African Journal of Biotechnology Vol. 10(70), pp. 15770-15776, 9 November, 2011
Available online at http://www.academicjournals.org/AJB
DOI: 10.5897/AJB11.848

Full Length Research Paper

Effects of cadmium on the growth and physiological characteristics of sorghum plants

Liu Da-lin*, Hu Kai-qi, Ma Jing-jing, Qiu Wei-wei, Wang Xiu-ping and Zhang Shu-pan

College of Animal Science and Technology, Yangzhou University, Yangzhou, 225009, P. R. China.

Accepted 18 July, 2011

The effects of cadmium (Cd) stress on the growth and physiological characteristics were studied in 3 sorghum species *viz*., sweet sorghum [*Sorghum bicolor* (L.) Moench. *cv*. Hunnigreen], sorghum hybrid sudangrass (*Sorghum bicolor* × *Sorghum sudanense*, *cv*. Everlush) and sudangrass [*Sorghum sudanense (Piper)* Stapf *cv*. Xinjiang]. The results show that low concentration of Cd^{2+} improved the growth of sorghum plants, but high concentrations of Cd^{2+} (50 mg kg^{-1} and 100 mg kg^{-1}) significantly depressed the growth of sorghum plants; Cd stress on chlorophyll synthesis positively correlated with the Cd^{2+} concentration; root activities negatively correlated with the concentration of Cd^{2+} at each growth stage; the malondialdehyde (MDA) contents increased under low concentration of Cd^{2+} (≤ 25 mg kg^{-1}) treatment, but significantly decreased when the concentration of Cd^{2+} was more than 50 mg kg^{-1}.

Key words: Cadmium, sorghum plants, physiological characteristics.

INTRODUCTION

With the rapid industrial development, soil environmental pollution in China has become increasingly serious. Cadmium (Cd) is a highly toxic heavy metal in the environment (Davis, 1984; Guo, 1994). Cd is a non-essential nutrient for plants, and excessive Cd has not only significant adverse effects (Shamsi et al., 2008), but also endangers human health via food chain (Naidu and Harter, 1998). The alleviation or inhibition of Cd damage in plants has therefore caused extensive attention of the whole society (Uraguchi et al., 2009; Wang et al., 2008). Heavy metal has an adverse impact on growth and development of the plants, showing some physiological and biochemical characteristics of damages. To a certain extent, plant growth and physiological characteristics can reflect the adverse impact of heavy metal externally or internally (Zhang and Shu, 2006). The research of the poisoning effect of the heavy metal Cd on plant mainly focuses on food crops such as rice, wheat and maize, but less on sorghum plants, which is often as animal feed sources. In the potted simulation experiment, this study reported the influence of heavy metal Cd on the growth and physiological characteristics of 3 species of sorghum plants, hoping to provide references on the mechanism of heavy metal damaging plants, and phyto-remediation for heavy metal polluted soil.

***Corresponding author. E-mail: jsdalin@163.com. Tel: +86-514-87979037. Fax: +86-514-87350440.**

MATERIALS AND METHODS

Plant material and experimental design

This experiment was performed at pasture and educational park in the Animal Science and Technology Institute of Yangzhou University, Yangzhou, China, from March 2009 to November 2009. Sweet sorghum [*Sorghum bicolor* (L.) Moench. *cv*. Hunnigreen], sorghum hybrid sudangrass (*Sorghum bicolor* × *Sorghum sudanense cv*. Everlush) and sudangrass [*S. sudanense (Piper)* Stapf cv. Xinjiang] were chosen as plant materials, and $CdCl_2{\cdot}2.5H_2O$ (AR) as heavy metal ions donor. Experimental soil was sandy loam, and basic fertility determination showed that it contained organic matter 1.2%, total nitrogen content 0.12%, available nitrogen content 100.4 mg kg^{-1}, available phosphorus content 36.3 mg kg^{-1}, available potassium content 88.7 mg kg^{-1}, and soil total Cd (HNO_3-$HClO_4$-HF extracted, ICP determined) content 0.67 mg kg^{-1}. After grinding to particles less than 3 mm in diameter, 10 kg soil each for 5 groups was mixed with Cd^{2+} at the rate of 5, 10, 25, 50 and 100 mg kg^{-1}, respectively. Meanwhile, base fertilizers (urea, diammonium phosphate and potassium sulfate) were applied on the basis of high-yield land application, which contained 2.0 g nitrogen, 0.26 g phosphorus (P_2O_5) and 0.35 g potassium (K_2O). After sufficient mixing, soil samples were transferred into plastic pots (diameter: 30 cm and height: 25 cm) 2 weeks before sowing. Each treatment was performed in triplicate, and the group without Cd addition acted as the control. These seeds were evenly sown in each pot in mid-May singling at trefoil stage (5 plantlets each pot), and watered according to the soil moisture content during the whole test course. After the plants started growing stably, heights were measured by tapeline every five days, and every treatment got ten measures. The roots and fresh leaves were harvested randomly at seedling, elongation and heading stage and every treatment got three repeats, then cleaned and measured for subsequent physiological indexes.

