XVIIth 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

THE EFFECTS OF TREATED WASTEWATER ON SOIL NITROGEN DYNAMICS AND WINTER WHEAT GROWTH UNDER DIFFERENT GROUNDWATER DEPTH

X.-B. QI[1], Z.-D. HUANG[1], P. LI[1], D.-M. QIAO[1], X.-Y. FAN[1]

[1] X.-B. QI, Farmland Irrigation Research Institute, Chinese Academy of Agricultural Sciences, Xinxiang 453003, China, qxb6301@yahoo.com.cn.

CSBE100096 – Presented at ASABE's 9th International Drainage Symposium (IDS)

ABSTRACT The reuse of treated wastewater for irrigation has become increasingly common in some areas of China due to water scarcity. Treated wastewater has high nitrogen and phosphorus content, which have negative impacts on soil and may pollute groundwater. Lysimeter studies were conducted with different groundwater depths (2m, 3m and 4m) and irrigation water (90mm and 120mm) to assess the effects of irrigation with treated wastewater on soil nitrogen dynamics and winter wheat growth. The results indicated that the nitrate nitrogen (NO3-N) concentration in both soil and groundwater increased substantially after irrigation. The increment of NO3-N concentration in groundwater depended on groundwater depth and irrigation water. When 90mm wastewater was applied, NO3-N concentrations observed in groundwater at three groundwater depths (2m, 3m and 4m) increased separately by 34.7%, 24.9% and 20.9%; while when irrigation water increased to 120mm, the values were 58.4%, 39.0% and 27.2% respectively. This reveals that groundwater depth had a significant influence on accumulation of NO3-N in groundwater, and smaller groundwater depth resulted in a higher risk of NO3-N pollution. Our study also reveals that treated wastewater encouraged winter wheat growth and improved the yield.

Keywords: Treated wastewater, Nitrogen, Groundwater depth, Winter wheat, Irrigation.

INTRODUCTION China is one of the countries, most short of water resources over the world. The development of industries and agriculture is severely limited by scarcity of available water. The reuse of wastewater for irrigation is spontaneously or passively considered to guarantee crop production. According to statistics in 2004, the area irrigated with wastewater was 361.8hm^2, about 6.4% of effective irrigation areas over the whole nation. This type of water if not well managed, can have negative impacts on cultivated crops, soil and groundwater environment.

Several researches had investigated the effects of wastewater irrigation on different crops. Residual characteristics of heavy metals in summary corn and winter wheat had been investigated under field conditions (Feng et al., 2003). Water and nitrogen use efficiency for summary corn irrigated with wastewater have been reported (Qi et al., 2003). Other researchers studied the root density and root water uptake under wastewater irrigation (Meng et al., 2003). Qiao et al. (2005) found that heavy metals could be neglected when secondary treated wastewater applied to agricultural irrigation, and suggested that the key point is ecological effect caused by nutrient and salinity. Others researches have investigated treated wastewater irrigation on vegetables. Treated effluent was used for eggplant irrigation through a trickle system to evaluate the accumulation of salts and heavy metals in the soil as well as concentration of the nutrients and heavy metal accumulation (G. A. Ai-Nakshabandi et al., 1997). O. Ai-Lahham et al. (2003) investigated the effect of different treatments of potable and treated wastewater on the quality of tomato fruit in Jordan.

The change of shallow groundwater depth will affect not only nitrogen transport in soil but also the growth of winter wheat. Cavazza L. et al. (1998) found that winter wheat had the largest yield when groundwater depth was 1.25m. If groundwater depth was bigger than 1.25m, yield of winter wheat would decrease without irrigation. Yang J. et al. (2002) and Ba B. et al. (2004) found that the optimal groundwater depth for winter wheat was 1.5m.

Most researches before mainly focused on crop yield affected by groundwater depth. Hence, we performed lysimeter experiments with treated wastewater to evaluate the impact of treated wastewater use on soil and groundwater nitrogen, leaf index area (LAI), plant height, dry mass and yield of winter wheat.

