REGULATION OF IRRIGATION WATER QUALITY CAN FURTHER IMMOBILIZE CD IN CONTAMINATED SOILS

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(Received 21st May 2020; accepted 17th Sep 2020)

Abstract. Combined use of surface water and groundwater is a common practice in agricultural activities, but how the immobilize cadmium and its decrease in grains induced with irrigation micro-polluted surface water and groundwater is still poorly understood. This paper presents field experimental results in attempts to reveal the effect of irrigation water quality on cadmium migration and accumulation in winter wheat/summer maize rotation systems in Huabei plain while the cadmium content in 0-10 cm topsoil is 3.8 times, permissible value for agricultural land in China. The results showed there was no obviously influence on cadmium accumulation in grains irrigated with micro-polluted surface water during emergence and seeding stage, but there was significantly increased Cd content and a higher bioaccumulation factor in grains with micro-polluted surface water irrigation during jointing and booting stage. It was found a significantly inhibition for grain weight and uniformity with groundwater irrigation during jointing and booting stage, and winter wheat yield was significantly decreased with micro-polluted surface water irrigation during jointing and booting stage. It could be concluded irrigation water type can further immobilize Cd in mild and moderate contaminated soils, thus micro-polluted surface water can be adopted in seeding stage, and groundwater irrigated in jointing and booting stage at heavy metal pollution arable farmland to minimize the risk of biological chain pollution and food safety.
Keywords: *cadmium, irrigation schedule, micro-polluted surface water, groundwater, bio-concentration factor, bio-accumulation factor*

Introduction

Soil heavy metals are a common abiotic stress inhibiting crop growth. Heavy metals in the soil not only pose a serious threat to the quality of cultivated land and agricultural products, through the food chain they ultimately threat the health of human beings (Yang et al., 2018; Peng et al., 2019; Huang et al., 2019). Due to its estrogen-like activity, exposure levels of 30-50 mu g per day have been estimated for adults and these levels have been linked to increased risk of bone fracture, cancer, kidney dysfunction and hypertension (Satarug et al., 2003; Franz et al., 2008), yet according to a case-control study, cadmium might be related to a decreased risk of ER- and ER-/PR- breast tumors (Amadou et al., 2020). Especially, a very strong Cd contamination in fish organs (gills, posterior intestine, liver, kidneys and skeletal muscle) collected downstream from the metal source (Andres et al., 2000), moreover, the period of ripening of sexual products led to an increase of condition index and to a decrease of Cd concentrations in the whole soft tissues of clams from both sites, hence reflecting the phenomenon of "biological dilution" (Smaoui-Damak et al., 2006). According to the results of the Ministry of Environmental Protection and the Ministry of Land and Resources' National Survey on Soil Pollution Status from China in 2014, the quality of cultivated soil in China is worrying. The total over-standard rate of soil in China is 16.1% and the pollution is mainly caused by inorganic heavy metals. The number of inorganic pollutants accounted for 82.8% of all over-standard points. At present, the over-standard rate of cultivated soil in China has reached 19.4%, among which the moderate to light pollution points account for 94.33% of the total pollution points, mainly including 8 pollutants such as Cd, Ni and Cu (Chen et al., 2017).

The Huabei Plain is an important grain production base and grain production accounts for 23.6% of China grain yield (Yin et al., 2016), which benefits from long-term high water and fertilizer input, agronomy technology and agricultural management since the 1980s (Chen et al., 2014; Wang et al., 2018a). Global climate change has resulted in more uncertainty in agricultural production systems, which cause potential risk to both food security and natural ecosystems (Hundecha and Bardossy, 2005; Wang et al., 2018b). Based on daily precipitation data from 63 national meteorological stations on the Huabei Plain from 1963 to 2012, the precipitation has since been in decline at a rate of 0.8 mm/per annum, the uncertainty of changes is more obvious due to the climate change (Li et al., 2015, 2018). That’s to say, micro-polluted surface water needed to be used for food security, but the average Cd concentration in the micro-polluted surface water and groundwater is 21.6 and 0.5 μg/L respectively (Hu et al., 2016), and approximately 43 times of Cd enters the district via micro-polluted surface water irrigation compared with groundwater irrigation. Rotational irrigation management is therefore essential to block the migration of heavy metals to plant bodies (Li et al., 2014). As in most irrigation areas, groundwater pumped for agricultural irrigation is the main way to solve the shortage of agricultural water for food production in China (Kong et al., 2016; Yin et al., 2017), conjunctive use of micro-polluted surface water and groundwater in this area is to block Cd induced by irrigation with the micro-polluted surface water because the groundwater is relatively less Cd contamination and higher salt content to hinder soluble salts in soil moving into the plant bodies (Li et al., 2014; Arefin et al., 2016; Zhang et al., 2018). The key parameters for managing water usage in the area are bio-concentration factor (BCF) and bio-accumulation factor (BAF) (Safahieh, 2018), we will define BAF here ratio of Cd content in grain and the above-ground plants to the 0 to 40 cm soil layers.