Biochemical assay

Using spectrophotometry, the chlorophyll content was determined according to the method of Zou (2000). Root activities were determined using TTC method according to the method of Zou (2000), while MDA activities using thiobarbituric acid (TBA), was determined by the method of Li (2009).

Statistic analysis

Data were treated using Excell (Excell, 2003) software. Differences among each treatment as well as interactions between these variables were tested by the SPSS (SPSS11.5) software. Statistical variance analysis and significance test of the data with three replicates were performed using One-Way ANOVA and compared with Duncan's at level 0.05 and 0.01.

RESULTS

Effect of Cd^{2+} on height of different species of sorghum plants

Low concentration of Cd^{2+} treatment could promote the plant height of sweet sorghum and sudangrass (Table 1). When the concentration of Cd^{2+} treatment reached 25 mg kg^{-1}, plant height reached maximum. As the concentration of Cd^{2+} treatment further increased, the plant height of the 3 species of sorghum plants decreased, and had a minimum when the concentration of Cd^{2+} treatment reached 100 mg kg^{-1}. It showed that to a certain extent, low concentration of Cd^{2+} treatment could promote the growth of sorghum plants, and high concentration of Cd^{2+} treatment could inhibit the growth of sorghum plants. In a Cd^{2+} stress environment, sudangrass showed a faster growth rate, followed by sorghum hybrid sudangrass and then sweet sorghum, which might be related to strong resistance to Cd^{2+} of sudangrass.

Effect of Cd^{2+} on chlorophyll contents of different species of sorghum plants

Cd^{2+} affected the chlorophyll contents in leaves of different sorghum plants (Table 2). The chlorophyll contents of the 3 sorghum plants had some certain effects at low concentration of Cd^{2+} treatment (5 and 10 mg kg^{-1}), but the variation was not significant (P>0.05). When the concentration was 50 mg kg^{-1} and 100 mg kg^{-1}, the chlorophyll contents significantly decreased (P<0.05). As growth continued, the chlorophyll contents in the leaves of the 3 species of sorghum plants increased to some degree. At seedling and elongation stage, the chlorophyll content in sorghum hybrid sudangrass was highest, followed by sudangrass and then sweet sorghum. In heading stage, the chlorophyll content in sudangrass was the highest, followed by sorghum hybrid sudangrass, while sweet sorghum had the lowest content.

Effect of Cd^{2+} on root activities in leaves of different species of sorghum plants

At the same growth stages, the root activities of the 3 sorghum plants decreased significantly at high concentration of Cd^{2+} treatment, which showed that high concentration could affect sorghum plants, an effect manifested by the decrease of root activities (Table 3). At different growth stages, root activities of the 3 species of sorghum plants were highest in the heading stage, followed by elongation stage and lowest in seedling stage. Among the 3 species of sorghum plants, sudangrass had the highest root activities, followed by sorghum hybrid sudangrass, while sweet sorghum had the lowest root activities thus reflecting the differences of species and the differences of tolerance to Cd among sorghum species.

Effect of Cd^{2+} on MDA contents in leaves of different species of sorghum plants

Under each concentration of Cd^{2+} treatment, the MDA activities in the leaves of the 3 species of sorghum plants increased first and then decreased, which showed similar trend at different growth stages. The MDA activities were higher in elongation stage than in any other stages, with the same contents in the leaves of the different sorghum species (Table 4).