MATERIALS AND METHODS

Experimental design and treatments The study was conducted at Hongmen experimental lysimeters of Farmland Irrigation Research Institute, in the middle of China (latitude 35°15′09″N, longitude 113°55′05″E).Two factors were considered in the experiment, one was groundwater depth, and the other was irrigation amount. There were three levels for groundwater depth and two for irrigation amount. Therefore the experimental design consisted of six treatments, as shown in Table 1.The characteristics of the wastewater are summarized in Table 2. Four irrigations were applied during the growing season, and irrigation dates were the same as sampling dates. Total effective rainfall during growing season was 96.9mm. Fertilizers were applied at rates of 330 N, 112.5 P, 112.5 K (kg ha^{-1}) in March 22, 2006. The winter wheat seeds were planted on October 19, 2005, and harvested on June 5, 2006.

Measurements The plant height, population density, top dry mass and leaf area index (LAI) were determined every ten days. Weather data were collected by an auto climate station (SKYE MINIMET, UK). Soil samples were collected 1d before irrigation and 1d, 2d, 5d, 10d after irrigation from depths of 5, 10, 15, 20, 30, 40, 60, 80, 100, 120, 140, 160, 180 and 200cm and were analyzed for soil water content (θ), ammonium nitrogen (NH_4-N) and nitrate nitrogen (NO_3-N).Soil solution and groundwater samples were gathered by suction cups from depths of 15, 30, 50, 70, 100, 150, 200, 250, 300, 350, 400 and 450cm and were analyzed for pH, EC, NO_3-N and NH_4-N, the same day as before. Soil water content was measured by a drying oven. The NO_3-N and NH_4-N concentrations were determined by Continuous Flow Analytical System (BRAN LUEBBE AA3, German). The pH value and EC were separately determined by an acidometer (PHS-1) and a conductivity meter (DDS-11A).

RESULTS AND DISCUSSION

Plant height Groundwater depth produces a significant effect on plant height of winter wheat. At the same irrigation water level, plant height of the treatment with smaller groundwater depth was larger (Figure 1). All treatments at irrigation water level of 120mm showed significant difference ($p = 0.05$), and that at irrigation water level of 90mm showed extremely significant difference ($p = 0.01$). At the same groundwater depth level, no significant differences between treatments were observed (Figure 2).

Leaf area index Leaf area index (LAI) of all treatments increased rapidly between 140d to 170d after planting, and arrived maximum at 172d, and then decreased gradually until harvest. Among treatments with same irrigation amount, LAI of the treatment with smaller groundwater depth was larger (Figure 3). Smaller groundwater depth enlivened the movement of soil water, and was advantageous for winter wheat to absorb moisture and nutrient from soil. Extremely significant difference ($p = 0.01$) was observed among treatments with lower irrigation water (90mm per irrigation), but no significant difference for those with higher irrigation water (120mm per irrigation).

Dry mass, yield and WUE The treatments which have the maximum and minimum dry mass were separately A_1B_1 (120mm per irrigation water, 2m groundwater depth) and A3B2 (90mm per irrigation water, 4m groundwater depth). At groundwater depth level of 2m, dry mass of treatment with lower irrigation water was larger than that of higher one. However, it was opposite of that at groundwater depth level of 3m and 4m. At the same irrigation water level, yield of all treatments showed significant difference ($p = 0.05$).Groundwater depth had a great effect on dry mass and yield of winter wheat. At the same groundwater depth level, WUE of treatment with lower irrigation water was bigger than that with higher irrigation water. At the irrigation water level of 120mm and 90mm, the maximum WUE of treatments were separately A2B2 (3m groundwater depth) and A1B1 (2m groundwater depth).

