSP<60%, SDR<1.5), indicating not much possibility for soil alkalinization when the drainage water was used for irrigation. During the beginning of irrigation, the drainage water at Longhu belongs to middle-Na water (7<SAR<13, SSP>60%, 1.5<SDR<2.5), indicating middle level alkalinization hazard to soil, but the drainage water had less hazard during the middle and later period of irrigation. The drainage water at Qianjin farm belongs to high-Na water during the beginning of irrigation, indicating high alkalinization hazard to soil. The drainage water at Yanzidun belongs to middle-Na water, better than Qianjin farm and poor than other 3 sites. Due to little CO_3^{2-} and low HCO_3^- concentration at each site, REC was negative. Based on the standard of RSC classification□the drainage reuse in this area has no influence on the sodium carbonate accumulation in the soil.

Comprehensive saline-alkaline hazard of the drainage reuse for irrigation The comprehensive hazard of irrigation water to soil and crop mainly depends on total soluble salts contained in the water, and could be estimated using mineralization (M) and harmful coefficient (K), seeing table 2.

Table 2 Mineralization and harmful coefficient of drainage water

Location	Mineralization/□ g/l)			Harmful coefficient K		
	22-May	30-Jun	18-Jul	22-May	30-Jun	18-Jul
Fifth ditch	0.97	0.53	0.91	15.5	8.5	14.0
Nuanquan Farm	1.21	0.79	1.10	18.8	12.5	16.6
Longhu	1.54	0.53	0.60	27.2	8.5	10.5
Yanzidun	3.24	0.81	1.17	49.3	13.9	22.3
Qianjin Farm	6.94	3.44	5.06	101.9	53.4	74.2

Based on irrigation water quality standard, the mineralization of irrigation water should be less than 1g/l in the non-saline area, less than 2g/l in the saline area and appropriately relaxed over good condition. The quality in the drainage water depends on the location, discharge in ditches, and wastewater disposal from upstream. Generally, the mineralization during the irrigation varied greatly, and the mineralization during the beginning of irrigation was more than that during middle and later period of irrigation. The drainage water at Qianjin farm had more than 3g/l mineralization in the different period, and not suitable for irrigation. The drainage water at other 4 sites was in the range of 0.53 and 1.17 g/l mineralization during the middle and later of irrigation, and suitable for irrigation. In the view of harmful coefficient, the drainage water at Qianjin farm was the salt water with K more than 44, and not good for irrigation. The drainage water at other 4 sites was good for irrigation with K less than 25 during the middle and later period of irrigation. In sum, when the drainage water was used for irrigation, the saline-alkaline hazard existed during the beginning of irrigation, and reduced during the middle and later period of irrigation.

Other toxic matters of water in ditches According to the environmental quality standards for surface water□NSPRC,2002□, the organic pollutant COD_{Cr} in the drainage water was in I-III class level at most time except Qianjin farm. The ammonium nitrogen index reached II *class* level water, the heavy metals such as Pb, As, Cr reached I class level water. There existed no heavy metals pollution. Except fifth ditch (main ditch), the drainage water from branch ditches was used for irrigation at other 4 sites, and the organic pollutants were obviously small due to less affected by the wastewater of small and medium-sized enterprises. COD_{Cr} was far less than upper limit value 300mg/l (upland crop), the heavy metals such as Pb, As, Cr were also far less than the standard of irrigation water quality. Thus, in the view of organic pollutants and heavy metals, it can be concluded that the drainage water belongs to non-toxic water.

PRACTICES AND PROBLEMS OF DRAINAGE REUSE The impact of drainage reuse on soil environment and crop depends on many factors, such as the drainage water quality, irrigation method, soil texture and nutrients, groundwater level, groundwater conductivity and soil-water management etc. In order to evaluate the impact of drainage reuse, especially the long-term impact on soil environment, the basic investigation and measurement at each site were carried out. The basic conditions and soil chemical characters at 5 sites were shown in table 3 and table 4.

