Effects of urea types and irrigation on crop uptake, soil residual, and loss of nitrogen in maize field on the North China Plain

T.Y. Ning[1], G.Q. Shao[2], Z.J. Li[1], H.F. Han[1], H.G. Hu[1], Y. Wang[1], S.Z. Tian[1], S.Y. Chi[3]

[1]*State Key Laboratory of Crop Biology, Chinese National Engineering Research Center for Slow/Controlled Release Fertilizers, Agronomy College, Shandong Agricultural University, Tai'an, Shandong, P.R. China*

[2]*Agrotechnology Extension Station, Agricultural Bureau of Weishan County, Jining, Shandong, P.R. China*

[3]*College of Mechanical and Electronic Engineering, Shandong Agricultural University, Tai'an, Shandong, P.R. China*

ABSTRACT

Water and nitrogen managements are both very important to increase crop yield. An experiment was carried out in split plot design to study the effects of urea types (normal urea and coated urea) and irrigation on soil and fertilizer nitrogen use in maize (*Zea mays* L.) field in 2006 and 2007. Irrigation was used as main plot, and urea types were used as split-plot. Two irrigation levels, no irrigation in the whole growth duration and 85 mm irrigation at the blister stage, were designed. There were five nitrogen treatments, which were no nitrogen used as control (N0), normal urea 75 kg N/ha (N1), normal urea 150 kg N/ha (N2), coated urea 75 kg N/ha (C1) and coated urea 150 kg N/ha (C2). The results showed that, at the same level of irrigation and nitrogen, the soil nitrogen contents of the treatments with coated urea (CU) applied were higher in 0~40 cm soil layers, but lower in deeper soil layers, than those with normal urea (NU) applied. Irrigation increased the nitrate losing, but the nitrate loss of CU was lower than those of NU. Using CU with irrigation could increase the nitrogen uptake by maize, and more nitrogen was transfered to grain. At the same nitrogen level, CU had higher N recovery efficiency but lower soil N dependent rate than NU. When applied with CU, the nitrogen release rate was lower and the nitrogen was quickly absorbed by maize, which reduced the risk of nitrogen loss and increased the use efficiency of soil and fertilizer nitrogen. These results suggest that coated urea combined with deficit irrigation should be applied for high yield and nitrogen use efficiency of maize on the North China Plain.

Keywords: water supply; coated urea; *Zea mays*; nitrate nitrogen; nitrogen utilization

Water and nitrogen managements are both very important to increase crop yield. The managements can increase the water and nitrogen use efficiency, save water and fertilizer, and lighten the pollution to environment (Bijay-Singh et al. 1995, Brevé et al. 1998). The fates of nitrogen fertilizer in crop field were uptake by crop, residual in soil, and loss (Cartagena et al. 1995, Sigunga et al. 2002). Because of the low soil adsorption capacity, the nitrate easily loses with the movement of soil water, which can pollute the source of water near the field (Ju et al. 2006). And the loss of nitrate need two conditions, which are a lot of nitrate reserved in soil and a movement of soil water (Yuan and Wang 2000). Suitable irrigation can increase the soil water content and also the nutrient availability, and as a result, increase the crop uptake and efficiency of fertilizer (Rego et al. 1988). So, the study on coupled effects of water and nitrogen, is presently one of the hotspot areas of researches on water and fertilizer use.

Supported by the Nature Science Fund of China, Project No. 30900876; by the Special Research Funding for Public Benefit Industries (Agriculture) of China, Project No. 201103001; by the National Scientific and Technological Support Plan of China, Projects No. 2011BAD11B01 and 2011BAD11B02; and by the Ministry of Agriculture of China, Project No. 948 (2011-G30).

Many articles report the coupled effects of water and nitrogen. Using suitable nitrogen fertilization could reduce the drought stress effect in crops, such as spring barley (Krček et al. 2008) and maize (Kirda et al. 2005, Zand-Parsa et al. 2006, Sun et al. 2009). But most of them used normal urea. The coupled effects of coated urea on changes of soil nitrate nitrogen in different stages and the fate of nitrogen were less reported. Compared with normal urea, coated urea can increase the crop yield, increase the nitrogen use efficiency, and reduce the pollution to field, water and environment (Diez et al. 1996, Ogola et al. 2002). And with the increase of product yield, the cost of CU will be decreased, and it will be broadly applied in crops planted (Shao et al. 2008, Zhang et al. 2001).

The objective of this paper was to study the effects of urea types and irrigation on soil nitrate content in different stages of maize, and to evaluate their effects on crop absorption, soil residual, and loss of nitrogen in a maize field.