NO_3-N in soil profile Average NO_3-N concentrations of 0-200cm soil layer for all treatments are shown in Table 4. NO_3-N concentrations of all layers were about 3-10 mg kg^{-1} before irrigation applied, and 10d after irrigation, Average NO_3-N concentrations of 0-200cm increased significantly. At irrigation water level of 90mm, it increased separately by 11.65, 24.57, 25.07 mg kg^{-1} for treatment A1B1, A2B1, A3B1, and at irrigation water level of 120mm, it increased separately by 18.88, 42.57, 48.84 mg kg^{-1} for treatment A1B2, A2B2, A3B2. Increasing irrigation water increased NO_3-N concentrations of 0-200cm soil layer at the same groundwater depth level, and increasing groundwater depth increased it at the same irrigation water level.

NH_4-N in soil profile Temporal changes of NH_4-N at 0-60 cm soil profile in different treatments are shown in Figure 3. Most of NH_4-N in irrigation water was absorbed by soil matrix 1d after irrigation applied, only a few percolated through macro pore, therefore NH_4-N concentrations increased rapidly. And then NH_4-N concentrations reduced as time went by, and return to that before irrigation. The reduction of NH_4-N in the soil profile can also be explained by the nitrification process. The potential of leaching towards groundwater is negligible. In general, groundwater depth has no significant influence on NH_4-N concentrations.

NO_3-N in soil solution and groundwater NO_3-N concentrations in soil solution and groundwater for six treatments increased separately by 5.50, 53.92, 16.84, 21.61, 11.64, 17.88 mg l^{-1} after irrigation (Figure 6). At the same groundwater depth level, the higher was the irrigation water, the larger was the increment of NO_3-N concentrations in the soil solution and groundwater, vice versa. At the irrigation water level of 90mm, NO_3-N concentrations in groundwater of treatment A1B1, A2B1 and A3B1 increased by 34.67%, 24.94% and 20.88%, and at the irrigation water level of 120mm, that of treatment A1B1, A2B1 and A3B1 increased by 58.42%, 38.98% and 27.21% (Table 5). At the same irrigation water level, the larger was the groundwater depth, the smaller was the increment of NO_3-N concentrations in groundwater, vice versa. It is showed that the variation of NO_3-N in groundwater was opposite to that in soil solution, that is, the variation of NO_3-N in soil solutions reflected that in groundwater. Additionally, smaller groundwater depth raised risks associated with shallow groundwater pollution caused by NO_3-N from leaching and nitrification.

CONCLUSIONS Wastewater irrigation promoted the growth of winter wheat, and had considerable influence on LAI, total dry mass and yield. Our experiment indicated that wastewater irrigation replenished soil nutrients which promoted the development of leaves. At the same irrigation water and fertilizer level, the growth of winter wheat at groundwater depth of 2m was best. This is because smaller groundwater depth enlivened the movement of soil water, and was advantageous for winter wheat to absorb water and nutrient from soil. NO_3-N concentrations of all soil layers increased after irrigation. At the same irrigation water level, the larger was the groundwater depth, the smaller was the increment of NO_3-N concentrations in groundwater, vice versa. It is showed that the variation of NO_3-N in groundwater was opposite to that in soil solution, that is, the variation of NO_3-N in soil solutions reflected that in groundwater. At the same groundwater depth level, the higher was the irrigation water, the larger was the increment of NO_3-N concentrations in the soil solution and groundwater. This is because NO_3-N leaching was restricted by irrigation water, groundwater depth, soil moisture and residual NO_3-N.Smaller groundwater depth promoted the interaction between soil water and groundwater, and the transport of nitrogen in soil-groundwater system was influenced by groundwater depth.

Acknowledgements. This research project was supported by National High-tech R&D Program (2006AA100205-6), National Key Technologies R&D Program (2006BAD17B02), and EC program (023168(SAFIR)).

REFERENCES

Feng S., Qi Z., 2003. Field Experimental study on the residue of heavy metal in summer corn. Journal of Irrigation and Drainage. 22(6), 9–13.

Qi Z., Feng S., Huang G., 2003. Experimental study on effects of irrigation water quality on plant growth of summer corn. Journal of Irrigation and Drainage. 22, 36–38.

Meng L., Zuo Q., 2003. Effects of reclaimed wastewater irrigation on distributions of root-length-density and root-water-uptake-rate in winter wheat. Journal of Irrigation and Drainage. 22(4), 25–29.