DISCUSSION

Effect of Cd^{2+} on plant growth of different species of sorghum plants

As a kind of oxidative stress, heavy metal stress affects the growth of plants. Jalil et al. (1994) reported that low concentration of Cd^{2+} can promote the growth of hard wheat, while under a relatively high concentration, the growth of wheat and tillering were both inhibited and the

Table 1. Effect of Cd^{2+} on height of different species of sorghum plants at different times.

Species	Treatment	Plant height (cm) at different time						
		6.12	6.17	6.22	6.27	7.2	7.7	7.12
Sweet sorghum	Cd-CK	5.70±1.21^{bc}	14.78±0.77^{b}	33.82±9.49^{ab}	55.36±12.00^{a}	80.58±7.95^{ab}	99.52±12.27^{a}	144.4±3.84^{a}
	Cd-5	6.38±0.58^{bc}	11.12±0.8^{c}	22.34±5.95^{c}	58.42±13.87^{a}	73.6±6.80^{b}	95±17.34^{a}	114.2±5.11^{d}
	Cd-10	8.46±1.61^{a}	17.50±2.96^{a}	34.5±10.34^{ab}	57.74±9.87^{a}	84.06±6.75^{a}	93.52±16.49^{a}	135.2±4.14^{b}
	Cd-25	7.14±0.91^{ab}	14.28±0.75^{b}	41.1±10.88^{a}	55.32±11.49^{a}	75.76±4.80^{ab}	93.46±11.66^{a}	133±2.91^{bc}
	Cd-50	5.20±1.03^{c}	13.18±2.33^{bc}	26.5±3.85^{bc}	58.26±10.64^{a}	53.52±4.58^{c}	96.18±7.56^{a}	128.8±4.09^{c}
	Cd-100	5.32±0.87^{c}	13.54±1.61^{bc}	26.74±3.31^{bc}	58.42±7.54^{a}	47.36±10.82^{c}	90.91±1.46^{a}	93.8±5.71^{e}
Sorghum hybrid sudangrass	Cd-CK	7±0.7^{b}	14.44±1.54^{bc}	41.5±7.57^{a}	66.22±4.51^{a}	84.32±3.62^{a}	109.51±0.47^{a}	148.8±3.56^{a}
	Cd-5	7.2±0.90^{b}	20.16±3.55^{a}	24.7±5.46^{b}	59.4±1.62^{b}	70.6±7.93^{b}	83.46±4.04^{c}	104.6±3.71^{c}
	Cd-10	7.64±1.52^{b}	12.1±1.09^{c}	45.14±6.51^{a}	66.96±4.77^{a}	86.88±4.21^{a}	119.28±12.28^{a}	144.6±3.97^{a}
	Cd-25	9.52±1.54^{a}	19.64±2.19^{a}	40.2±4.54^{a}	70.04±6.17^{a}	88.16±7.11^{a}	94.68±3.79^{b}	117.4±5.48^{b}
	Cd-50	6.56±1.11^{b}	17.48±3.19^{ab}	37.96±3.98^{a}	56.36±4.19^{b}	73.74±7.71^{b}	95.92±3.94^{b}	116.4±3.51^{b}
	Cd-100	6.18±1.65^{b}	11.5±1.53^{c}	22.6±4.73^{b}	27.44±2.22^{c}	40.8±7.69^{c}	66.82±7.78^{d}	84.8±4.14^{d}
Sudangrass	Cd-CK	6.86±0.81^{bc}	20.54±1.68^{a}	59.14±6.20^{a}	88.26±7.06^{a}	115±4.14^{a}	134.96±3.89^{b}	175±4.12^{b}
	Cd-5	10.56±1.23^{a}	20.6±3.05^{a}	56±3.30a^{b}	80.2±3.23^{b}	118.08±3.24^{a}	146.02±4.09^{a}	181.2±1.92^{a}
	Cd-10	8.18±1.17^{b}	12.1±1.10^{c}	46.24±9.91^{c}	77.5±3.87^{b}	107.3±5.43^{b}	134.9±3.97^{b}	163.6±4.93^{c}
	Cd-25	7.52±2.29^{b}	17.66±2.48^{b}	49.26±5.79^{bc}	68.6±8.04^{c}	93.42±5.63^{c}	115.88±3.80^{c}	144.8±5.26^{d}
	Cd-50	6.98±0.58b^{c}	15.22±1.80^{b}	35.58±8.03^{d}	57.84±4.38^{d}	82.04±5.64^{d}	104.8±4.59^{d}	134.8±4.96^{e}
	Cd-100	5.5±0.81^{c}	9.56±1.03^{c}	14.8±2.27^{e}	23.12±2.14^{e}	24.72±3.63^{e}	54.92±3.59^{e}	84±3.39^{f}

