한작지(Korean J. Crop Sci.), 52(3): 296~302(2007)

N Use Efficiency and Nitrate Leaching by Fertilization Level and Film Mulching in Sesame Cultivated Upland

Dong-Wook Lee*, Ki-Do Park*, Chang-Young Park**, Il-Soo Son*, Ui-Gum Kang*, Jee-Yeon Ko*
Kang-Bo Shim*, Young-Son Cho***†, and Sung-Tae Park*

*Yeongnam Agricultural Research Institute, National Institute of Crop Science, RDA, Milyang, 627-803, Korea
**National Institute of Highland Agriculture, RDA, 232-955, Korea
***National Institute of Crop Science, RDA. Suwon 441-857, Korea

ABSTRACT This study was conducted to evaluate the effect of slow release fertilizers (SRF), crotonylidene diurea (CDU) and latex coated urea (LCU), on nitrogen (N) use efficiency (NUE) and nitrate-N leaching in a silty clay loam soil under polyethylene film mulching (PFM) for sesame cultivation. In PFM plot, concentrations of NO_3-N and NH_4-N in SRF applied soils were less than that in the urea plot during the whole growing period. However, NO_3-N and NH_4-N in all the non-mulched plots (NM) were not significantly different. Urea-N in soil treated with SRF was higher than urea plot until 50 days after application and was comparable in all the treatments after 50 days. NO_3-N concentrations in leached solution in 21 days after urea fertilization in PFM and NM were 26 mg L^{-1} and 83 mg L^{-1}, respectively. However, NO_3-N in leached solution at applied CDU and LCU was less than that of urea similar to nitrate concentration in soil. NO_3-N in leached solution in applied CDU and LCU in 44 days after application was about 25% lower than that urea plot and PFM, while the NO_3-N concentration of CDU and LCU treatment in NM did not changed. Application of SRF increased the yield of sesame and N recovery compared to urea and there was a little difference between SRF and N levels. In conclusion, application of 80% N level with SRF increased N recovery and reduced nitrate leaching without reduction of yields compared with urea application.

Keywords : slow release fertilizer, nitrate leaching, sesame, polyethylene film mulching

The importance of soil mineral N in crop nutrition has been widely studied. Current studies on mineral-N in N dynamics have attracted attention mainly on NO_3^- leaching, ammonia volatilization and N_2O emissions. Of the various N losses nitrate leaching from arable land has been prime concern which causes contamination of groundwater and has become a matter of worldwide concern. Nitrate leaching occurs in many vegetable production areas because N application rates often exceed crop demand. Excessive use of readily soluble chemical fertilizers and manure are the main sources of groundwater contamination (Thomsen *et al.*, 1993; Chang and Entz, 1996). According to reports (Morihiro *et al.*, 2003), it is essential to substitute slow release fertilizers (SRF) with readily available fertilizers to reduce N loss from agriculture lands.

SRF have been used to save labor in farming systems where frequent application of chemical fertilizer is needed and to increase N recovery by crops. Some effects of SRF on vegetable crops have been investigated and have been very successful in controlling N losses. Increase in plant growth and yields of vegetable crops such as Chinese cabbage, onion etc. have also been observed in previous papers (Seong *et al.*, 1991; Lim *et al.*, 1995; Choi *et al.*, 2000). However, information of SRF on nitrate leaching and N dynamics especially in upland soils is very little.

Soil mulching with plastic film has long been used in an intensive agriculture. Mulching of soil can reduce water infiltration and evaporation (Unger, 1975; Oh *et al.*, 1996), thus reducing the loss of NO_3^- leaching and increasing the water and nutrient availability to plant (Bowen and Frey, 2002; Schmidt and Worthington, 1998). However, when water from heavy rainfall and irrigation enters into the root zone through a hole for seeding in the plastic film, then the soil water content increases and nutrient such as nitrate

†Corresponding author: (Phone) +82-31-290-6687
(E-mail) ycho@rda.go.kr <Received June 11, 2007>

may percolate downward soil.

Mulching practice needs basal application of whole amount of nutrient needed by plant throughout the growing period. In this case, basal application of readily soluble fertilizer in single application as a urea may be responsible for low N use efficiency. To solve this problem, impact of SRF such as CDU and LCU was evaluated on N transformation and nitrate leaching in soil and N use efficiency of plant for sesame under PFM and NM in a silty clay loam soil.