MATERIAL AND METHODS

Experiment site. The experiment was carried out in the Experimental Farm of the Shandong Agricultural University (36°10'19''N, 117°9'03''E) located on the North China Plain in 2006 and 2007. The precipitation and air temperature in maize growth stage (June to September) in 2006 and 2007 and the long-term average were shown in Figure 1. The soil of the study area is classified as Cambisols with thick soil layer. It contained 1.3% organic matter, 0.10% total N and had water pH of 6.7. Alkali-hydrolyzable N, Olsen-P and NH_4Ac-K in the soil were 89.8, 52.6, and 88.9 mg/kg soil, respectively.

Experimental design. An experiment, with three replications, was carried out in a split plot design to discuss the effects of urea types (normal urea and coated urea) and irrigation on soil and fertilizer nitrogen use in maize (*Zea mays* L.) field. Irrigation was used as main plot, and urea types were used as split-plot. Two irrigation levels included no irrigation during the whole growth stages (W0) and irrigation with 85 mm through channels at the blister stage (W1). Between the two irrigation plots, there was a 4-m-wide zone without irrigation to minimize the effects of two adjacent plots. There were five nitrogen treatments, which were no nitrogen used as control (N0), normal urea 75 kg N/ha (N1), normal urea 150 kg N/ha (N2), coated urea 75 kg N/ha (C1) and coated urea 150 kg N/ha (C2), respectively. All urea was applied as base fertilizer when the maize was sown. The coated urea (CU) is urea coated in a plastic membrane, which is designed by the Shandong Agricultural University, and made by the Shandong Kingenta Ecological Engineering Co., Ltd. The nitrogen content of CU is 43.47%. In two years, maize cultivars of Zhengdan 958 was sown in June 12 with a density of 67500 plants/ha, and harvested in Oct 1. The area of individual replication was 60 m^2.

Soil nitrate nitrogen content and total nitrogen content measurements. A 50 mm diameter auger was used to collect the soil sample. At the maize stages of sowing, 14^{th} leaf, silking and physiological maturity, three composite soil samples were collected in 10 cm increments in 0–40 cm soil layers and 20 cm increments in 40–140 cm soil layers, respectively. Three replicates of 10 g (fresh weight) portions of soils were extracted with 50 mL 2 mol/L KCl for 30 min to determine the concentrations of mineral N (including NO_3^- and NH_4^+) using a continuous-flow analyzer (TRAACS 2000, Bran Luebbe, Nordstadt, Germany). Soil total nitrogen content was analyzed using the Kjeldahl method (AOAC 1990).

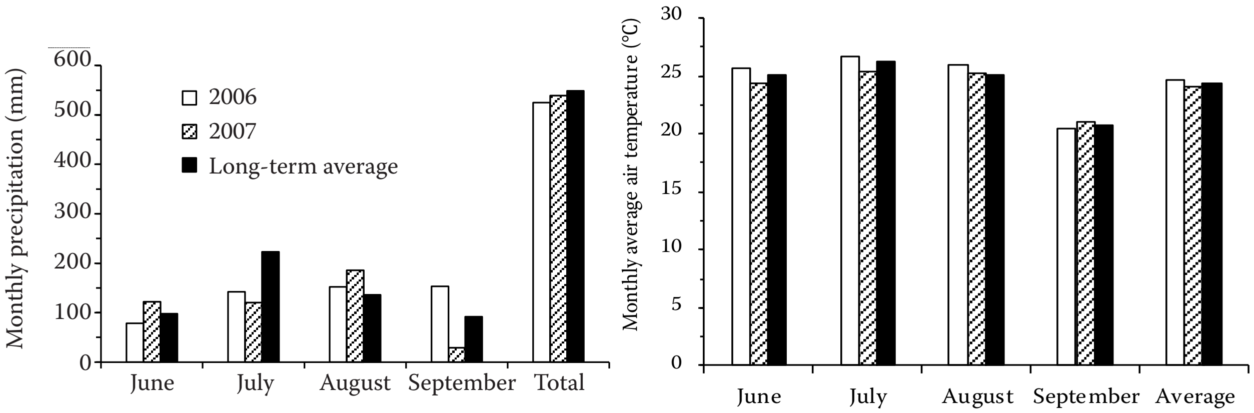

Figure 1. Precipitation and air temperature during the maize growth stages in 2006 and 2007 and the long-term average

Aboveground biomass and nitrogen uptake measurements. At the physiological mature stage of maize, two adjacent rows in the middle of each replication were harvested (area = 5 m × 1.2 m). Five plants were selected at random in the harvested plants, and then divided into grains and stover (including stalk, leaves, husks and cob), and weighed separately. The organ samples were put into oven to deactivate enzymes at 105°C for 30 min, and then oven-dried at 80°C for 72 h to determine dry matter yield. Nitrogen content of each sample was analyzed using the Kjeldahl method (AOAC 1990). The total biomass was obtained by summing up grains and stover dry matter yields.