Figures followed by the different lowercase letters of same row means significant difference at 0.05 level.

degree varied among different varieties. Yang et al. (2005) found that when the concentration of Cd^{2+} was 0 ~ 1 mg kg^{-1}, the height of grape increased as the concentration of Cd^{2+} increased, which explained that Cd^{2+} can promote the growth of grape. Liu's (2004) research also showed that corn seedling's height under Cd^{2+} treatment reduced significantly as the concentration of Cd^{2+} increased with prolonged growth period. These researches showed that lower concentration of Cd^{2+} (≤25 mg kg^{-1}) stimulated the increase of sorghum height, which may be related to the certain resistance of sorghum genus plants to Cd, while higher levels of Cd^{2+} inhibited height growth of sorghum genus plant. Thus, lower concentration of Cd^{2+} stress stimulated the growth of sorghum plants to a certain extent, and higher concentrations inhibited their growth.

Reasons for the inhibition effect of heavy metal to plant growth were probably due to: (1) a series of physical and chemical reactions between excess heavy metal and soil components which changes soil properties, thus affecting soil fertility levels (Cieslinski et al., 1996; Chang and Wu, 2005). For example, heavy metal pollution can enhance the fixation of soil phosphorus, which affected the plants absorbing phosphorus, thus influenced the growth of plants (Li et al., 2004; Zhang et al., 2004); (2) heavy metal poisonous effects caused a reduction in plant photosynthesis, thereby reducing the plant water and nutrient absorption, which affected the normal growth and development of plants (Qin et al., 2000).

Effect of Cd^{2+} on chlorophyll contents and root activities of different species of sorghum plants

In plant body, photosynthesis is the most fundamental and most important physiological and biochemical process, and its initial link is chlorophyll

Table 2. Effect of Cd^{2+} on chlorophyll contents of different species of sorghum plants.