Qiao L., Gong H., Zhao W., 2005. Research on application of reclaimed water for agriculture irrigation. Water Saving Irrigation. 4, 13–15.

G. A. Ai-Nakshabandi, M. M. Saqqar, M. R. Shatanawi, M. Fayyad, H. Al-Horani, 1997. Some environmental problems associated with use of treated wastewater for irrigation in Jordan. Agricultural Water Manage. 34, 81–94.

Armon R., D.Gold, M.Brodsky, G.Oron, 2002. Surface and subsurface irrigation with effluents of different qualities and presence of Cryptosporidium in soil and on crops Water. Science and Technology. 46(3), 115–122.

O. Ai-Lahham, N. M. El Assi, M. Fayyad, 2003. Impact of treated wastewater irrigation on quality attributes and contamination of tomato fruit. Agricultural Water Management. 16, 51–62.

A. Pollice, A. Lopez, G. Laera, P. Rubino, A. Lonigro, 2004. Tertiary filtered municipal wastewater as alternative water source in agriculture: a field investigation in Southern Italy. Science of t he Total Environment. 324, 201–210.

C. J. Smith, P. Hopmans, F. J. Cook, 1996. Accumulation of Cr, Pb, Cu, N I, Zn and Cd in Soil Following Irrigation with Treated Urban Effluent in Australia. Environmental Pollution. 94, 317–323.

Ragab R., Pearce G., J. C. Kim, 2001. Proceeding of International Work shop on Wastewater Reuse Management. Seoul, Korea. 2001, 137–146.

Lei Z., Yang S., Ni G., 1992. Water continuum feature in response to the type of groundwater level. Journal of Hydraulic Engineering. 2, 1–6.

Bergstrom L., 1987. Nitrate leaching and drainage from annual and perennial crops in tile drained plots and lysimeters. Journal of Environmental Quality . 16, 11–18.

Lord E., 1992. Modeling of nitrate leaching: nitrate sensitive areas. Aspects of Applied Biology. 30, 19–28.

Ge L., Aly E., 1998. A lumped parameter model for nitrogen transformation in the unsaturated zone. Water Resources Research. 34(2), 203–212.

Cavazza L., Rossi Pissa P., 1988. Effect of water table depth and water logging on crop yield. Agricultural water management, 14(1), 29–34.

Yang J., Wan S., 2002. Crop developing influence of groundwater. Water Saving Irrigation. 2, 36–38.

Ba B., Zheng D., Jia Y., 2004. Influence of water table on the soil water variation and crop yield of winter wheat field. Water Saving Irrigation. 5, 5–9.

Kang L., Qi X., Ma Y., 2007. Effects of reclaimed water irrigation on winter wheat growth under different groundwater tables. Transactions of the CSAE. 23(6), 95–100.

Feng S., Shao H., 2002. Field Experimental study on the residue of heavy metal in wheat crop. Transactions of the CSAE. 18(4), 113–115.

APPENDIX A

Table 1. Details of irrigation treatments for winter wheat

Factor	Treatments					
	A_1B_1	A_1B_2	A_2B_1	A_2B_2	A_3B_1	A_3B_2
Groundwater depth (m)	2	2	3	3	4	4
Irrigation water (mm)	90	120	90	120	90	120

Table 2. Physical and chemical characteristics of wastewater

Sampling Date	pH	EC ($dS\ m^{-1}$)	NO_3-N ($mg\ l^{-1}$)	NH_4-N ($mg\ l^{-1}$)
13/10/2005	7.75	1.98	25.13	0.20
30/12/2005	7.68	2.00	23.18	0.25

22/03/2006	7.81	1.96	31.51	0.08
19/04/2006	7.63	2.03	25.37	0.14

Table 3. Dry matter, yield and WUE of all treatments for winter wheat

Treatments	Dry mass (kg ha^{-1})	Yield (kg ha^{-1})	WUE (kg m^{-3})
A1B1	19404.70a	8573.10a	1.63
A1B2	18556.25b	7388.73b	1.19
A2B1	15177.68c	7314.80c	1.52
A2B2	18550.42a	7912.73c	1.27
A3B1	14963.29c	7115.13a	1.48
A3B2	16951.75b	7603.13b	1.22

Different letters show significant differences at the 95% level for comparison between treatments.