Nitrogen use efficiency computing methods. N uptake (N_{up}) was calculated as shown in Equation 1, and the various components of N recovery efficiency (NRE) and soil N dependent rate (SND) were calculated using Equations 2–3 below (Sigunga et al. 2002).

$$N_{up} = [(NCS \times SY) + (NCG \times GY)] \quad (1)$$

$$\%NRE = 100\ (N_{up}f - N_{up}0)/FN \quad (2)$$

$$\%SND = 100\ (N_{up}0/N_{up}f) \quad (3)$$

Where: NCS – nitrogen content (mass fractions) in stover; NCG – nitrogen content in grains; SY – stover dry matter yields; GY – grain dry matter yields; $N_{up}f$ – nitrogen uptake by fertilized; $N_{up}0$ – nitrogen uptake by unfertilized crops; FN – the amount of fertilizer N applied.

To evaluate N loss from 0–140 cm soil layers (N_{lost}), N balance was established from the beginning (maize sowing) to the end (maize harvesting) of the experiment for each plot (Cartagena et al. 1995, Asadi et al. 2002). The following equation was used:

$$N_{lost} = N_f + N_{min} + N_{initial} - N_{up} - N_{final} \quad (4)$$

Where: N_f – the N input from fertilizer; N_{min} – the N input from mineralization of soil organic matter; $N_{initial}$ – the inorganic N initially present in the soil; N_{final} – the inorganic N present in the soil after harvest.

Mineralized N from soil organic matter was estimated from the total N uptake in the N0 plot as follows:

$$N_{min} = N_{up} + N_{final} - N_{initial} \quad (5)$$

In this experiment, the nitrogen supplied with irrigation is negligible, because of its very low nitrogen content. The other minor components such as biological nitrogen fixation, groundwater contribution, ammonium volatilization and weeds productions were ignored.

Statistical analysis. Data for each independent variable were analyzed separately using the General Linear Models of SPSS package (Ver. 11, SPSS, Chicago, IL, USA). Differences between treatments were considered significant if $P \leq 0.05$.

RESULTS AND DISCUSSION

Soil nitrate content at different stages of maize. At the 14th leaf stage, the soil nitrate content of treatment supplied with nitrogen fertilizer was increased in 0–140 cm soil layer more than the control (N0) in 2006 and 2007 (Figure 2). When urea type was the same, the soil nitrate content

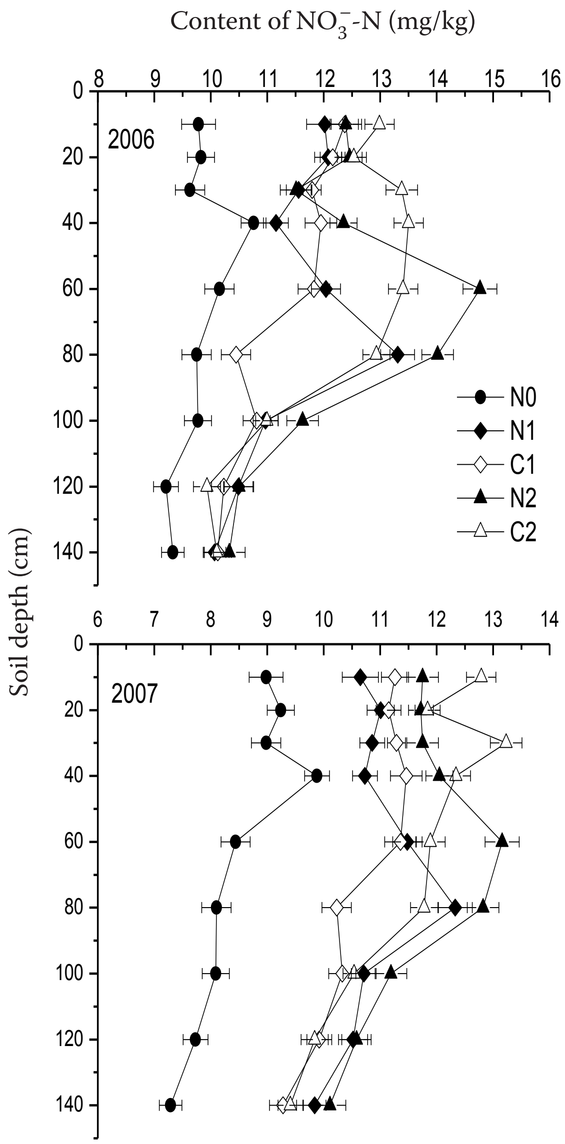

Figure 2. Content of NO_3^--N in 0~140 cm soil layer at the maize 14th leaf stage in 2006 and 2007. N0 – no nitrogen used as control; N1 – normal urea 75 kg N/ha; N2 – normal urea 150 kg N/ha; C1 – coated urea 75 kg N/ha; C2 –coated urea 150 kg N/ha. Horizontal bars are standard errors

could be increased with the increment of nitrogen fertilizer used. Main soil nitrate stayed in the 0–80 cm soil layers. At the same level of nitrogen used, the soil nitrate content of CU was higher in 0–40 cm soil layers, but lower in 60–140 cm soil layers, than those of NU. This indicated that the released quantity of CU was increased at this stage, but the soil nitrate content of deep soil layers was lower than NU because of the lower released quantity of CU. As compared to the nitrate content of the same soil layer in 2006, those in 60–140 cm soil layer in 2007 were higher, mainly because of the larger rain that increased the nitrate loss to deep soil layers.