Stage	Species	Chlorophyll content (mg g^{-1} FW)	Cd treatment (mg kg^{-1})					
			CK	5	10	25	50	100
Seedling stage	Sweet sorghum	Chl. a	2.03^{ab}	1.94^{c}	2.20^{a}	2.06^{ab}	1.73^{c}	1.63^{d}
		Chl. b	0.75^{ab}	0.69^{b}	0.73^{ab}	0.93^{a}	0.69^{b}	0.60^{b}
		Chl. a +b	2.78^{ab}	2.63^{abc}	2.93^{a}	3.00^{a}	2.42^{bc}	2.23^{c}
	Sorghum hybrid sudangrass	Chl. a	2.06^{a}	2.11^{a}	1.98^{a}	2.07^{a}	1.70^{b}	1.39^{c}
		Chl. b	0.79^{ab}	1.01^{ab}	1.25^{a}	1.23^{a}	0.62^{ab}	0.43^{b}
		Chl. a + b	2.86^{ab}	3.12^{a}	3.23^{a}	3.31^{a}	3.31^{bc}	1.82^{c}
	Sudangrass	Chl. a	1.82^{b}	2.15^{b}	2.78^{a}	1.95^{a}	2.84^{b}	2.04^{b}
		Chl. b	0.51^{b}	0.69^{ab}	0.74^{ab}	0.54^{b}	0.98^{a}	0.53^{b}
		Chl. a + b	2.16^{a}	2.35^{a}	2.38^{a}	1.22^{b}	2.39^{a}	1.29^{b}
Elongation stage	Sweet sorghum	Chl. a	2.24^{a}	2.05^{b}	2.26^{a}	1.79^{c}	2.14^{ab}	2.21^{ab}
		Chl. b	0.42^{d}	0.55^{cd}	1.02^{a}	0.71^{bc}	0.85^{ab}	0.89^{ab}
		Chl. a + b	2.67^{c}	2.61^{c}	3.28^{a}	2.50^{c}	3.00^{b}	3.10^{ab}
	Sorghum hybrid sudangrass	Chl. a	2.24^{a}	2.08^{a}	2.18^{a}	1.28^{b}	1.98^{a}	1.37^{b}
		Chl. b	1.81^{a}	0.97^{bc}	1.02^{b}	0.74^{c}	0.82^{bc}	0.46^{d}
		Chl. a + b	4.06^{a}	3.05^{b}	3.20^{b}	2.02^{c}	2.81^{b}	1.83^{c}
	Sudangrass	Chl. a	2.16^{a}	2.35^{a}	2.38^{a}	1.22^{b}	2.39^{a}	1.29^{b}
		Chl. b	0.88^{a}	0.85^{a}	0.72^{b}	0.91^{a}	0.84^{a}	0.53^{b}
		Chl. a + b	3.05^{a}	3.21^{a}	3.10^{a}	2.13^{b}	3.23^{a}	1.83^{b}
Heading stage	Sweet sorghum	Chl. a	2.55^{de}	2.64^{cd}	2.84^{b}	3.24^{a}	2.74^{bc}	2.48^{e}
		Chl. b	1.51^{a}	1.28^{b}	1.25^{b}	1.26^{b}	1.07^{c}	1.15^{bc}
		Chl. a + b	4.06^{b}	3.92^{b}	4.10^{b}	4.50^{a}	3.81^{bc}	3.63^{c}
	Sorghum hybrid sudangrass	Chl. a	2.27^{c}	2.52^{b}	2.75^{a}	2.62^{ab}	2.56^{b}	2.16^{c}
		Chl. b	0.96^{bc}	1.14^{b}	1.57^{a}	1.06^{b}	1.46^{a}	0.79^{c}
		Chl. a + b	3.23^{d}	3.66^{c}	4.32^{a}	3.69^{c}	4.03^{b}	2.95^{d}
	Sudangrass	Chl. a	2.36^{b}	2.53^{a}	2.56^{a}	2.36^{b}	2.33^{b}	2.31^{b}
		Chl. b	1.67^{a}	1.64^{a}	1.15^{b}	0.94^{b}	0.96^{b}	0.86^{b}
		Chl. a + b	4.03^{a}	4.18^{a}	3.71^{b}	3.31^{c}	3.29^{c}	3.18^{c}

Figures followed by the different lowercase letters in the same line means significant difference at 0.05 level.

Table 3. Effect of Cd^{2+} on root activities in leaves of different species of sorghum plants.

Stage	Species	CK	Cd Treatment (mg kg^{-1})				
			5	10	25	50	100
Seedling stage	Sweet sorghum	80.33±1.45^{ab}*	86.37±2.60^{a}	73.00±3.46^{bc}	63.67±2.60^{c}	43.53±0.88^{d}	26.46±2.47^{e}
	Sorghum hybrid sudangrass	86.66±2.58^{a}	91.32±1.15^{a}	85.43±1.45^{a}	70.25±2.30^{b}	65.31±2.30^{b}	45.67±1.55^{c}
	Sudangrass	87.25±2.64^{ab}	91.66±2.02^{a}	79.04±3.21^{b}	76.63±2.33^{b}	60.48±2.08^{c}	34.33±1.76^{d}
Elongation stage	Sweet sorghum	89.24±2.60^{ab}	96.18±1.52^{a}	81.67±2.96^{b}	80.54±1.52^{b}	57.23±2.88^{c}	41.67±2.02^{d}
	Sorghum hybrid sudangrass	97.87±3.46^{a}	103.24±4.51^{a}	90.33±2.02^{bc}	80.57±1.15^{bcd}	77.26±2.33^{d}	60.51±2.02^{e}
	Sudangrass	97.32±1.73^{ab}	103.04±0.57^{a}	91.57±1.73^{b}	81.64±1.45^{c}	67.52±2.88^{d}	50.66±1.85^{e}
Heading stage	Sweet sorghum	103.46±3.84^{a}	104.33±1.21^{a}	116.25±4.35^{a}	88.72±1.85^{b}	61.27±1.75^{c}	57.53±2.51^{c}
	Sorghum hybrid sudangrass	117.33±1.45^{b}	127.33±2.33^{a}	116.46±2.02^{b}	99.24±1.73^{c}	86.53±2.08^{d}	72.81±1.73^{e}
	Sudangrass	136.66±2.40^{b}	149.38±1.15^{a}	128.83±1.76^{b}	115.14±2.08^{c}	93.33±2.47^{d}	73.73±1.66^{e}

Figures followed by the different capital letters of same row means significant difference at 0.05 level.
* Activities of root (μg g^{-1} FW).

