SIMULATION AND PREDICTION OF CD CUMULATION IN SOIL IRRIGATED BY RECLAIMED WATER BASED ON MATLAB

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Abstract: Based on the hypothesis that reclaimed water for irrigating is the cardinal source of heavy metals pollution in soil, and the heavy metals leave from soil mainly by plant harvest, the article constructs a differential equation and simulates the cumulation of Cd in wheat soil of southeast suburb in Beijing based on simulink of matlab. With the data relative Cd mass proportion in soil as predictor parameter in stems and leaves as response ones, the fitting curves are produced respectively. The curves show that the amount of Cd leave from soil is very small compared with the amount entering into soil via irrigation water. But in the condition of lower concentration in soil, the proportion of Cd left from soil is bigger relatively. The prediction shows that the content of Cd will exceed the national standard of China after 40 years in the condition of the content of Cd in reclaimed water with 10mg • m^{-3} and concentration in soil with 0.1333mg • kg^{-1}, but it should be 100 years if the concentration of Cd in reclaimed water for irrigation reduced to 5mg • m^{-3}.

Keywords: reclaimed water, soil, Cd, simulation and prediction

1. INTRODUCTION

In China, the development of industry and economy is on the way of transition, and agriculture irrigation still consumes the largest water resource, which proportion should be over 65%. The water resource in not abundant in China, the everage of a person's possession of water resource is about $2300m^3$, which equals 1/4 of the world everage. China is the largest agriculture country in the world, in 1998 the area of irrigation land is $0.53\times10^8hm^2$, and in 2006, $0.56\times10^8hm^2$. So the conflict in using water resource shows very consuming in China. The lack of agriculture water resource could reach $300\times10^8m^3$, meanwhile the total lack in China is $360\times10^8m^3$ (M.Ma et al.,2006).

The use of poor quality irrigation water generally can be divided into three stages, before 1957 , the spontaneous period, and since the 1940s, Beijing began to use the surrounding industrial waste water for irrigation, until the late 1950s, domestic awareness of environmental issues is not serious, consider to increase agricultural production from resource of water and fertilizer in town sewage, but also to resolve the issue of way out of industrial wastewater , should be vigorously promoted. Because at that time the sewage emission was little, to the 1963 national sewage irrigation area of $4.2 \times 10^4hm^2$, the environmental impact of sewage irrigation was not obvious. It went into the second phase, 20 late 1960s to the mid-1970s, the rapid development period, in 1957 the Ministry of Agriculture and Ministry of Medical setoff to research the project of sewage irrigation. At this stage, the development of sewage irrigation was rapid, China's sewage irrigated area reached $9.3\times10^4hm^2$ in 1972, and environmental issues during that period gradually aroused community attention, but due to the tense situation of the agricultural water resource and increasing sewage emissions, many farmland near cities increased use of sewage irrigation, in 1976, national sewage irrigation area has increased to $18.0 \times 10^4hm^2$. 1972 date for the third stage, is actively and carefully stage of development, in 1972 in Shijiazhuang national conference of sewage irrigation meeting to draw up a "positive cautious" approach to development, and formulated the interim sewage irrigation water quality standards. China in the early 1980s sewage irrigation area was about 133.3×10^4 hm^2, of which, Tianjin has reached more than15.3×10^4 hm^2 , which was the largest one, Beijing reached 8.9×10^4 hm^2, in addition, Xi'an, Shijiazhuang, Taiyuan, Ji'nan and Shenyang is also famous sewage irrigation district (X.H. Hu, 1999). In 1991, sewage irrigation area developed to $306.7\times10^4hm^2$, and 1980's average annual growth rate reached 11.5 percent. The result of irrigation using reclaimed water is that the soil and environment was degradated and the yield was decreased in some places.