MATERIALS AND METHODS

Treatments and application

A field experiment was conducted on silty clay loam soil for sesame cultivation at the Yeongnam agricultural research institute, Milyang, in 2005. The average annual rainfall was 972 mm, precipitation during the cultivation period (20 May to 30 Aug) was 592 mm. Other properties of the soil used are given in Table 1. The two mulching treatments were polyethylene film mulching (PFM) and non-mulching (NM). Treatments of N fertilizers were urea, CDU and LCU. N content of urea, CDU and LCU was 46, 32, and 40%, respectively. CDU is formed by the acid-catalyzed reaction of urea and acetic aldehyde. LCU was coated latex material with urea as produced by Chobi Co. Ltd.

Levels of treated N were: (1) urea (80 kg N ha^{-1}); (2) CDU80% (equivalent to 64 kg ha^{-1}); (3) CDU100% (equivalent to 80 kg ha^{-1}); (4) LCU80% (equivalent to 64 kg ha^{-1}); (5) LCU100% (equivalent to 80 kg ha^{-1}); (6) no N fertilizer. All treatments were basally applied together with 40 kg P_2O_5 ha^{-1} and 90 kg K_2O ha^{-1}. A sesame variety, "Yangbaeckkae" was sown on 22 May. Each treatment had two rows with 30-cm distances and 10-cm for hole distances. Three replicates of six treatments were allocated to both PFM and NM in a split plot design.

Sampling and analysis

Soil samples were taken randomly from each plot with soil depth 0-10, 10-20, and 20-30 cm depth. The soil was air-dried and ground to pass 2 mm sieve. The chemical and physical properties of soil were analyzed by Soil analysis method (NIAST, 2000). Soil pH was measured in 1 : 5 (soil: water) suspensions. Organic matter content was determined by Turin's method. Exchangeable cations were extracted with 1 M ammonium acetate (pH 7) and Ca, Mg and K in the extracts were analyzed by ICP (Inductively Coupled Plasma, Perkin Elmer 3300DV, U.S.A.). Cation exchange capacity (CEC) was measured by ammonium acetate method (NIAST, 2000).

Soil mineral N was extracted by shaking samples of field-moist soil with 2 M KCl (1 : 5, soil: extractant ratio) for 1 h and analyzed by colorimetric method for NH_4-N and NO_3-N by using AA3 continuous flow analyzer (Bran Luebbe). To measure concentration of urea-N, samples of 5 g soil was extracted by shaking with 50 ml 2 M KCl-PMA (phenylmercuric acetate), and the extract analyzed by diacetyl monoxime-colorimetric analysis. Soil water content was determined gravimetrically after drying for 24 h at 105℃. Sesame plant was harvested separately into shoot + leaf, capsule and seed, and dry matter was measured after drying for 48 h at 70℃. Total plant N was measured by Kjeldahl method and fertilizer N recovery was calculated as follows:

Fertilizer N recovery (%) = [(N absorbed in N fertilized plot-N absorbed in no N fertilized plot) / Amount of N applied] × 100.

Leaching water analysis

A ceramic porous cup was installed at soil depth of 50 cm in each plot. Soil solutions leached through soil were collected at least once a month, depending on precipitation amount. The soil solution samples extracted from the porous

Table 1. Chemical properties of soil before the experiment

pH (1 : 5)	T-N (%)	O. M. (g kg^{-1})	Av. P_2O_5 (mg kg^{-1})	Ex. Cations ($cmol_c$ kg^{-1})			CEC ($cmol_c$ kg^{-1})
				K	Ca	Mg	
7.25	0.15	25.2	337	0.78	6.31	1.32	11.3

cups were filtered and then stored at 5℃. NO_3-N and NH_4-N concentration of filtered leachate were analyzed with an AA3 continuous flow auto analyzer (Bran Luebbe).

Statistical analysis

The statistical significance of experimental treatments was determined by ANOVA in SAS procedure. Mean values of N content and N recovery were compared by Duncan's multiple range test at the 5% level.