Table 4. Average NO_3-N of 0-200cm soil layer before and after irrigation

Treatments	Average NO3-N concentrations (mg kg^{-1})				
	1d BI	1d AI	2d AI	5d AI	10d AI
A1B1	4.90d	5.10c	4.68e	12.54b	16.55a
A2B1	5.27d	4.79e	7.23c	14.08b	29.84a
A3B1	7.78d	6.84e	9.41c	21.61b	32.85a
A1B2	9.10c	4.94e	7.28d	18.64b	27.99a
A2B2	4.61d	3.48e	9.19c	11.49b	47.18a
A3B2	5.08e	5.83d	9.55c	12.38b	53.92a

Different letters show significant differences at the 95% level for comparison between treatments. BI means before irrigation, and AI means after irrigation.

Table 5. NO_3-N concentrations of groundwater for different treatments before and after irrigation

Treatments	NO_3-N concentrations (mg l^{-1})	
	17 March	31 March
A1B1	26.01b	31.51a
A2B1	115.18b	133.02a
A3B1	236.63b	248.27a
A1B2	115.18b	169.10a
A2B2	139.56b	161.17a
A3B2	177.42b	195.29a

Different letters show significant differences at the 95% level for comparison between treatments.

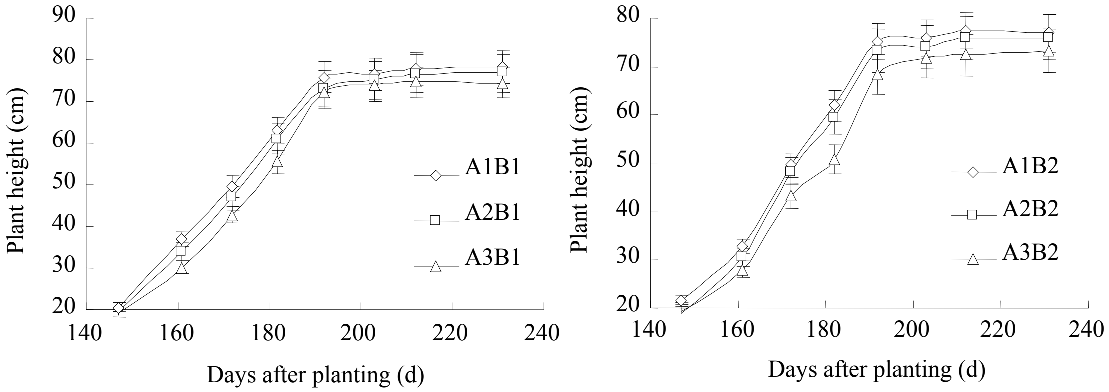

Figure 1. Plant height of treatments with the same irrigation water for winter wheat