Table 3 Basic conditions of drainage reuse

Location	Drainage Reuse Pattern	Irrigation Crops	Soil Texture	Irrigation Time
Fifth ditch	Water in main ditch	Wheat, maize and cash crop	Medium loam	About 8 years
Nuanquan farm	Water in branch ditch	Rice, wheat, maize	Sandy loam	About 10 years
Longhu	Water In Branch Ditch	Wheat, Maize	Sandy Loam	About 17 Years
Yanzidun	Water In Branch Ditch	Wheat, Maize, Oil- Sunflower	Sandy	About 20 Years
Qianjin farm	Supplementary *irrigation*	Wheat, maize, oil-sunflower, rice	Medium loam	About 10 years

Table 4 Soil chemical characters at two plots of each site in 2008

Location	Crop	pH	Total salinity (g/kg)	Ion composition of soil salts/(cmol/kg)							
				CO_3^{2-}	HCO_3^-	SO_4^{2-}	CL^-	K^+	Na^+	Ca^{2+}	Mg^{2+}
Fifth ditch	Watermelon	8.05	1.46	0.00	0.46	1.04	0.54	0.05	1.30	0.50	0.49
	Intercrop corn with wheat	7.91	1.02	0.00	0.46	0.92	0.14	0.03	0.87	0.40	0.16
Longhu	Maize	7.81	1.12	0.00	0.41	1.04	0.54	0.08	1.13	0.30	0.16
	Wheat	7.84	1.43	0.00	0.41	1.44	0.14	0.05	1.57	0.30	0.16
Yanzidun	Oil-sunflower	8.10	1.42	0.00	0.46	1.25	0.71	0.05	1.61	0.40	0.25
	Oil-sunflower	8.29	0.68	0.00	0.34	0.19	0.34	0.08	0.61	0.20	0.16
Qianjin Farm	Oil-sunflower	8.07	1.16	0.00	0.46	0.81	0.59	0.05	0.87	0.50	0.33
	Maize	7.77	1.23	0.00	0.46	0.54	0.39	0.05	1.09	0.50	0.25
Nuanquan Farm	Rice	7.91	2.33	0.00	0.46	2.83	0.71	0.08	1.91	0.75	0.99

At 5 sites irrigated by drainage water, the salinity of top soil was 2.33g/kg at the paddy plot of Nuanquan farm, belonging to middle-degree salinization soil, mostly varied from 1 to 2 g/kg at other sites belonging to light-degree salinization soil.

From the ion composition of soil salts, CO_3^{2} concentration was zero, indicating no carbonate hazard in this area. The ratio of □CO_3^{2-}+HCO_3^-□and (Cl^- + SO_4^{2-}) was all less than 1.0, indicating that the bicarbonate was also in the secondary compounds except carbonate. The ratio of Cl^- and SO_4^{2-} was mostly in the order of 0.2~1.0, belonging to Chloride-sulfate soil, among which the salinity of top soil was 0.68g/kg with high Cl^-/SO_4^{2-} ratio of 1.81 at Yanzidun, belonging to sulfate –chloride soil. The cations were mainly dominated by Na^+, and the second was Ca^{2+}, illustrating that the dominant soluble salt in the soil was the Chloride-sulfate bearing sodium and calcium. Based on environmental quality standard for soil□NSPRC,1995□, Pb and Cr concentrations in the soil were far lower than upper limit value, As concentration was in the order of 6.5~16.8mg/kg and also lower than upper limit value of 25mg/kg. Therefore, it is less possible for heavy metals pollution.

The investigation results also showed that the surface ponding water after irrigation lasted the longer time in the clay soil due to poor permeability, and the salt was easily accumulated in the top soil, and the crop yield was often the lower. The soil texture listed in table 4 was medium loam or sandy loam, and light soil texture might be main factors which the salt was not easily accumulated in the soil. The organic matter of top soil at Yanzidun was the highest, and played a good role in meliorating the soil, plus intercrop with oil-sunflower and flushing from the flood of Helan Mountain, the effect of drainage reuse was relatively stable for many years in spite of high mineralization. Compared to other sites, the total salinity of top soil was the higher at Nuanquan farm where the rice was planted continually for a long time so that the groundwater level was high and the salt leaching from soil was slow. From the view of maintaining the soil improvement, it is suitable to adopt rice-upland crop rotation system. The investigation from Nuanquan farm and Qianjin farm also showed that the waterlogging problem was serious for the upland crop due to high water table after the large-area rice was planted. Therefore, the drainage water should be combined with fresh water for irrigation and water table controlling should be considered. In recent years, the practices from Nuanquan farm showed that the mineralization of drainage water was high during the beginning of irrigation, which was not suitable for irrigation, whereas the drainage water was used as a complement to irrigation during middle and later period of irrigation. This was consistent with above-mentioned analysis results.