Therefore, the overarching purposes of this paper are (1) to investigate cadmium accumulation in crop-soil system induced with micro-polluted surface water/groundwater irrigation; and (2) to reveal irrigation schedule with micro-polluted surface water/groundwater to ensure grain quality in typical rotation system of Huabei plain, China.

Materials and Methods

The study area

With Chinese economic fast development from 1980s, it has substantially increased water demand for this region which cannot be met from natural recharge to surface and subsurface watercourse as the average annual precipitation in the area was only 550 mm

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1901_107118

since 1980s (Li et al., 2015). Currently, border irrigation with conjunctive use of micro-polluted surface water and groundwater is the dominant irrigation technology in the area. For food security in China, reclaimed water and sewage water from surface rivers participated in agricultural production, a clear increase in the quantity of annual wastewater recycled and reused was observed during the last decade, reaching 3.5 billion m^3 account for 1.60% of total agricultural water consumption in 2013 (Wang et al., 2017). The lasted research results of heavy metal contamination of cultivated soils in Huabei Plain showed exceedance percentages was 12.22% and the proportion of Cd, Ni, Cu, Zn, and Hg increased by 16.07%, 4.56%, 3.68%, 2.24%, and 1.96%, respectively (Shang et al., 2018).

The experiment was carried out in a typical winter wheat /summer maize rotation system area (latitude 35°23′45″ N, longitude 113°59′31″ E, and altitude 70 m) in Weihe irrigation district, Xinxiang city Henan Province, China from 2012 to 2013. The basic physical and chemical properties of the soil of the study area site are shown in *Table 1*. The winter wheat variety AiKang 58 was planted on October 8 and 2012, harvested on June 6, 2013, and the whole growth period was 241 days. According to the soil fertility status and target yield of the experimental site, urea (TN≥46.4%) 300 kg/hm^2 and compound fertilizer (N-P_2O_5-K_2O=16%:22%:10%) 750 kg/hm^2 was applied as base fertilizer, and urea 225 kg/hm^2 was applied as topdressing at the jointing stage. The summer maize variety DanFu 6 was tested, planted on June 8, 2013, harvested on September 26, 2013, the whole growth period was 110 days, and the summer maize jointing stage was applied with urea 600 kg per hectare. The row spacing of winter wheat and summer maize is 20 cm, 60 cm, respectively, and the sowing rate for winter wheat and summer maize is 150 kg, 45 kg per hectare, respectively. The average annual precipitation in the region is 580 mm, of which 70% falls between June and September; the average annual evaporation measured from the 30 cm pan is 1860 mm. Irrigation is usually needed in the dry seasons including January, March, May and June at the withering, jointing and grain-filling stages of the winter wheat, with irrigation amount varying from 750 m^3/hm^2 to 1000 m^3/hm^2 depending on soil moisture and the potential demand of water for the crops. The precipitation occurred in the study period was shown in *Fig. 1*.