Cd is not indispensable to human. When the environment is polluted, Cd may cumulate in kidney of human, make pathological changes of kidney and liver, and farther, the bones, alimentary canal and vascular pathological changes. Last century the FuShan Event of Japan is due to the Cd pollution of rice and drinking water in FuShan area in Japan. Reclaimed water is a kind of resource refreshed from city sewage, which measures up to certain standards and can apply in some situation. The second treatment water from wastewater treatment factory may be often applied to irrigate for the economic reasons (M.Ma et al., 2006), but its some indexes may not match the standard of irrigation, for example the Gaobeidian Wastewater Treatment Plant in China--the biggest wastewater treatment factory in China, which proportion of Cd in second treatment water is about $10 mg\cdot m^{-3}$ in continuously three years. In China the area of arable land polluted by heavy metal is $2\times10^7 hm^2$， which have 1/6 of the arable area(Q.X. Zhou. 2005)

2. MATERIALS AND METHODS

The absorption coefficient of plant to Cd is higher than Cu, As and Pb, so the transference ability of Cd is stronger in soil-plant system. Cd may cumulate in plant and endanger the health of human in the condition of long-term irrigation using reclaimed water. Research in Xi'an and Beijing in China shows that the irrigation of shot time has not caused heavy metal exceeding the national standards (T.H. Sun.,2005), but research to long-term cumulating is scarce. This research is about simulation and prediction to the cumulating rule of Cd in soil by long-term irrigation using reclaimed water.

A great deal of experiments show that heavy metal stay the surface layer and scarcely transfer down to underground in dry farming soil (T.H. Sun.,2005). Heavy metal in irrigated farming soil can always stay in the cultivated layer for cultivating. Based on the data from references and our experiments (Table 1) and according to data character we can make fitting curves modeled as $y=a \cdot x^b$. The fitting curves produced with the data of relative Cd mass proportion in soil as predictor parameter and in stems and leaves as response ones, which result can be described as Fig 1. Adjusted R^2 shows the fitting is satisfying.

The heavy metal pollution derives mainly from irrigation water but not dry or wet sedimentation in the area where inferior water is used, namely the main source of heavy metal in soil is irrigation water (N.M. Zhang, 2002, M. Del,2002). Here we presume the primary reason of digressions of Cd in soil is the absorption of plant for Cd from soil to the environment (T.H. Sun , 2005), and presume Cd in soil can not cause the plant product decline evidently or it has been remedied by some ways, for example irrigation water or fertilization measure, then the prediction can be processed by means of designing some formula.

Table 1. Content of Cd in soil & plant Unit: mg • kg^{-1}

Sn	Item	Code	Content of Cd				
1	soil-1	x1	0.22	0.48	1.84	9.55	112.50
	wheat stem & leaf	y11	0.93	2.04	6.45	8.00	49.00
	wheat seed	y12	0.08	0.12	0.89	1.30	3.22
2	soil-2	x2	0.24	3.12	4.98	29.50	296.50
	rice stem & leaf	y21	0.15	4.56	11.20	50.00	198.00
	rice seed	y22	0.064	0.54	0.78	1.32	1.57

Partially based on reference [4]

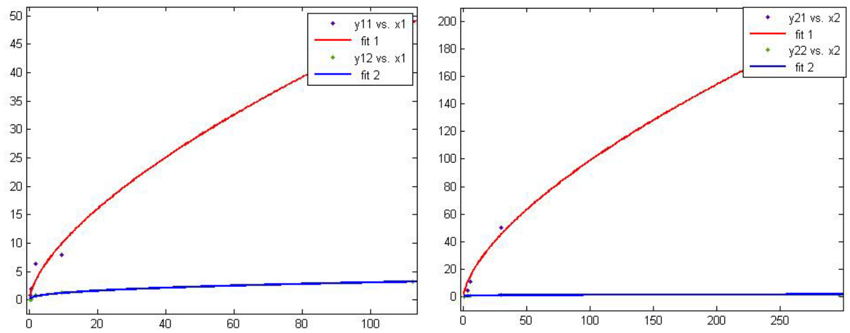

Fig.1. Curve-fitting illustration (wheat & rice)