At the silking stage, the soil nitrate content in superficial layer was decreased but the deep layer was more increased than at the 14th leaf stage, except N0 treatment in 2006 and 2007 (Figure 3).

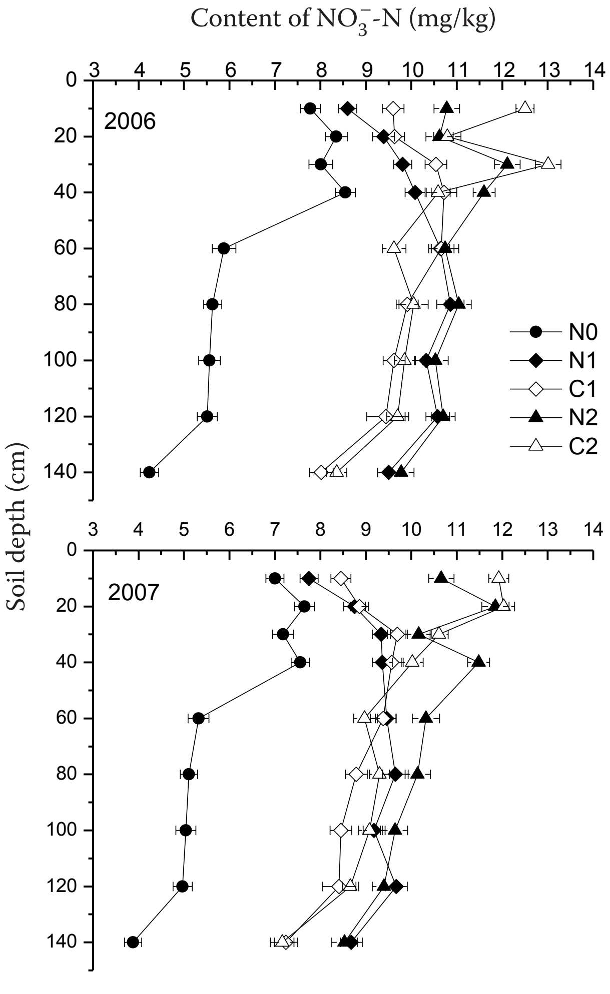

Figure 3. Content of NO_3^--N in 0~140 cm soil layer at the maize silking stage in 2006 and 2007. N0 – no nitrogen used as control; N1 – normal urea 75 kg N/ha; N2 – normal urea 150 kg N/ha; C1 – coated urea 75 kg N/ha; C2 –coated urea 150 kg N/ha. Horizontal bars are standard errors

It is firstly because of the quick growth of maize, which, as a result, increased the nitrogen uptake in superficial soil layers. Secondly, the quantity of nitrate loss with rainwater infiltration was also increased, which increased the nitrate content of deep soil layers. Compared with N0 treatment, the soil nitrate content of the treatment supplied with urea was increased in 0–140 cm soil layer. When the urea type was the same, the soil nitrate content could be increased with the increment of nitrogen fertilizer used. At the same level of nitrogen used, the soil nitrate content of CU was higher in 0–40 cm soil layers, but lower in 60–140 cm soil layers, than those of NU. But the reason was not the same as that at the 14th leaf stage. This is mainly because the N uptake by maize is increased and the loss of nitrate to deep soil layer was reduced when supplied with CU. The differences of the nitrate content in 60–140 cm were larger than in 2006, because of the greater precipitation rain in 2007.

At the physiological maturity stage, the soil nitrate content in each layer was decreased significantly than those of the early stages both in 2006 and 2007 (Figure 4). Without irrigation, the soil nitrate content of CU was lower than NU at the same level of nitrogen used. But with irrigation at the blister stage, the soil nitrate content of C2 in 30–40 cm soil layers were higher than those of N2, which can be used by following crops. When urea type was the same, the soil nitrate content could be increased with the increment of nitrogen fertilizer used. When only normal urea was used, the soil nitrate content could be increased with increased nitrogen supplied (Fang et al. 2006). The soil nitrate content with irrigation was higher than that without irrigation, and the soil nitrate content of CU was lower than that of NU. Leaching of nitrate may be the main reason of soil nitrate decrease. Compared with NU, CU can increase the yield of maize (Shoji et al. 1991), which resulted in its 'early-decrease-and-late increase (EDLI)' effect, that is, the growth of CU was lower at the 14th leaf stage, but significantly higher after the silking stage, than that of NU (Shao et al. 2008, 2009). The higher nitrate content of 0–40 cm soil layers of CU during the silking stage to the physiological maturity stage, which can be easily absorbed by maize, may be one of the key reasons for the effect of EDLI.