Table 1. *Basic physical and chemical properties of the soil at the study area*

Soil layer depth (cm)	**Available Cd** ($mg\cdot kg^{-1}$)	**Total Cd** ($mg\cdot kg^{-1}$)	**pH**	**TN** ($g\cdot kg^{-1}$)	**TP** ($g\ kg^{-1}$)	**OM** ($g\cdot kg^{-1}$)	**Soil texture**	**Bulk density** ($g\cdot cm^{-3}$)
0-10	1.6505	2.2678	8.00	0.95	1.16	19.90	Silt clay	1.40
10-20	0.1915	0.3388	8.05	0.46	0.58	9.90	Silt clay	1.41
20-30	0.0345	0.1110	8.10	0.39	0.52	8.60	Silt clay	1.43
30-40	0.0083	0.0852	8.06	0.35	0.46	7.80	Silt clay	1.43

Experimental design

According to local irrigation schedule and production habits, the winter wheat needs supplementary irrigation during emergence stage, jointing stage and booting stage, and the summer maize during seeding stage. Two irrigation water sources were available for the experiments, namely micro-polluted surface water and groundwater (W stands for micro-polluted surface water and T stands for groundwater). WTT represents micro-polluted surface water irrigation at the emergence stage, and groundwater irrigation at

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1901_107118

the jointing and booting stage. CK represents groundwater irrigation at the emergence stage, jointing and booting stage. The field trial was a fully randomized design with three replicates of eight treatments using micro-polluted surface water and groundwater irrigation with border irrigation. Each experiment plot area is 100 square meters. Other management practices during the whole growth season were completely consistent.

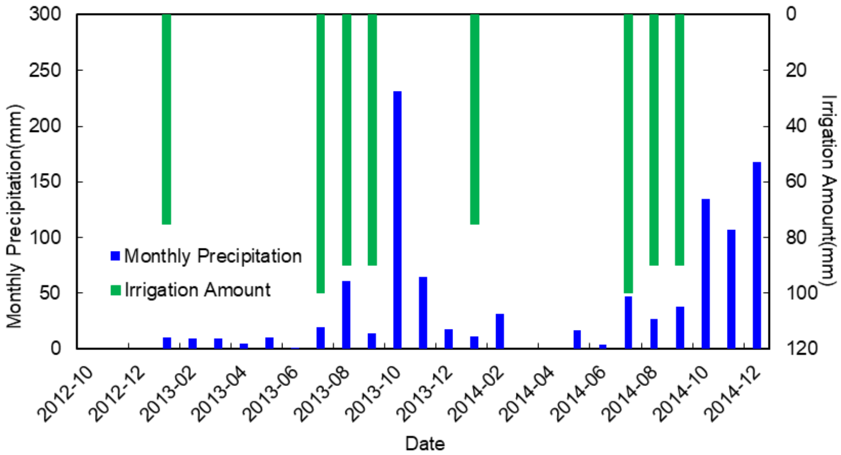

***Figure 1.** Change of monthly irrigation and precipitation within the experimental site*

The experiment design was shown in *Table 2*. The ingredient of irrigation water sources was shown in *Table 3*.

***Table 2.** Experiment design in the study area*

Growth stage	Emergence stage	Jointing stage	Booting stage	Seeding stage
Irrigation date	2012-10-18	2013-4-3	2013-5-2	2013-6-15
Days after sowing	7	174	203	8
Irrigation amount ($m^3.hm^{-2}$)	750	1000	900	900
WTT	MPSW	GW	GW	MPSW
TWT	GW	MPSW	GW	MPSW
TTW	GW	GW	MPSW	MPSW
WWT	MPSW	MPSW	GW	MPSW
WTW	MPSW	GW	MPSW	MPSW
TWW	GW	MPSW	MPSW	MPSW
CK	GW	GW	GW	MPSW
WWW	MPSW	MPSW	MPSW	MPSW

*MPSW means micro-polluted surface water, GW means groundwater

***Table 3.** Composition of irrigation water used in the field experiment*

Irrigation type	Cl^- ($mg·L^{-1}$)	K^+ ($mg·L^{-1}$)	TN ($mg·L^{-1}$)	Pb^{2+} ($mg·L^{-1}$)	Cu^{2+} ($mg·L^{-1}$)	Cd^{2+} ($\mu g·L^{-1}$)	Cr^{6+} ($\mu g.L^{-1}$)	COD_{Mn} ($mg·L^{-1}$)	pH	Salinity ($g·L^{-1}$)
GW	321.27	18.67	17.16	0.0015	0.005	0.5	3.4	40.66	7.30	1.85
MPSW	291.42	13.26	23.17	0.0020	0.006	21.6	2.5	54.35	7.32	1.51
GB*	350	-	-	0.2	1	10	100	200	5.5-8.5	2