Table 4. Effect of Cd^{2+} on MDA contents in leaves of different species of sorghum plants.

Stage	Species	CK	Cd Treatment (mg kg^{-1})				
			5	10	25	50	100
Seedling stage	Sweet sorghum	0.51±0.02^{c}*	0.69±0.02^{b}	0.93±0.02^{a}	0.95±0.06^{a}	0.81±0.02^{ab}	0.72±0.02^{b}
	Sorghum hybrid sudangrass	0.49±0.04^{d}	0.64±0.02^{cd}	1.04±0.04^{ab}	1.24±0.11^{a}	0.81±0.03^{bc}	0.7±0.02^{cd}
	Sudangrass	0.38±0.03^{d}	0.56±0.04^{c}	0.83±0.03^{b}	1.55±0.04^{a}	0.75±0.03^{b}	0.52±0.02^{cd}
Elongation stage	Sweet sorghum	0.85±0.05^{bc}	1.16±0.35^{b}	1.95±0.13^{a}	1.93±0.04^{a}	0.91±0.02^{abc}	0.66±0.05^{bc}
	Sorghum hybrid sudangrass	0.78±0.05^{c}	0.92±0.02^{c}	2.19±0.20^{a}	1.78±0.05^{b}	1.14±0.04^{ac}	0.77±0.03^{bc}
	Sudangrass	0.74±0.02^{c}	1.25±0.06^{b}	1.7±0.09^{a}	1.92±0.08^{a}	1.41±0.06^{b}	0.61±0.03^{c}
Heading stage	Sweet sorghum	0.51±0.03^{c}	0.75±0.05^{b}	1.05±0.06^{a}	0.75±0.07^{b}	0.69±0.01^{b}	0.66±0.02^{b}
	Sorghum hybrid sudangrass	0.82±0.01^{ab}	0.67±0.02^{bc}	1.11±0.05^{a}	0.64±0.04^{c}	0.59±0.04^{c}	0.58±0.04^{c}
	Sudangrass	1.27±0.17^{a}	1.31±0.08^{a}	0.71±0.14^{b}	0.65±0.10^{b}	0.71±0.01^{b}	0.65±0.07^{b}

Figures followed by the different lowercase letters of same row means significant difference at 0.05 level.
* MDA (umol g^{-1} FW).

synthesis and function realization. The results of this study showed that chlorophyll synthesis was affected by Cd stress (Zhu et al., 2008), and with the increase of Cd stress level, the inhibition effect was increasingly severe. Chlorophyll a and chlorophyll b assay showed that under Cd stress condition, chlorophyll a decreased greatly, while the chlorophyll b did not, thus indicating that Cd stress on the influence of chlorophyll synthesis is mainly manifested in the inhibition of chlorophyll a synthesis. The chlorophyll contents showed a similar trend under Cd stress in different growth stages. The reason for changes in chlorophyll contents in the leaves of sorghum plants might be that chlorophyll synthesis was formed under the action of a series of enzymes in proplastid and chloroplast (Stobart and Griffiths, 1985; Wang, 2000). Cd stress inhibited relevant enzymes activities in the leaves of sorghum plants in the process of chlorophyll synthesis, affecting chlorophyll synthesis process and leaf chlorosis, thus leading to the change in chlorophyll contents.

There have been many reports about heavy metal pollution to root activities of Gramineae. For example, through the hydroponic way, Yang et al. (2005) researched the effects of sewage directly irrigated on root and seedlings of wheat. The results showed that the stress of sewage irrigation accelerated the decline of wheat seedling and root, reducing the root number and the root activities significantly. Jiang et al. (2004) research also showed that infected soil made the roots of rice seedling yellow and red, enlarged the rhizome, root color was brown and yellow, while Huang's (2008) research showed that under matrix or soil with Cd^{2+} and Pb^{2+} single or complex, the root activities of Jiao bai significantly decreased.