Nitrogen accumulation and use. At the physiological maturity stage, the nitrogen accumulated in grains and stover were both increased with the use of urea, accumulation amounts of nitrogen were C2 > N2 > C1 > N1 > N0 in 2006 and

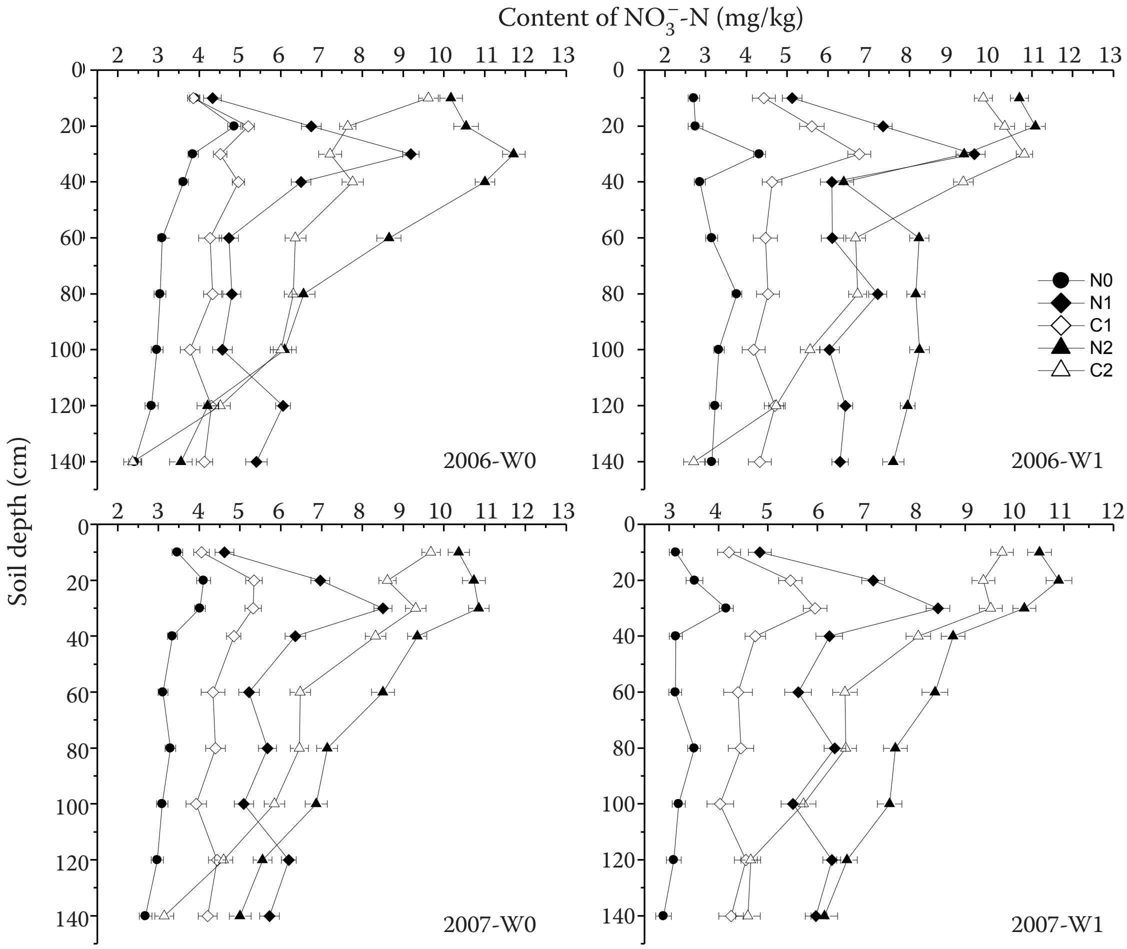

Figure 4. Content of NO_3^--N in 0~140 cm soil layer at the maize physiological maturity stage in 2006 and 2007. W0 and W1 stand for no irrigation during the whole growth stages and 85 mm irrigation through channels at the blister stage, respectively. N0 – no nitrogen used as control; N1 – normal urea 75 kg N/ha; N2 – normal urea 150 kg N/ha; C1 – coated urea 75 kg N/ha; C2 –coated urea 150 kg N/ha. Horizontal bars are standard errors

2007 (Table 1). And at the same nitrogen level, the nitrogen absorbed by maize using CU was higher than that of NU. Irrigation can increase the nitrogen absorption of maize, and the nitrogen accumulation in grains and stover were increased. Irrigation would do no good to the transportation of nitrogen from vegetative organs to grain, and more nitrogen was retained in vegetative organs (Huang et al. 2006). But in this experiment, when using CU, more nitrogen is transported from vegetative organs to grain.