*GB represent Standards for irrigation water quality (GB 5084-2005)

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1901_107118

Sampling and measurement

Soil samples were collected before winter wheat planting, winter wheat harvesting, and summer maize harvesting, for detecting available cadmium content and total cadmium content. At each sample, there were further five sub-sampling points scattered uniformly over an area of 100 m^2. At each sampling point, soil was cored using a 3.5 cm Ø soil auger at an interval of 10 cm down to the depth of 40 cm; approximately 100-200 g fresh soil was collected from each interval. The soils cored from the same depth from all the five sampling points at the same experimental plot were pooled and then stored in an aseptic bag before being shipped to the laboratory. The samples were then air dried at room temperature for one week and the electrical conductivity of each sample was measured based on the standard protocol from the 5:1 (w/v) water/soil extract (Rhoades et al., 1989). The pH was measured using a pH meter (PHSJ-5, Leici, Shanghai, China), the EC was measured using a conductivity meter (DDSJ-308A, Leici, Shanghai, China). The available Cd, Total Cd were measured using atomic absorption spectrometer (AA-7000, SHIMADZU, Kyoto, Japan).

Ten square meters was selected as the production area in each treatment, and the indexes of winter wheat yield, 1000-grain weight, dry matter weight and root weight were determined. 100 winter wheat plants were randomly selected to measure the Cd content in different parts (roots, stems, leaves and grain) of the plant. 20 summer maize were randomly selected for each treatment, and the yield, 100-grain weight, dry matter weight, root weight and Cd content in different parts (root, stem, leaves, package, grain) were determined. Dry matter weight was determined by oven drying method, with temperatures set at 105 ℃ for 0.25 h and 70 ℃ for 20 h. The determined method of Cd content in plants was similar to soil samples.

Data processing and calculation

Data were analyzed by Excel 2013 and DPS Statistical software package. Two-way analysis of variance (ANOVA) was performed with the general linear model procedure to calculate the effects of irrigation water type and irrigation period on the investigated parameters. When the F value was significant, a multiple means comparison was performed with Duncan's new multiple range test ($p < 0.05$). The graphs were generated using Microsoft Excel 2013, and the standard error of the mean were calculated and presented in the tables.

Cd accumulation related indicators in soil and plant were calculated from:

$$Cd_g = C_g Y \qquad \text{(Eq.1)}$$

$$Cd_{sl} = C_{sl} Y_{sl} \qquad \text{(Eq.2)}$$

$$Cd_s = 4\rho C_s \qquad \text{(Eq.3)}$$

$$R_{r/s} = \frac{C_r}{C_s} \qquad \text{(Eq.4)}$$

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DOI: http://dx.doi.org/10.15666/aeer/1901_107118

$$BCF = \frac{C_{sl}}{C_s} \quad \text{(Eq.5)}$$

$$BAF = \frac{(Cd_g + Cd_{sl})}{10^6 \times Cd_s} \quad \text{(Eq.6)}$$

where Cd_g, Cd_{sl}, Cd_s, C_g, C_{sl}, C_s, C_r, Y, Y_{sl}, $R_{r/s}$, ρ, BCF, BAF is Cd accumulation in grain (mg/hm^2), Cd accumulation in the above-ground plants (mg/hm^2), Cd accumulation in the 0 to 40 cm layer (mg/hm^2), content in grain (mg/kg), content in the above-ground plants (mg/kg), content in the 0 to 40 cm layer (mg/kg), content in the root (mg/kg), yield of summer maize (kg/hm^2), biomass of the above-ground plants (kg/hm^2), ratio of Cd content in root and 0 to 40 cm soil layer, soil density (g/cm^3), bio-concentration factor (BCF) (Yadav et al., 2017) and bio-accumulation factor (BAF) (Safahieh, 2018) (%), respectively.