RESULTS AND DISCUSSION

Dynamics of available N in soil during the cropping period

Changes in NO_3-N concentration in the soil profile with PFM and NM by applied different N fertilizers are shown in Fig. 1. While comparing the PFM and NM, NO_3-N concentration in NM was less than 20 mg kg^{-1} during the growth period and not significantly different in the treatments and soil depth, while that in PFM was significantly higher than in NM. In PFM, NO_3-N concentration at soil depth of 0-10 cm in the urea treated plot after 21 days (DAF) was about 130 mg kg^{-1}, and decreased with increasing soil depth. However, NO_3-N concentration at 0-10 cm depth in the plots treated with CDU and LCU were 60-80 mg kg^{-1} that were markedly less than that of urea and also in deep soil were less than that of urea treated soils. Nitrate concentrations in SRF and urea treated soils at 50 DAF and 90 DAF were similar to 21 DAF.

In NM, nitrate concentrations in all the treatments at 0-10 cm soil depth at 21 DAF were significantly lower (7-17 mg kg^{-1}) than nitrate in PFM treatment. In urea treated soils, NO_3-N concentration at 0-10 cm soil depth was less than those in LCU and CDU plots. Changes in nitrate concentrations at 50 DAF and 90 DAF were similar to 21 DAF.

Nitrate concentration in PFM soil was higher than that in NM and decreased with increasing soil depth compared to NM. This indicated that leaching of nitrate decreased with the increasing of soil depth because of prevention of soil water infiltration by film mulching (Rhee *et al.*, 1990; Oh *et al.*, 1996). Also when readily soluble fertilizer like urea was applied in upland soils, it was rapidly hydrolyzed to the plant available forms then nitrification of NH_4-N to NO_3-N and it was subjected to loss. However N losses such as ammonia volatilization, nitrate leaching, nitrous oxide emission etc. in soil treated with SRF such as CDU and LCU were decreased because SRF was slowly released during the whole growing season.

Changes in NH_4-N concentration in the soil profile with PFM and NM by N fertilization level are shown in Fig. 2. Similar changes occurred in NO_3-N in PFM and NM soils. In PFM plots, NH_4-N concentration in the surface soil layer in urea plot was highest in 55 mg kg^{-1} at DAF 21, and decreased with increasing soil depth and time. However, ammonium concentration in the CDU and LCU plots was below 30 mg kg^{-1}, and decreased significantly with increasing time than that in urea treated soils. In NM soil, ammonium concentration in all the treatments was below 20 mg kg^{-1} during the growth period and did not changed significantly between the treatments and soil depths as compared with that of PFM.

Concentrations of urea-N in soil applied with urea and SRF are shown in Fig. 3. Urea concentrations in both PFM

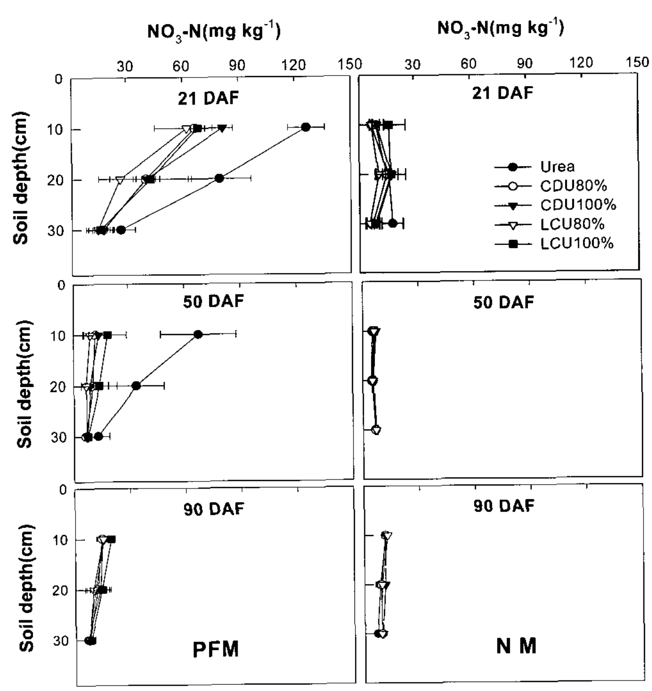

Fig. 1. Changes in NO_3-N concentration on soil depth treated different N fertilizers under polyethylene film mulching (PFM) and non-mulching (NM).