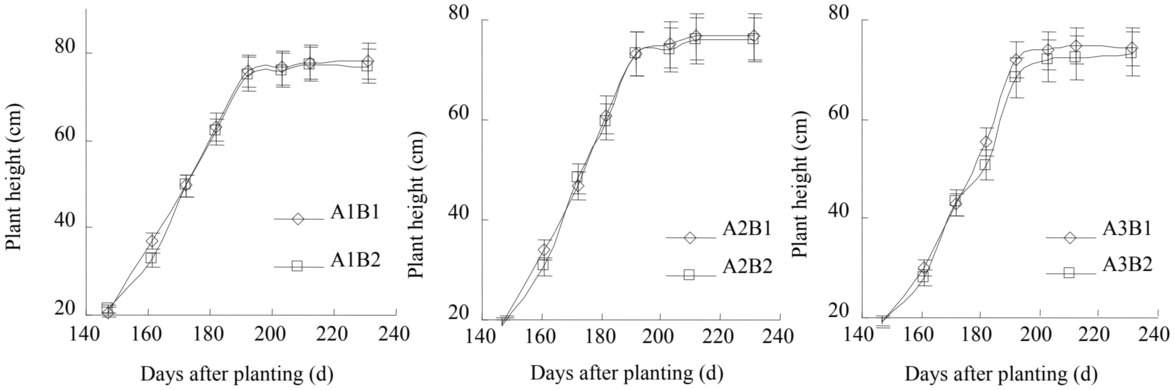

Figure 2. Plant height of treatments with the same groundwater depth for winter wheat

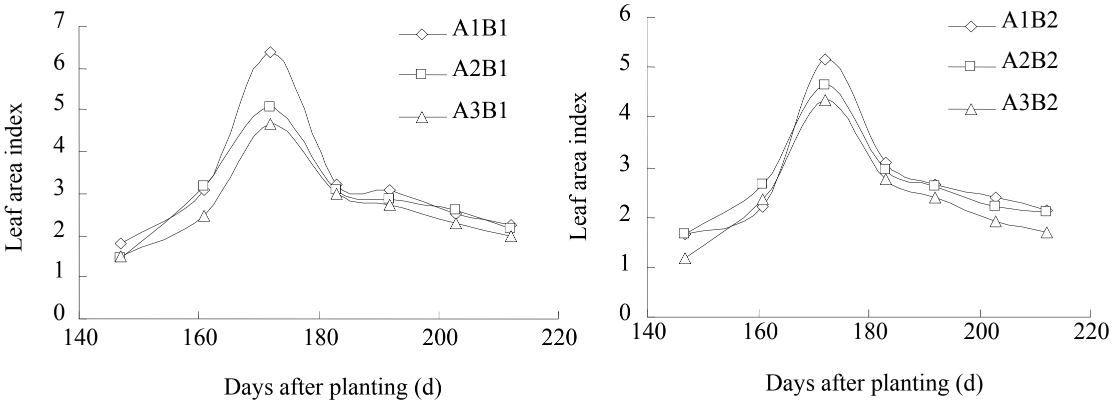

Figure 3. Leaf area index of treatments with the same irrigation water for winter wheat

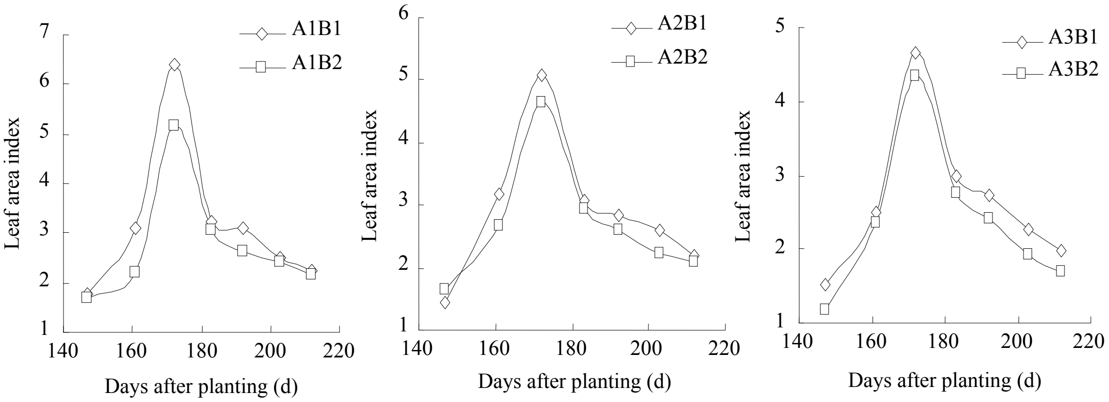

Fig 4. Leaf area index of treatments with the same groundwater depth for winter wheat