Results and Discussion

The effect of different treatments on Cd content in winter wheat and summer maize

The Cd content in roots, stems, leaves and grains of winter wheat under different treatments was shown in *Table 4*. The cumulative characteristics of Cd content in winter wheat plants indicated that the content of Cd in roots was the highest, accounting for 57.94% to 75.52% of the above-ground plants, followed by leaves, stems and grains, and the content of Cd in grains was the lowest, accounting for 1.55% to 4.09% of the above-ground plants.

Table 4. *Cd content in winter wheat plants under different treatments*

Treatment	root (mg·kg^{-1})	stem (mg·kg^{-1})	leaves (mg·kg^{-1})	grain (mg·kg^{-1})
TTW	4.070±0.909ab	0.299±0.084c	0.880±0.106c	0.141±0.028de
CK	2.036±0.104c	0.231±0.029c	0.659±0.052c	0.083±0.001f
WTT	4.300±0.436ab	0.283±0.045c	1.200±0.200b	0.091±0.003ef
TWT	4.200±1.000ab	0.490±0.095ab	1.200±0.100b	0.133±0.009def
TWW	3.453±0.162b	0.490±0.0240ab	1.773±0.214a	0.244±0.048ab
WWT	3.453±0.428b	0.537±0.045a	1.521±0.275ab	0.174±0.010cd
WTW	4.622±0.683a	0.417±0.027b	1.230±0.194b	0.203±0.047bc
WWW	4.808±0.297a	0.581±0.032a	1.230±0.112b	0.263±0.037a
Significance based on two-way analysis of variance (ANOVA) (*F* value)				
W (water type)	1.210*	5.861*	13.491**	35.886**
S (growth stage)	1.604*	0.574*	2.714	0.246
W×S	1.526*	3.716	2.933	6.204*

Note: Different letters after the same column data indicate the difference between the treatments at the 0.05 level (Duncan new complex range method), the same below. **,* Significance at the $p < 0.01$, $p < 0.05$, respectively

The content of Cd in stems and grains treated by WTT was no significantly difference than that of CK treatment, but the content of Cd in roots and leaves treated by WTT was significantly higher than that of CK treatment, which increased by 2.11 and 1.82 times, respectively. The Cd content in grain treated by WTT was significantly

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DOI: http://dx.doi.org/10.15666/aeer/1901_107118

lower than TWW, WWT, WTW and WWW treatment. Furthermore, the Cd content in grain treated by WTT was lower than that of TTW and TWT, which decreased by 35.17%, 31.38%, respectively.

The Cd content in roots, stems, leaves, corn coating and grains of summer maize under different treatments was shown in *Table 5*. The cumulative characteristics of Cd content in summer maize plants indicated that the content of Cd in roots was the highest, accounting for 36.05% to 58.83% of the above-ground plants, followed by leaves, corn coating, stems and grains, and the content of Cd in grains was the lowest, accounting for 0.25% to 0.60% of the above-ground plants. The content of Cd in stems, leaves and grains treated by WTT was no significant difference from that in CK treatment, but the content of Cd in roots and corn coating treated by WTT was significantly higher than that in CK treatment, which increased by 1.90 and 1.59 times respectively. The Cd content in grain treated by WTT was significantly lower than TWT, TWW, WWT, WTW and WWW treatment. Furthermore, the Cd content in grain treated by WTT was lower than that in TTW, TWT, which decreased by 26.47%, 51.75%, respectively. It showed that the Cd content in grains was increased significantly by irrigation with micro-polluted surface water during jointing and booting stage, which may be due to the lower content of chloride ions and higher content of TN in micro-polluted surface water compared with groundwater (Jiang et al., 2019).