Under Cd stress, root activities of 3 kinds of sorghum plants all decreased significantly in different growth stages. Underground part and aerial part of plants existed with interdependence and mutual restriction relevance. Roots and leaves of plants not only existed in sink-source relationships in assimilation products, but also in supply-demand relationships between water and inorganic nutrition. Cd stress could directly reduce root activities, impeding water and mineral nutrient absorption and influencing the aerial part of growth by showing a drop in height, leaf area, and tillering number. It might also influence the root growth by reducing the allocation of photosynthesis products to root, thus influencing the photosynthetic capacity in leaf (Foy et al., 1978; Kastori et al., 1992).

Effect of Cd^{2+} on MDA contents in leaves of different species of sorghum plants

Under senescence and stress, plant organs undergo lipid membrane peroxidation because of free radical toxicity, and the product, malondialdehyde, damages cell membrane system severely. In normal circumstances, because of the active oxygen scavenging system in plant body, active oxygen in cells exists at very low levels, so it cannot cause damage. When adversity exceeds a certain degree, the active oxygen scavenging system in plant will be destroyed, and active oxygen ($O_2^-\cdot$, $\cdot OH$, H_2O_2 and $^1O_2$) becomes accumulated (Richter and Schweizer, 1997; Shah et al., 2001), deflating or reducing the structure, activities and contents of active oxygen scavengers such as SOD, POD, CAT etc, which lead to further accumulation of active oxygen, thus destroying the oxygen balance. Meanwhile, the increase of reactive oxygen not only causes or aggravates membrane lipid peroxidation (Filek et al., 2009; Tamas et al., 2009), but also dehydrogenated protein and produces proteins free radicals, causing damage to chain polymerization and membrane system, with the accumulation of MDA acting as an indicator of the degree of damage of membrane system cells (Phindsa et al., 1981). The research results therefore suggest that low concentration of Cd stress treatments increase the MDA contents in leaves of 3 sorghum plants, thus increasing the activities of cell membrane system, while high concentration damages membrane system in cells of sorghum.

Conclusion

Cd^{2+} stimulated the growth of sorghum plants in a certain range, but inhibited significantly when Cd^{2+} content was more than 25 mg kg^{-1}. The synthesis of chlorophyll was restrained by Cd stress, and the inhibition effect became increasingly severe with the increase of Cd stress. The influence of Cd stress was mainly presented as inhibiting the synthesis of chlorophyll a and decreasing the root activities of 3 species of sorghum plants significantly at different growth stages.

Low concentration of Cd^{2+} treatment could promote the MDA contents in the leaves of 3 species of sorghum plants, while at a high concentration of Cd^{2+} (more than 50 mg kg^{-1}), the MDA contents decreased significantly.

ACKNOWLEDGEMENT

This research was supported by Science and Technology Support Plan (Agriculture) Project, Jiangsu, 2010 (E2010308).

REFERENCES

Chang Z M, Wu XH (2005). Difference comparison of three alfalfa varieties resistant to cadmium pollution. Pratacult. Sci., 22(12): 20-23.

Cieslinski G, Neilser GH, Hogue EJ (1996). Effect of soil cadmium applicat ion and pH on growth and cadmium accumulation in roots, leaves and fruit of strawberry plants. Plant Soil, 180: 267-271.

Davis RD (1984). Cadmium-a complex environmental Problem: Cadmium in sludge used as Fertilizer. *Experiment*, 40(12): 117-126.

Filek M, Zembala M, Hartikainen H, Miszalski Z, Komas A, Wietecka-Posluszny R, Walas P (2009). Changes in wheat plastid membrane properties induced by cadmium and selenium in presence/absence of 2,4-dichlorophenoxyacetic acid. Plant Cell Tissue Organ Cult. 96: 19-28.

Foy CD, Chaney RL, White MC (1978). The physiology of metal toxicity in plants. Ann. Rev. Plant Physiol., 29: 511-566.

Guo DF (1994). Lead and cadmium sources in environment and the harms on human and animal. Environ. Sci. Progress, 12(3): 71-76.

Huang KF (2008). Effects of heavy metal cadmium and lead stress on the growth and development of Zizania. Dr yangzhou university graduate paper. pp. 76-78.

Jalil A, Selles F, Clarke JM (1994). Effects of cadmium on growth and the uptake of cadmium and other elements by durum wheat. Plant Nutr., 17: 1839-1895.