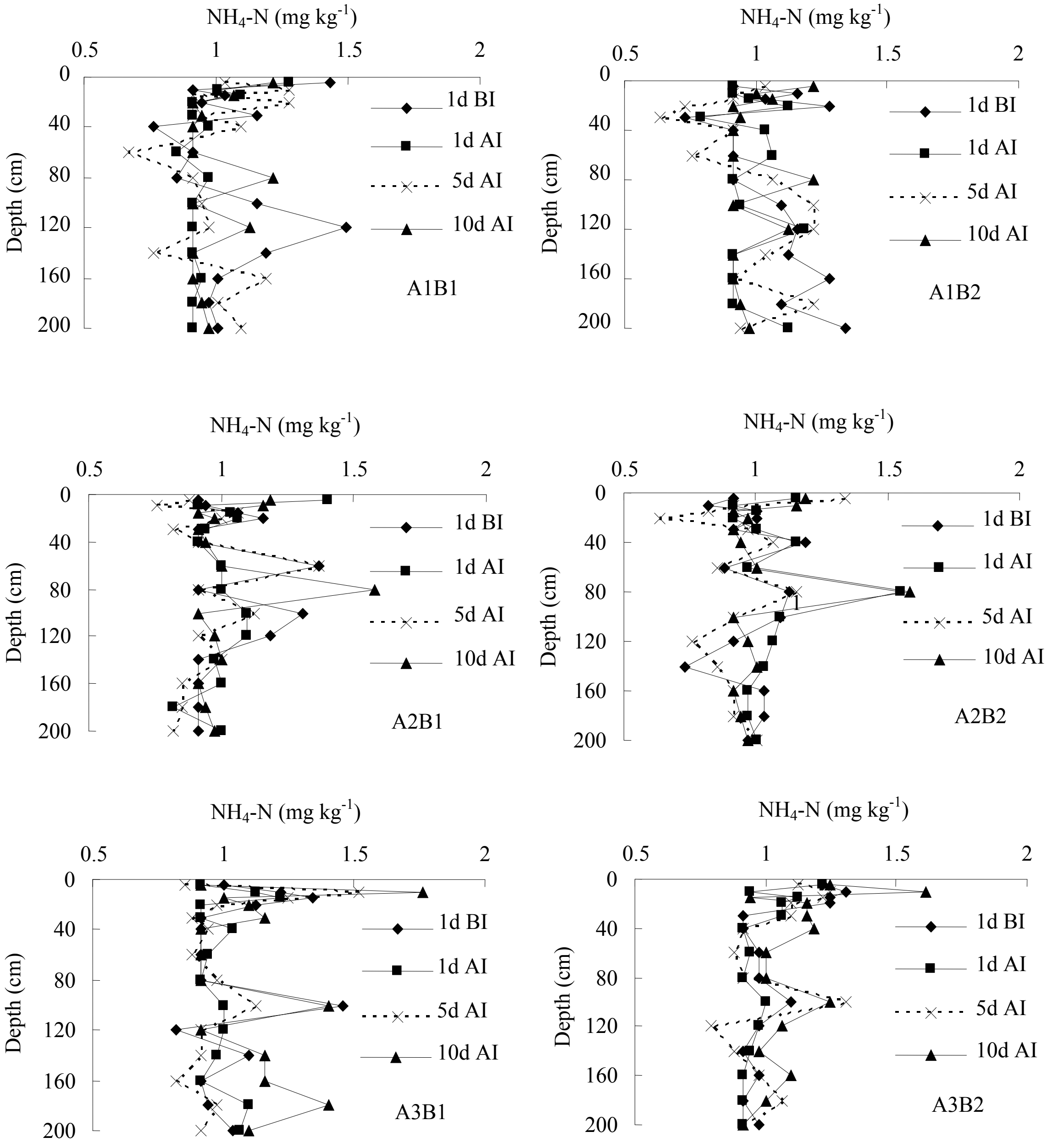

Figure 5. NH_4-N concentrations of soil profile for different treatments before and after irrigation. BI means before irrigation, and AI means after irrigation.