Table 5. *Cd content in summer maize plants under different treatments*

Treatment	root (mg·kg^{-1})	stem (mg·kg^{-1})	leaves (mg·kg^{-1})	corn coating (mg·kg^{-1})	grain (mg·kg^{-1})
TTW	1.870±0.110cd	0.176±0.011bc	0.898±0.151b	0.475±0.048de	0.013±0.002c
CK	1.123±0.119f	0.120±0.049c	0.689±0.187b	0.365±0.020e	0.009±0.001c
WTT	2.133±0.208bc	0.124±0.033c	0.780±0.060b	0.580±0.010cd	0.009±0.001c
TWT	2.400±0.200b	0.227±0.064abc	0.920±0.171b	0.637±0.015bcd	0.019±0.004b
TWW	2.753±0.208a	0.266±0.048ab	1.680±0.140a	0.880±0.092a	0.024±0.001ab
WWT	2.333±0.081b	0.252±0.012ab	1.520±0.139a	0.776±0.108ab	0.019±0.001b
WTW	1.528±0.233e	0.276±0.098ab	1.587±0.162a	0.705±0.122bc	0.024±0.006ab
WWW	1.677±0.112de	0.312±0.105a	1.720±0.302a	0.915±0.166a	0.028±0.005a
Significance based on two-way analysis of variance (ANOVA) (*F* value)					
W (water type)	1.462*	3.622*	20.328**	3.524*	13.432**
S (stage)	1.268*	0.665	2.641	0.632	0.123
W×S	1.328*	1.572*	12.347*	1.468*	3.204*

The effect of different treatments on Cd BAF and BCF of summer maize

The Cd BAF and bio-concentration factor of summer maize under different treatments were shown in *Table 6*. There was no significant difference between Cd accumulation in grain of WTT and CK treatment, but the Cd accumulation in grain of WTT was significantly lower than TTW, TWT, TWW, WWT, WTW and WWW treatment, decreased by 21.89%, 50.15%, 57.86%, 47.39%, 58.34% and 61.85%, respectively. And the same rule appeared in above-ground Cd accumulation between treatments, the Cd accumulation in above-ground of WTT was significantly lower than TTW, TWT, TWW, WWT, WTW and WWW treatment, decreased by 26.08%, 44.95%, 49.47%, 48.15%, 52.51% and 56.44%, respectively. The content in the 0 to 40 cm soil layer of WTT treatment was significantly higher than CK, and the content of WTT treatment was obviously lower than TWW, WWT, WTW and WWW, decreased by

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DOI: http://dx.doi.org/10.15666/aeer/1901_107118

1.30%, 1.12%, 1.09% and 1.75%, respectively. And then ratio of Cd content in root and 0 to 40 cm soil layer of WTT treatment was significantly higher than TTW, CK, WTW and WWW, increased by 13.94%, 47.10%, 28.80% and 22.40%, respectively. Especially, BCF of WTT treatment was obviously lower than CK, TWT and TWW, decreased by 28.35%, 12.04% and 32.55%, respectively. But the BAF between WTT and CK treatment was no significant difference, and BAF of WTT was obviously lower than TTW, TWT, TWW, WWT, WTW and WWW, decreased by 26.27%, 44.46%, 49.78%, 47.70%, 50.83% and 54.75%, respectively.

Table 6. *Cd BAF and BCF of summer maize under different treatments*

Treatment	Cd_g ($mg \cdot hm^{-2}$)	Cd_{sl} ($mg \cdot hm^{-2}$)	Cd_s ($kg \cdot hm^{-2}$)	$R_{r/s}$	BCF	BAF
TTW	98.697±10.86d	1530.245±75.25e	3.195±0.005c	3.279±0.160d	0.684±0.032d	0.051±0.002d
CK	77.093±7.71e	1132.695±139.76e	3.181±0.004d	1.977±0.097f	0.984±0.047a	0.038±0.002e
WTT	76.192±5.40e	1133.739±32.62e	3.192±0.004c	3.737±0.183c	0.705±0.032cd	0.038±0.002e
TWT	154.114±8.17c	2022.404±123.90d	3.194±0.003c	4.208±0.206b	0.802±0.037b	0.068±0.004c
TWW	182.968±10.76b	2246.042±69.52bc	3.223±0.003b	4.785±0.234a	1.045±0.048a	0.075±0.004b
WWT	146.902±7.71c	2181.490±103.88cd	3.217±0.006b	4.062±0.198b	0.763±0.035bc	0.072±0.003bc
WTW	183.717±9.40b	2302.374±48.92b	3.216±0.004b	2.661±0.130e	0.550±0.025e	0.077±0.002b
WWW	204.819±6.02a	2514.756±71.07a	3.237±0.004a	2.900±0.142e	0.725±0.033cd	0.084±0.004a
Significance based on two-way analysis of variance (ANOVA) (*F* value)						
W (water type)	51.168**	65.147**	3.416*	12.643**	21.214**	25.617**
S (stage)	12.402*	20.475*	0.714	1.246	0.604	1.574*
W×S	101.625*	123.622*	1.248	8.423*	12.639*	13.978**