Jiang Y, Liang WJ, Zhang YG, Xu YF (2004). Research on effects of sewage irrigation on soil heavy metal environmental capacity and rice growth. China Ecological Agric. J. 12(3): 124-127.

Kastori R, Petrovic M, Petrovic N (1992). Effects of excess lead, cadmium,copper and zinc on water relations in sunflower. *Plant Nutr*, 15: 2427-2439.

Li F, Li MY, Pan XH, Xu YF (2004). Biochemical and physiological characteristics in seedlings roots of different rice cultivars under low phosphorus stress. Chinese J. Rice Sci., 18(1): 48-52.

Li L (2009). Plant Physiology Experimental Guide. Science Press. Beijing.

Liu JX (2004). Effects of cadmium and zinc interaction on corn seedling physiological and biochemical characteristics. Yi Chun college Journal (natural science edition), 26(6): 55-57.

Naidu R, Harter RD 1998. Effect of different ligands on cadmium sorption by and extract ability from soils. Soil Sci. Soc. Am. J., 62: 644-650.

Phindsa RS, Dhindsaa PP, Thorpe TA (1981). Leaf senescence: correlated with increased levels of membrane permeability and lipid peroxidation and decreased levels of superoxide dismutase and catalase. J. Exp. Bot., 32: p. 93.

Qin TC, Ruan J, Wang LJ (2000). Effects of cadmium on plant photosynthesis. Environ. Sci. Technol., 13(supplement): 33-35.

Richter C, Schweizer M (1997). Oxidative stress in mitochondria. Cold Spring Harbor Laboratory Press, 34: 169-200.

Shah K, Kumar RG, Verma S, Dubey RS (2001). Effect of cadmium on lipid peroxidation, superoxide anion generation and activities of antioxidant enzymes in growing rice seedlings. Plant Sci., 161(6): 1135-1144.

Shamsi IH, Wei K, Zhang GP, Jilani GH, Hassan MJ (2008). Interactive effects of cadmium and aluminum on growth and antioxidative enzymes in soybean. Biologia Plantarum, 52: 165-169.

Stobart AK, Griffiths WT (1985). Effects of Cd^{2+} on the biosynthesis of chlorophyll in leaves of barley. Physiol Plant, 63: 293-298.

Tamas L, Dudikova J, Durcekova K, Haluskova L, Huttova J, Mistrik I (2009). Effect of cadmium and temperature on the lipoxygenase activity in barley root tip. Protoplasma, 235: 17-25.

Uraguchi S, Kiyono M, Sakamoto T, Watanabe I, Kuno K (2009). Contributions of apoplasmic cadmium accumulation, antioxidative enzymes and induction of phytochelatins in cadmium tolerance of the cadmium-accumulating cultivar of black oat(Avena strigosa Schreb). Planta, 230(2): 267-276.

Wang L, Zhou Q X, Ding LL, Sun Y (2008). Effect o f cadmium toxicity on nitrogen metabolism in leaves of Solanum nigrum L. as a newly found cadmium hyperaccumulator. *Hazard. Mater*, 154(1-3): 818-825.

Wang Z (2000). Plant Physiology. China Agriculture Press. Beijing.

Yang JF, Bu YS, Guo XY (2005). Research on effects of soil exogenous cadmium and lead pollution on rape growth. *Shanxi Agricultural Science*, 3: 26-28.

Zhang EH, Zhang XH, Wang HZ (2004). Adaptable effects of phosphorus stress on different genotypes of faba-bean. Acta Ecologica Sinica, 24(8): 1589-1593.

Zhang J, Shu WS (2006). Mechanisms of heavy metal cadmium tolerance in plants. J. Plant Physiol. Mol. Biol., 32(1): 1-8.

Zhang YQ, Miao GY, Zhang DY (2005). Effects of sewage irrigation on antioxidant enzymes activities, root and seedling growth in spring wheat. Agric. Environ. Sci. J. 24(4): 662-665.

Zhu JL, Xu ZF, Cao HL, Ye WH (2008). Effect of cadmium on photosynthetic traits in Wedelia trilobata.. Ecol. Environ. 17(2): 657-660.

Zou Q (2000). Plant Physiology Experimental Guide. Agriculture Press. China.