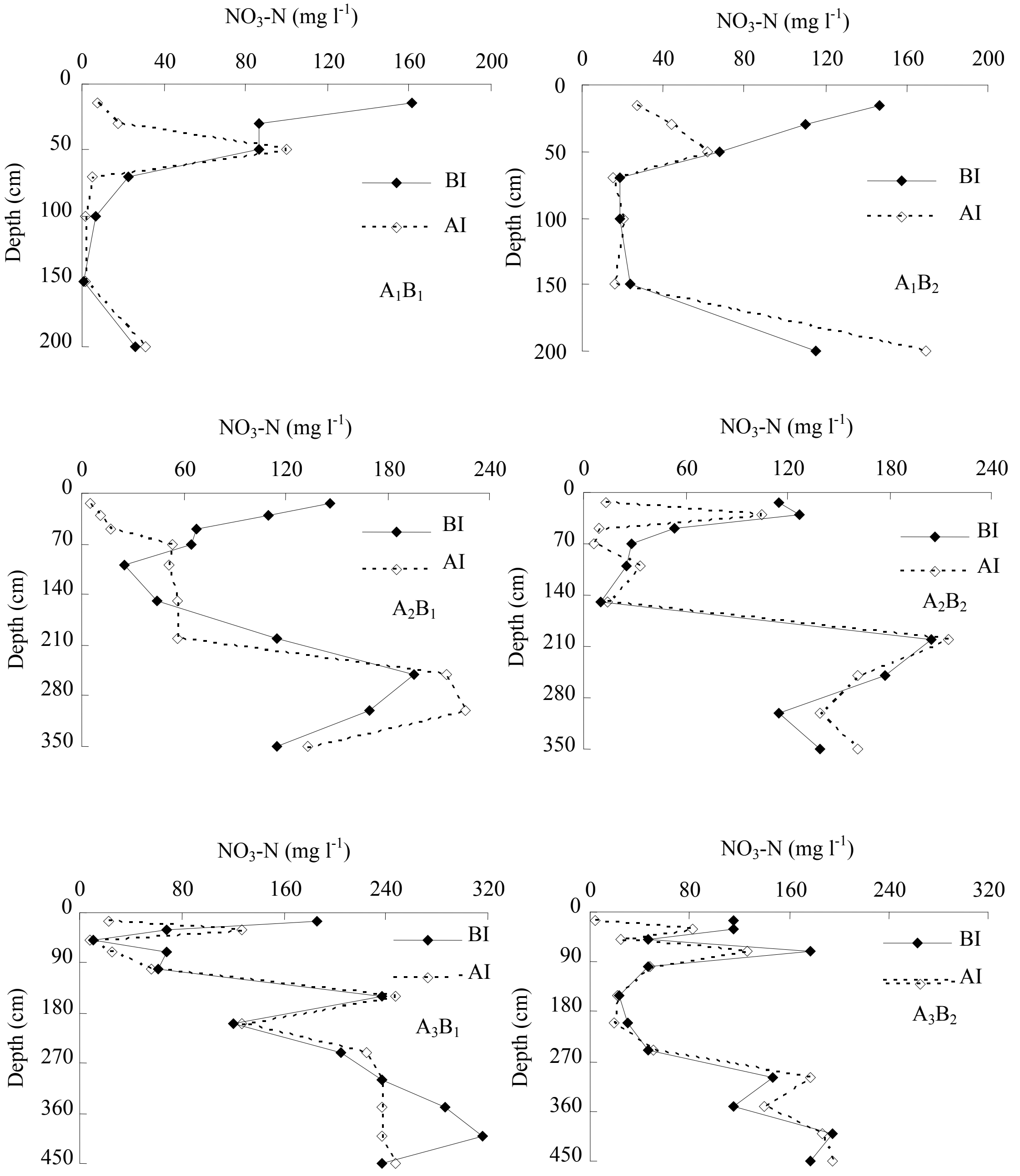

Figure 6. NO_3-N concentrations of soil solution and groundwater for different treatments before and after irrigation. BI means before irrigation, and AI means after irrigation.