With or without irrigation, the N recovery efficiency (NRE) of CU was higher than that of NU, both in 2006 and 2007. Without irrigation, at the level of 75 kg N/ha and 150 kg/ha, the NREs of CU were 72.3% and 22.0% higher than NU, respectively. With irrigation, at the level of 75 kg N/ha and 150 kg N/ha, the NREs of CU were 49.8% and 35.7% higher than NU, respectively. The NREs of CU and NU with irrigation were on average by 4.9% and 3.0% lower than those treatments without irrigation. Similar finding was reported by Sigunga et al. (2002), where the NRE could be decreased when undrained after rain in sub-humid environments. So, the NRE of fertilizer was affected by soil water condition and water management.

The soil N dependent rates (SNDs) were N1 > C1 > N2 > C2. SNDs of CU were lower than those of NU, no matter with or without irrigation. Since the release of CU was controlled, more of it is retained in 0–40 cm soil layer, which can be absorbed by maize easily (Shoji et al. 1991).

As compared to those in 2006, the nitrogen accumulated in grains and stover, N recovery efficiency, and soil N dependent rates in 2007 were higher.

Nitrogen fate of maize uptake, soil residual and loss. Table 2 showed that using CU can increase the total nitrogen absorption by aboveground organs and soil residual, but decrease the loss, which is same to the result reported by Shoji

Table 1. Accumulation of nitrogen in maize at the physiological maturity, N recovery efficiency and soil N dependence rate under different treatments in 2006 and 2007

Treatment	ANG (kg/ha)	ANS (kg/ha)	N recovery efficiency (%)	Soil N dependent rate (%)
Year 2006				
W0N0	85.8^{h}	57.6^{f}	–	–
W0N1	101.0^{fg}	66.7^{e}	32.3^{f}	85.6^{a}
W0C1	109.1^{de}	76^{d}	55.6^{a}	77.5^{b}
W0N2	118^{bc}	91.2^{b}	43.9^{d}	68.5^{c}
W0C2	126.1^{a}	97.6^{a}	53.5^{b}	64.1^{d}
W1N0	83.1^{h}	54.6^{f}	–	–
W1N1	97.5^{g}	65.7^{e}	34.0^{f}	84.4^{a}
W1C1	107.1^{ef}	68.8^{e}	50.9^{c}	78.3^{b}
W1N2	113.6^{cd}	82.4^{c}	38.9^{e}	70.3^{c}
W1C2	123.3^{ab}	93.5^{b}	52.7^{bc}	63.5^{d}
Year 2007				
W0N0	99.5^{f}	63.1^{f}	–	–
W0N1	113.3^{e}	83.0^{d}	45.1^{d}	82.8^{a}
W0C1	143.4^{c}	88.3^{c}	92.1^{a}	70.2^{c}
W0N2	157.5^{a}	81.0^{de}	50.7^{c}	68.1^{d}
W0C2	154.1^{ab}	141.6^{a}	88.8^{a}	55.0^{f}
W1N0	98.1^{f}	60.8^{f}	–	–
W1N1	115.0^{e}	82.0^{de}	50.8^{c}	80.6^{a}
W1C1	135.7^{d}	79.5^{e}	75.0^{b}	73.9^{b}
W1N2	145.0^{c}	88.9^{c}	50.0^{c}	67.9^{d}
W1C2	151.6^{b}	118.9^{b}	74.4^{b}	58.7^{e}

ANG – accumulation amount of nitrogen in grain; ANS – accumulation amount of nitrogen in stover. Small letters show difference at 5% level. W0 and W1 stand for no irrigation during the whole growth stages and 85 mm irrigation through channels at the blister stage, respectively. N0 – no nitrogen used as control; N1 – normal urea 75 kg N/ha; N2 – normal urea 150 kg N/ha; C1 – coated urea 75 kg N/ha; C2 –coated urea 150 kg N/ha

(2005). No matter with or without irrigation, N uptake by maize were C2 > N2 > C1 > N1 > N0. N uptakes with irrigation were a little lower than those treatments without irrigation, but the effects were not significant.

Soil residuals were C2 > N2 > C1 > N1 > N0, no matter with or without irrigation. But there were no significant differences between C1 and N2 under irrigation. At the level of 75 kg N/ha, soil residual of treatments with irrigation were lower than those of treatments without irrigation. At the level of 150 kg N/ha, soil residual of treatments with irrigation were higher than those of treatments without irrigation, but there were no significant difference between with and without irrigation when using 150 kg N/ha of coated urea.