Lacking of the background level of soil salinity, the soil salt accumulation or desalinization could not be exactly judged after a long-term drainage reuse, the further measurement need to be carried out. Based on the soil investigation for 4 times during 1957~1958, 1962, 1978~1983 and 1985 in Yinhuang irrigation district, Ningxia, the results showed that the soil salinization had been decreasing, and controlled to some extent by salt leaching measures. In sum, under a favorable soil texture and water quality conditions, and assistant drainage measures and crop planting pattern, the drainage reuse could obtain a good effect. Otherwise, the drainage reuse for irrigation is still at large hazard without appropriate measures and might cause negative effect on crop growth and soil environment.

CONCLUSIONS Based on five drainage reuse sites in Yinbei irrigation districts, Ningxia, namely Nuanquan farm, Qianjin farm, Longhu, Yanzidun and Fifth drainage ditch, the chemical characteristics of drainage water, saline-alkaline hazard and its impacts of drainage reuse on soil and crop were analyzed. The result showed that pH of drainage water during the irrigation was between 7.22 and 8.45; the hydro-chemical type is C^{Na} at Nuanquan farm and CI^{Na} at other four sites. Except Qianjin farm, the mineralization in the drainage water was mostly within 2.0g/l, not exceeding upper-limit standard of irrigation water quality required in the saline-alkaline area. Every alkaline index in the drainage water was obviously smaller during the middle-late irrigation than those during the early irrigation so that the saline-alkaline hazard was reduced. Except Qianjin Farm, the saline-alkaline hazard of drainage reuse for irrigation was relatively slight. The drainage reuse at Qianjin farm might cause the higher saline-alkaline hazard, which was not suitable for adopting the drainage water alone for irrigation. The drainage water during the beginning of irrigation has the middle-level saline-alkaline hazard at Yanzidun and Longhu. There was no heavy metal pollution for drainage reuse. The organic pollution indexes in the drainage water were also far smaller than upper-limit standard of irrigation water quality, so the drainage water belongs to non-toxic water.

Through the field survey and soil quality observation, the result showed that the dominant soluble salt in the soil was the Chloride-sulfate bearing sodium and calcium. After adopting the drainage water for irrigation, the soil was not polluted by heavy metals and the soil texture had an obvious impact on soil saline-alkaline. The lightly textured soil, such as sandy loam, was not easy to accumulate the salt in the soil, while the heavily clay and albicans soil was easy to accumulate the salt in the top soil. In the area where the rice was planted for a long term, the groundwater level was high and the better choice was to adopt the paddy-upland rotation system in order to maintain the effect of soil improvement. Adopting rotation system with anti-saline crops, soil flushing with fresh water, paddy-upland rotation and so on would play the important role in controlling soil-water salinity and improving the soil, and the effects of drainage reuse were good. Under a favorable soil texture and water quality conditions, and assistant drainage measures and crop planting pattern, the drainage reuse could obtain a good effect. In order to avoid the higher mineralization in the drainage water during the early irrigation, the first irrigation for wheat should use the smaller irrigation quota.

Acknowledgements

This work was supported financially by the National Key Technology R&D Program in the 11th Five year Plan of china (2006BAD11B06).

REFERENCE

Chen Jingsheng. 1987. Water Environment Chemical. China Higher Education Press, 40-69 (in Chinese)

Giveson Zulu, Masaru Toyota, Shin-ichi Misawa. 1996. Characteristics of water reuse and its effects on paddy irrigation system water balance and the Riceland ecosystem. Agricultural water management,31(3):269-283

National Standards of the People's Republic of China (NSPRC). 1995. Environmental Quality Standard for Soils. *Standards Press* of China (in Chinese).

National Standards of the People's Republic of China (NSPRC). 2002. Environmental Quality Standards for Surface Water. China Environmental Science *Press (in Chinese)*

National Standards of the People's Republic of China (NSPRC). 2005. Standard for Irrigation Water Quality. *Standards Press* of China (in Chinese)

Qadir M, Oster J D. 2004. Crop and irrigation management strategies for saline-sodic soils and waters aimed at environmentally sustainable agriculture. Science of the Total Environment, 323:1-19

Tanji K K□Kielen N C. 2002. Agricultural Drainage Water Management in Arid and Semi-Arid Areas. FAO Irrigation and Drainage Paper No. 61. Rome.

William A J, Atac Tuli, John Letey. 2003. Effect of Travel Time on Management of a Sequential Reuse Drainage Operation[J]. Soil Sci. Soc. Am. J., 67:1122–1126

Xu Di, Lingen Cai, Wang shaoli et al. 2000. Study on Soil and Water Management for Sustainable Agricultural Development. China Water Power Press (in Chinese).