The effect of different treatments on yield and grain character of winter wheat and summer maize

The yield and grain character of winter wheat and summer maize under different treatments were shown in *Table 7*. CK treatment of winter wheat has the highest 1000-grains weight, reaching 42.34 g, followed by WTT, TTW, TWT, WWT, WTW, TWW and WWW treatment. Furthermore, CK treatment of winter wheat has the highest yield, reaching 8007.41 kg/hm^2, followed by WTT, TTW, TWT, WTW, WWT, TWW and WWW treatment.

Table 7. *Yield and grain character of winter wheat and summer maize under different treatments*

Treatment	Winter Wheat		Summer Maize		
	10^3 Grains weight (g)	Yield ($kg \cdot hm^{-2}$)	10^2 Grains weight(g)	Cob Weight (g)	Yield ($kg \cdot hm^{-2}$)
TTW	40.29±0.43b	7824.07±59.92ab	26.94±0.17a	25.91±0.21a	7916.84 abc
CK	42.34±0.22a	8007.41±77.05a	26.96±0.19a	26.07±0.25a	8581.02 a
WTT	41.12±0.32ab	7964.81±59.92ab	26.17±0.14ab	25.17±0.28a	8311.87 ab
TWT	39.98±0.22bc	7751.85±103.99b	26.16±0.49ab	23.58±0.32b	8111.24 abc
TWW	38.84±0.95cd	6629.63±78.04de	25.69±0.18b	21.92±0.38c	7687.71 bc
WWT	39.88±0.51bc	6825.93±277.85d	26.21±1.26ab	22.55±0.37c	7869.73 abc
WTW	39.63±0.70bc	7248.15±120.74c	25.75±0.81b	21.89±0.77c	7583.58 bc
WWW	38.18±1.43d	6531.48±97.87e	25.64±0.54b	21.73±1.09c	7327.38 c
Significance based on two-way analysis of variance (ANOVA) (*F* value)					
W (water type)	6.127*	105.735**	1.915	2.684*	86.474**
S (stage)	1.423*	10.474*	0.682	0.547	6.457*
W×S	4.625*	123.612**	1.036	1.376	68.927*

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1901_107118

CK treatment of summer maize has the highest 100-grains weight, reaching 26.96 g, followed by TTW, WWT, WTT, TWT, WTW, TWW and WWW treatment. And cob weight of summer maize in WTT treatment has no significantly difference with CK treatment. Furthermore, CK treatment of winter wheat has the highest yield, reaching 8581.02 kg/hm^2, followed by WTT, TWT, TTW, WWT, TWW, WTW and WWW treatment.

The 1000-grains weight and yield of winter wheat between WTT and CK treatment had no obvious difference, but the values of WTT treatment were significantly higher than TWW, WWW treatment, furthermore, the standard deviation of 1000-grain weight for WTT and CK treatment was only 0.22, 0.32. It indicated that grain filling and yield formation of winter wheat had been slightly affected by the irrigated micro-polluted surface water in emergence stage and groundwater in jointing stage and booting stage, however, yield formation of winter wheat had been obviously affected by the irrigated micro-polluted surface water in jointing stage and booting stage (Gao et al., 2012).

The 100-grains weight and yield of summer maize between WTT, CK, TWT and WWT treatment had no obvious difference, but the values of WTT treatment were significantly higher than that of WTW, TWW and WWW. The results indicated that grain filling and yield formation of summer maize had been stressed from irrigated micro-polluted surface water in the winter wheat booting stage, which may be due to the limited root growth of winter wheat and summer maize under micro-polluted surface water irrigation (Rafiq et al., 2014; Yu et al., 2014).