3. RESULTS

We can do some more appointment according to the cultivation condition in North China that the quantity of irrigation water is 6000m^3 • hm^{-2}; 75% of biomass may leave the soil and seed will be harvested entirely. For wheat, the yield may be about 6.75t • hm^{-2}, stem and leaf in biomass is 4.5t • hm^{-2}, and the arable soil may be about 2250t • hm^{-2}. Then, (1) the mass of Cd leaving the soil:

$$(0.75 \cdot 4.5 \cdot y11 + 6.75 \cdot y12) \cdot 1000$$

$$= (3.375 \cdot y11 + 6.75 \cdot y12) \cdot 1000/mg \cdot hm^{-2}$$

and (2) the mass entering into the soil:

$$6000c/mg \cdot hm^{-2}.$$

here, y11-Cd mass in stems and leaves of wheat, mg • kg^{-1}; y12-Cd mass in seeds of wheat, mg • kg^{-1}; c- Cd mass in irrigation water , mg • kg^{-1}.From this, we can produce a equation, the residue ratio of Cd in soil:

$$K = \frac{x1 \cdot 2.25 \times 10^6 - (6000 \cdot c - (3.375 \cdot y11 + 6.75 \cdot y12) \cdot 1000)}{x1 \cdot 2.25 \times 10^6}$$

here, K--the residue ratio of Cd in soil of year, %; x1--Cd mass in soil , mg • kg^{-1}.

Substituting fitting results in table2 $y11=2.318 \cdot x1^{0.6435}$, $y12=0.5044 \cdot x1^{0.3944}$ for the parameter of K equation, we can have:

$$K = \frac{x1 \cdot 2.25 \times 10^6 - (6000 \cdot c - (7.823 \cdot x1^{0.6453} + 3.405 \cdot x1^{0.3944}) \cdot 1000)}{x1 \cdot 2.25 \times 10^6} \quad (1)$$

On the other hand, treating x1 as a continuous variable we can have:

$$\frac{dx1}{dt} = \frac{6000 \cdot c - (7823 \cdot x1^{0.6453} + 3405 \cdot x1^{0.3944})}{2.25 \cdot 10^6} \quad (2)$$

hear, *t*--time, a. This is an ordinary differential equation with the initial value $x1|_{t=0}=B$ (background value). The background value of ratio of Cd mass in arable soil in the southeast suburb of Beijing City of China is: *B*=0.1333mg • kg^{-1}, which is found by our scene inspecting. The other results on the irrigation water from Gaobeidian Wastewater Treatment Plant is that the content of Cd in the second treatment water is: c=10mg • m^{-3}. Continuous monitor for 3a shows that the content is stable. Then the simulation for *x1* can be made and the result is indicated by table3 and Fig.2 based on Simulink of Matlab. The model of Simulink showed by Fig.3.

Table 2. Result of curve-fitting

Expressions	a (with 95% confidence bounds)	b (with 95% confidence bounds)	Adjusted R^2
$y11=a \cdot x1^b$	2.318 (-0.1408, 4.776)	0.6453 (0.4166, 0.8741)	0.9892
$y12=a \cdot x1^b$	0.5044 (0.1255, 0.8832)	0.3944 (0.2229, 0.5659)	0.9649
$y21=a \cdot x2^b$	5.129 (1.519, 8.739)	0.6423 (0.5162, 0.7684)	0.9964
$y22=a \cdot x2^b$	0.4841 (0.03934, 0.9288)	0.2203 (0.02374, 0.4169)	0.813