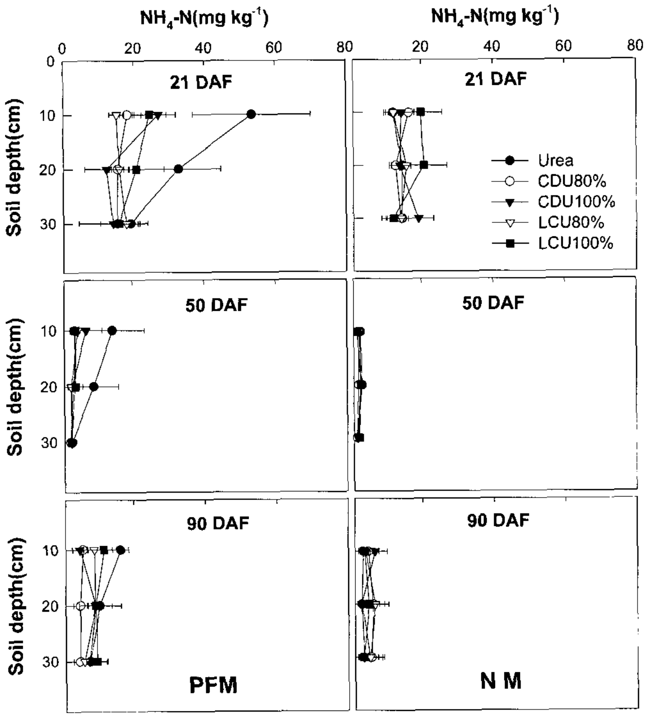

Fig. 2. Changes in NH_4-N concentration on soil depth treated different N fertilizers under polyethylene film mulching (PFM) and non-mulching (NM).

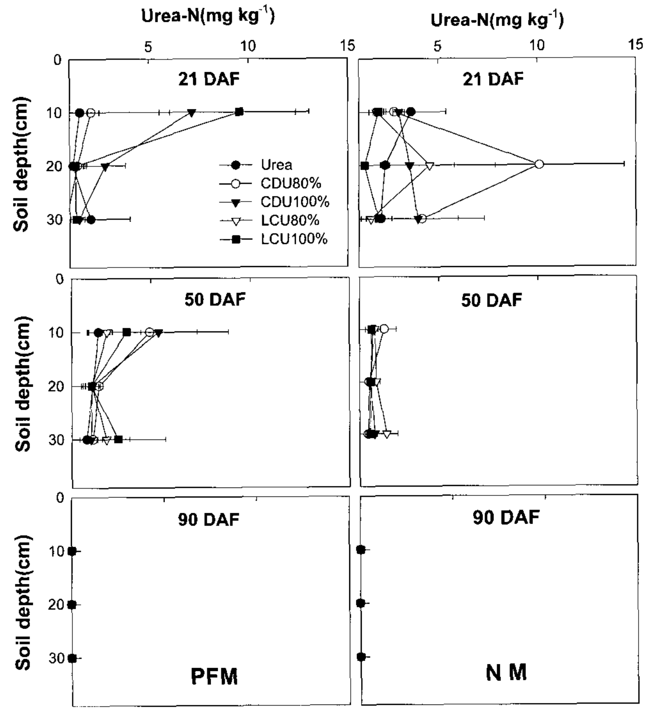

Fig. 3. Changes in Urea-N concentration on soil depth treated different N fertilizers under polyethylene film mulching (PFM) and non-mulching (NM).

and NM were detected until 50 DAF and were negligible after that. In PFM plots, urea-N concentration in SRF treatments was higher than that of urea treated plot and was highest in the surface soil but rapidly decreased in the deep soil.

In NM plots, urea-N in soil was significantly less than urea-N in PFM plots. Urea hydrolysis after application of fertilizer was affected by soil pH, soil texture, temperature, water content, and organic matter (Reynolds, C. M. *et al.*, 1985). N fertilizer applied to the soil with suitable water content without mulch was rapidly hydrolyzed and nitrified, and the urea-N content remaining in NM soil decreased and followed by the decrease in ammonium and nitrate concentrations in the soil (Fig. 1 and 2) but N loss such as nitrate leaching and nitrous oxide increased.

While comparing the CDU and LCU, it seems to be difference due to mechanism of mineralization from CDU and LCU. When CDU dissolved in water it gradually decomposes to urea and crotonaldehyde. CDU is decomposed by both hydrolysis and microbial processes in the soil; temperature, soil moisture and biological activity affect the release rate, though even in acid soils the degradation is slower than LCU. While N release pattern of LCU which was coated with latex to control the water penetration was affected by soil moisture and temperature regardless of soil pH and microbial decomposition.