Correlation analysis between Cd content in summer maize grain and soil layers

The scatter plot and fit curve between Cd content in grain and available Cd, total Cd content in soil layers before summer maize planting were shown in *Fig. 2*. The determination coefficient of Cd content in grain and available Cd in 0-10 cm soil layer was the highest, reaching 0.9095, followed by 10-20, 20-30, 30-40 cm soil layers, and the determination coefficients were 0.8002, 0.2106, 0.0001, respectively. Furthermore, the determination coefficient of Cd content in grain and total Cd in 10-20 cm soil layer was the highest, reaching 0.8081, followed by 0-10, 20-30, 30-40 cm soil layers, and the determination coefficients were 0.7780, 0.4802 and 0.1463, respectively.

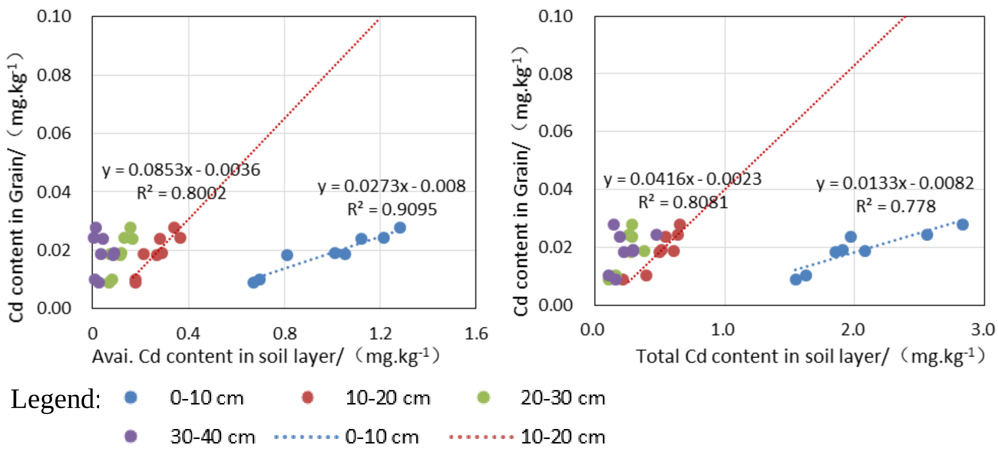

***Figure 2.** Correlation analysis between Cd content in grain and soil layers after summer maize harvest*

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The grains Cd limit value specified in National Food Safety Standards of China (GB 2762-2012) is 0.1 mg/kg. According to our prediction model for available Cd content between soil layers and grains, for ensuring the grain Cd content meets the Standards, the maximum value of available Cd content in 0 to 10, 10 to 20 cm soil layer was 3.95, 1.21 mg/kg, respectively. While we choose the prediction models for total cadmium between soil layers and grains, the maximum of total Cd content in 10-20 cm soil layer was a shocking 2.45 mg/kg, and the corresponding available Cd content in 10-20 cm soil layer was reached 1.24 mg/kg (Zhao et al., 2006; Li et al., 2016). Thus, in order to ensure food security, it is more suitable for us to choose the available cadmium content in 10 to 20 cm soil layer as the prediction index.

Conclusions

Content of Cd in winter wheat and summer maize plants indicated, the value in root was highest, followed by leaves, stem, grain in winter wheat, while the value in root was highest, followed by leaves, corn coating, stem and grain in summer maize.

The Cd content in winter wheat and summer maize grain was lower than the National Standards when crops irrigated with micro-polluted surface water during the emergence stage, and groundwater was adopted during the jointing and booting stage in the study area.

Further work is needed, for example, soil types, fertilizers, precipitation and crop genotypes all affect the expressed model and the threshold range for the available Cd content in 10-20 cm soil layer, thus, it is necessary to study the effects of irrigation water quality on cadmium induced in winter wheat summer maize rotation system in different soil types and irrigation schedules. The threshold of soil environmental quality of producing areas should be set according to local conditions for ensuring the food safety.

Acknowledgements. This work was funded by Central Public-interest Scientific Institution Basal Research Fund (Grant No.: Y2020GH04), the National Key Research and Development Program of China (Grant No.: 2017YFD0800403) and the Agricultural Science and Technology Innovation Program of Chinese Academy of Agricultural Sciences (Grant No.: CAAS-ASTIP).

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