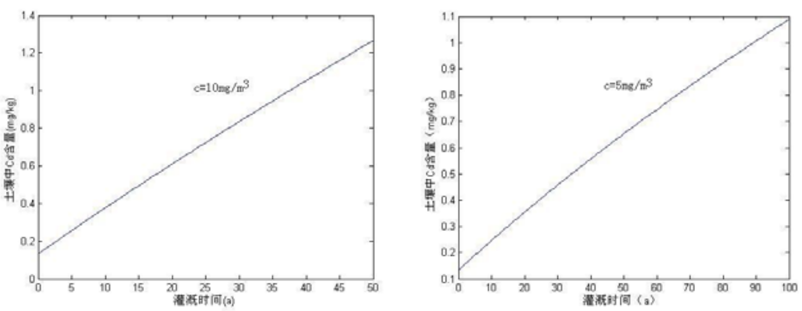

Fig.2. Curve of Cd's concentration in soil

Table 3 showed that the concentration of Cd in soil will exceed the third level standard of Environmental Quality Standard for Soils (GB15618-1995), namely 1.0mg • kg^{-1} after 40 years. From Fig. 2 we can see that the concentration rise linearly, which indicates that the proportion of Cd leaving the soil via plant harvest versus entering the soil is very small. Considering the improving on wastewater treatment and descending the concentration of Cd in irrigation water to c=5mg • m^{-3}, then the result will show that the time is about 100 years after the concentration of Cd reach 1.0mg • kg^{-1}, which validate that the concentration for 5mg • m^{-3} as the standard is rational.

Table3 Forecast of Cd's content in soil

Time of irrigation /a		1	10	20	30	40	50	100
Concentration of Cd in soil /mg • kg^{-1}	c=10mg • m^{-3}	0.1333	0.3531	0.5872	0.8131	1.0321	1.2450	---
	c=5mg • m^{-3}	0.1333	0.2469	0.3548	0.4581	0.5574	0.6532	1.0068

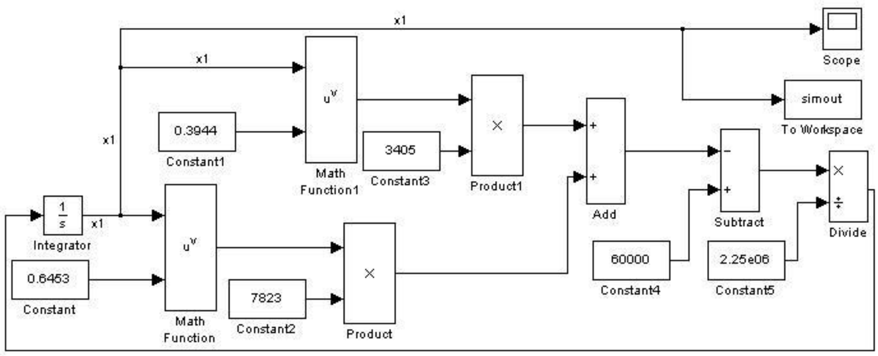

Fig.3. Model of Simulink

The heavy metal in soil comes mainly from irrigation water in dry region in China, which has been focused on by people because heavy metal pollutions have the character of concealment, long-term delitescence, strong toxicity and difficulty to treatment. The research above showed that the Cd proportion leaving the soil with plant harvest is very small compared with entering into with irrigation. The result of simulation showed that the concentration of Cd in soil will exceed the national standard of China, 1.0mg • kg^{-1}, after 40 years if using the second treated water from Gaobeidian Wastewater Treatment Factory, and if the concentration descend below 5mg • m^{-3}, the time can be about 100 years.

4. DISCUSSIONS

Reclaimed water derived from the domestic sewage of city whose contents of organic compound, inorganic compound and suspended particles are very complex, but the concentration is light. So it may not cause serious environmental problems to irrigate with reclaimed water, but there are latent menace to soil environment, so the long-term irrigation using reclaimed water should be attached more importance. This research indicates that the heavy metal pollutions would be inevitable if the wastewater treatment technique not be improved.

The research doesn't take the pH's effects to fittings into account, although the variety of pH is an important factor for the activity and absorptivity to plant, which can be consider at more research. More research can be processed based on this research, such as the choice between the alternate or mix irrigation. Considering the cost of different irrigation technique, it can be researched the feasibility of irrigation using reclaimed water. We can predicate plant restoring time of heavy metal pollution of soil by super-accumulation plant.

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