Nitrate concentration in leached solution

Nitrate concentrations in the leached solutions at 50 cm depth of soil under PFM and NM are shown in Fig. 4. Ammonium concentrations were negligible in PFM and NM during period of sesame growth (data not shown). PFM soil showed lower nitrate concentration in comparison with the treatment without mulching. In PFM plots, nitrate concentrations of all the treatments were less than 30 mg L^{-1} throughout the growing season. At 21 DAF, nitrate leaching was highest in the urea treated plot, while it was greatly lower in LCU treatment. After 21 DAF, nitrate concentrations in all the treatments were rapidly decreased in less than 3 mg L^{-1} and not significant between the treatments. However, NM soil showed a tendency to increase nitrate leaching. Nitrate concentration in urea treatment was up to 85 mg L^{-1} at 21 DAF, while nitrate in other treatments was similar to PFM. Nitrate concentration at 44 DAF was rapidly decreased but was higher than that of PFM. At 92 DAF, nitrate in all the treatment was less than 2 mg L^{-1}, the same as those of PFM. As the results, the highest potential nitrate leaching loss was observed in urea plot with mineral N concentration at soil depths of 20-30 cm (Fig. 1), while application of CDU and LCU could decrease N loss by nitrate leaching. Application of SRF with PFM which can prevent water infiltration and evaporation reduced not only ammonia volatilization and nitrous oxide emission but also leaching (Minami, 1992; Morihiro *et al.*, 2003).

Yield and yield components

The effect of soil mulching on stem length, capsule setting stem length, and 1000-grain weight (g) was considerably significant, but there was not a significant difference among the fertilizer treatments except increment by SRF (Table 2). The number of grain per capsule was not

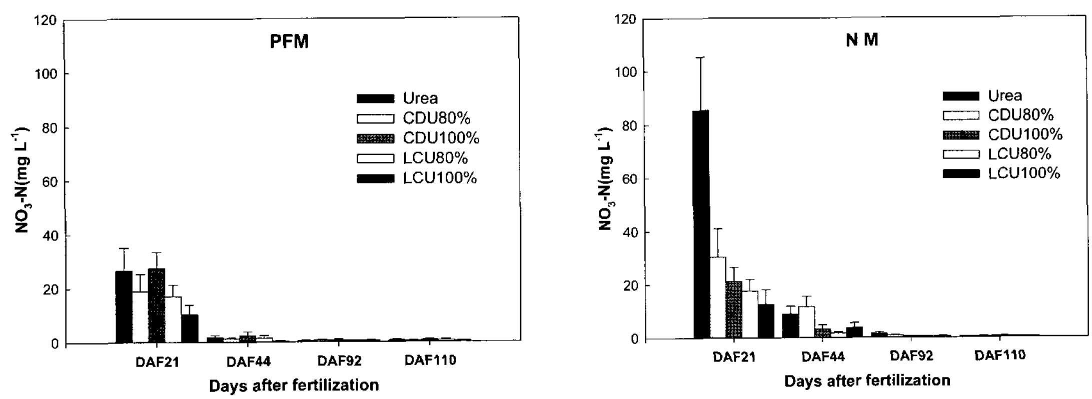

Fig. 4. Concentration of nitrate into the leached solution at 50-cm soil depth from different application of fertilizers under polyethylene film mulching (PFM) and non-mulching (NM).

Table 2. Yield and yield components of sesame at the different N fertilizers under polyethylene film mulching(PFM) and non-mulching (NM)

Mulch	Treatment	Stem length (cm)	Capsule setting stem length (cm)	No. of capsules $plant^{-1}$	No. of grain $capsule^{-1}$	1000 grain weight (g)	Yield (kg $10a^{-1}$)	Yield index
PFM	Urea	158ns[†]	104ns	98ab	58.3ns	2.70c	123.0a	100
	CDU80%	169	113	96ab	55.4	2.80abc	126.7a	103
	CDU100%	162	109	97ab	60.3	2.76bc	128.1a	104
	LCU80%	166	111	101a	58.1	2.91a	131.3a	107
	LCU100%	163	108	102a	57.3	2.88ab	129.8a	106
	No-N	157	112	86b	58.1	2.89c	107.6b	88
NM	Urea	124ns	90ns	54ns	60.1ns	2.71ns	55.4b	100
	CDU80%	123	86	57	58.4	2.51	58.4ab	105
	CDU100%	127	91	58	58.0	2.54	60.9ab	109
	LCU80%	131	93	60	55.2	2.72	67.9a	122
	LCU100%	127	93	56	57.1	2.57	66.7a	119
	No-N	124	94	54	58.0	2.51	40.3c	73
Mulching (M)		***	***	***	ns	***	***	
Treatment (T)		ns	ns	*	ns	ns	***	
M×T		ns	ns	ns	ns	*	ns	