Without irrigation, the loss rates of NU at the level of 75 kg N/ha and 150 kg N/ha were 10.3% and 19.3%, while those of CU were 2.1% and 8.1%, respectively. With irrigation, the loss rates of NU at the level of 75 kg N/ha and 150 kg N/ha were 18.1% and 22.8%, while those of CU were 11.4% and 11.1%, respectively. The loss rates of CU and NU with irrigation were higher than those without irrigation.

Two-year results indicated that using CU could increase the nitrogen absorption of maize, decrease the loss of nitrate by soil water and irrigation, and then increase the nitrogen use efficiency. The slow release of CU can supply enough nitrogen for maize, especially after the silking stage, but the quickly soluble NU can be easy lost by water.

Table 2. Crop uptake, soil residual and loss of soil and fertilizer nitrogen in maize field in 2006 and 2007

Treatment	Maize uptake		Soil residual		Loss	
	(kg/ha)	(%)	(kg/ha)	(%)	(kg/ha)	(%)
Year 2006						
W0N0	143.4^{g}	57.0	108.3^{f}	43.0	0	0.0
W0N1	167.6^{f}	51.3	125.6^{c}	38.4	33.5^{ef}	10.3
W0C1	185.1^{de}	56.7	134.7^{b}	41.2	6.9^{g}	2.1
W0N2	209.2^{bc}	52.1	115.0^{e}	28.6	77.5^{b}	19.3
W0C2	223.7^{a}	55.7	145.5^{a}	36.2	32.5^{f}	8.1
W1N0	137.7^{g}	53.3	120.7^{d}	46.7	0	0.0
W1N1	163.2^{f}	49.0	109.9^{f}	33.0	60.3^{c}	18.1
W1C1	175.9^{ef}	52.8	119.4^{d}	35.8	38.1^{e}	11.4
W1N2	196^{cd}	48.0	119.1^{d}	29.2	93.3^{a}	22.8
W1C2	216.8^{ab}	53.1	146.2^{a}	35.8	45.4^{d}	11.1
Year 2007						
W0N0	162.5^{g}	61.0	104.1^{d}	39.0	0	0.0
W0N1	196.3^{f}	57.5	99.4^{e}	29.1	45.9^{e}	13.4
W0C1	231.6^{d}	67.8	105.5^{d}	30.9	4.5^{h}	1.3
W0N2	238.6^{c}	57.3	100.1^{e}	24.0	77.9^{a}	18.7
W0C2	295.7^{a}	71.0	109.9^{c}	26.4	11.0^{g}	2.6
W1N0	158.9^{h}	58.1	114.8^{b}	41.9	0	0.0
W1N1	197.0^{f}	56.5	99.1^{e}	28.4	52.6^{c}	15.1
W1C1	215.2^{e}	61.7	113.4^{b}	32.5	20.2^{f}	5.8
W1N2	233.9^{d}	55.2	126.7^{a}	29.9	63.1^{b}	14.9
W1C2	270.5^{b}	63.8	118.5^{b}	28.0	34.7^{e}	8.2

Small letters show difference at 5% level. W0 – no irrigation during the whole growth stages; W1 – 85 mm irrigation through channels at the blister stage; N0 – no nitrogen used as control; N1 – normal urea 75 kg N/ha; N2 – normal urea 150 kg N/ha; C1 – coated urea 75 kg N/ha; C2 – coated urea 150 kg N/ha

And the leaching of nitrate was closely related with soil water condition, and the profit or loss of soil nitrogen was change with the situation (Yuan and Wang 2000). With irrigation or heavy rain, the removal of nitrogen in soil to deeper soil layer was increased (Sigunga et al. 2002). When NU was used, the absorption and loss before the silking stage decreased the nitrogen availability of soil, which resulted in available N deficit, aggravated the contradiction between the supply and requirement of nitrogen. And the nitrate loss was closely related to nitrogen use efficiency and environment protection (Ju et al. 2006).

In conclusion, CU can make a synchronization of nitrogen release and maize absorption, shorten the time of nitrate remained in soil, so, decrease the risk of leaching. Although irrigation may increase the nitrogen loss risk before the silking stage, it could increase the nitrogen uptake by maize. So applied CU and irrigated 85 mm at the blister stage is benefit for increasing the N use efficiency of maize.

REFERENCES

AOAC (1990): Official Methods of Analysis. Association of Official Analytical Chemist, Arlington.

Asadi M.E., Clemente R.S., Das Gupta A., Loof R., Hansen G.K. (2002): Impacts of fertigation via sprinkler irrigation on nitrate leaching and corn yield in an acid-sulphate soil in Thailand. Agricultural Water Management, *52*: 197–213.

Bijay-Singh, Yadvinder-Singh, Sekhon G.S. (1995): Fertilizer-N use efficiency and nitrate pollution of groundwater in developing countries. Journal of Contaminant Hydrology, *20*: 167–184.

Brevé M.A., Skaggs R.W., Parsons J.E., Gilliam J.W. (1998): Using the DRAINMOD-N model to study effects of drainage system design and management on crop productivity, profitability and NO_3-N losses in drainage water. Agricultural Water Management, *35*: 227–243.

Cartagena M.C., Vallejo A., Diez J.A., Bustos A., Caballero R., Roman R. (1995): Effect of the type of fertilizer and source of irrigation water on N use in a maize crop. Field Crops Research, *44*: 33–39.

Diez J.A., Caballero R., Bustos A., Roman R., Cartagena M.C., Vallejo A. (1996): Control of nitrate pollution by application of controlled release fertilizer (CRF), compost and an optimized irrigation system. Nutrient Cycling in Agroecosystems, *43*: 191–195.

Fang Q.X., Yu Q., Wang E.L., Chen Y.H., Zhang G.L., Wang J., Li L.H. (2006): Soil nitrate accumulation, leaching and crop nitrogen use as influenced by fertilization and irrigation in an intensive wheat-maize double cropping system in the North China Plain. Plant and Soil, *284*: 335–350.

Huang Y., Ma E.P., Yang Q.H., Liu Y.Y., Li C.H. (2006): Effects of post-anthesis irrigation on carbon and nitrogen assimilate translocation in high-oil corn. Journal of Soil and Water Conservation, *20*: 127–127. (In Chinese)

Ju X.T., Kou C.L., Zhang F.S., Christie P. (2006): Nitrogen balance and groundwater nitrate contamination: comparison among three intensive cropping systems on the North China Plain. Environmental Pollution, *143*: 117–125.

Kirda C., Topcu S., Kaman H., Ulger A.C., Yazici A., Cetin M., Derici M.R. (2005): Grain yield response and N-fertilizer recovery of maize under deficit irrigation. Field Crops Research, *93*: 132–141.

Krček M., Slamka P., Olšovská K., Brestič M., Benčíková M. (2008): Reduction of drought stress effect in spring barley (*Hordeum vulgare* L.) by nitrogen fertilization. Plant, Soil and Environment, *54*: 7–13.

Ogola J.B.O., Wheeler T.R., Harris P.M. (2002): Effects of nitrogen and irrigation on water use of maize crops. Field Crops Research, *78*: 105–117.

Rego T.J., Grundon N.J., Asher C.J., Edwards D.G. (1988): Comparison of the effects of continuous and relieved water stress on nitrogen nutrition of grain sorghum. Australian Journal of Agricultural Research, *39*: 773–782.

Shao G.Q., Li Z.J., Ning T.Y., Zhang M., Jiang X.D., Wang Y., Zhao J.B., Lü M.R., Zhao J. (2009): Effects of normal urea and release-controlled urea on root and shoot growth and yield of maize in different water conditions. Acta Agronomica Sinica, *35*: 118–123. (In Chinese)

Shao G.Q., Li Z.J., Ning T.Y., Zhang M., Jiao N.Y., Han B., Bai M., Li H.J. (2008): Effects of irrigation and urea types on N utilization, yield and quality of maize. Scientia Agricultura Sinica, *41*: 3672–3678. (In Chinese)

Shoji S. (2005): Innovative use of controlled availability fertilizers with high performance for intensive agriculture and environmental conservation. Science in China. Series C, Life Sciences, *48*S: 912–920.

Shoji S., Gandeza A.T., Kimura K. (1991): Simulation of crop response to polyolefin-coated urea. II. Nitrogen uptake by corn. Soil Science Society of America Journal, *55*: 1468–1473.

Sigunga D.O., Janssen B.H., Oenema O. (2002): Effects of improved drainage and nitrogen source on yields, nutrient uptake and utilization efficiencies by maize (*Zea mays* L.) on Vertisols in sub-humid environments. Nutrient Cycling in Agroecosystems, *62*: 263–275.

Sun Z.X., Zheng J.M., Sun W.T. (2009): Coupled effects of soil water and nutrients on growth and yields of maize plants in a semi-arid region. Pedosphere, *19*: 673–680.

Yuan X.M., Wang Z.Q. (2000): Nitrate nitrogen leaching and factors influencing it. Arid Zone Research, *17*: 46–52. (In Chinese)

Zand-Parsa Sh., Sepaskhah A.R., Ronaghi A. (2006): Development and evaluation of integrated water and nitrogen model for maize. Agricultural Water Management, *81*: 227–256.

Zhang M., Shi Y.X., Yang S.X., Yang Y.C. (2001): Status quo of study of controlled-release and slow-release fertilizers and progress made in this respect. Journal of Chemical Fertilizer Industry, *28*: 27–30. (In Chinese)

Received on May 26, 2011

Corresponding author:

Prof. Shuyun Chi, Shandong Agricultural University, College of Mechanical and Electronic Engineering, 271018, Tai'an, Shandong, P.R. China
e-mail: chishujun1955@163.com