Within a column and mulching means followed by same letters are significantly different by DNMRT at the 0.5% level.
[†]ns is not significant
*Significant $P < 0.05$, **Significant $P < 0.01$, ***Significant $P < 0.001$.

Table 3. Nitrogen uptake and recovery of sesame at the different N fertilizers under polyethylene film mulching (PFM) and non-mulching (NM)

Mulch	Treatment	Stem+leaf	Capsule	Grain	Total	N recovery (%)
		(kg 10a^{-1})				
PFM	Urea	2.42ns	2.70ns	4.32bcd	9.4ab	27.9b
	CDU80%	2.89	2.28	3.94cd	9.1b	29.8b
	CDU100%	2.67	2.80	4.52bc	10.0ab	35.0ab
	LCU80%	2.67	2.55	4.83ab	10.1ab	44.6a
	LCU100%	2.83	2.92	5.12a	10.9a	46.0a
	No-N	1.39	2.05	3.73d	7.2c	-
NM	Urea	0.67ns	1.40ab	1.61bc	3.7b	11.2b
	CDU80%	0.59	1.33abc	1.95ab	3.9b	16.8ab
	CDU100%	0.98	1.17bc	1.99a	4.1b	16.9ab
	LCU80%	1.01	1.14bc	2.30a	4.5ab	26.0a
	LCU100%	1.13	1.72a	2.29a	5.1a	29.4a
	No-N	0.47	0.92c	1.36c	2.8c	-
Mulching (M)		***	***	***	***	***
Treatment (T)		ns	*	***	***	*
M×T		ns	ns	*	ns	ns

Within a column and mulching means followed by same letters are significantly different by DNMRT at the 0.5% level.
†ns is not significant
*Significant P < 0.05, **Significant P < 0.01, ***Significant P < 0.001.

significant by both soil mulching and fertilizer treatments. Yield of sesame was significantly different both soil mulching and fertilizer treatments, but it was not different interaction between soil mulching and fertilizer treatments. While comparing the urea and SRF treatments, yield of sesame in NM was significantly different, but it was not different in PFM.

Yields of sesame in NM plot were about 1/2 compared with those of PFM. It seems that NM soil reduce soil water content, temperature and nutrient uptake of plant because of increasing water evaporation and nitrate loss by leaching etc.

N uptake and recovery rate

N uptake in different parts of sesame at harvesting time is shown in Table 3. The soil mulching effect on N uptake was significant, and also between fertilizer treatments except N uptake of stem and leaf. Amount of N uptake increased by CDU and LCU which had high sesame yield. In PFM, N recovery with application of CDU and LCU were 29.8~35% and 44.6~46%, respectively and those of SRF were 2~18.1% higher than that of urea application. N recovery rate in NM soil was remarkably less than those of PFM soil and SRF application increased N recovery compared with that in urea treatment.

N uptake and recovery was improved with PFM and SRF which decreased nitrate leaching and retained more mineral N than NM during growing the sesame growing period. Also, the differences in N recovery between the two soil mulching might come have from the different N losses such as nitrous oxide emission and ammonia volatilization as affected by fertilizer type and environmental conditions such as water content, evaporation, temperature etc. (Unger, 1975; Schmidt and Worthington, 1998; Bowen and Frey, 2002).

CONCLUSION

There was a difference in soil N distribution between PFM and NM when different types of N fertilizers were applied for sesame in upland soil. The dominant N in PFM soil was nitrate rather than ammonium but N concentration in NM was not significantly different from nitrate and ammonium.

In PFM soil, mineral N (nitrate + ammonium) showed various distribution in urea applied plot compare with SRF plots during the growing season. However, urea-N in soil was higher in CDU and LCU plots where N released slowly than that in urea plot. High N accumulation in the surface soil led to nitrate leaching down to the deep soil layer (Fig. 1). Among fertilizer treatments the potential of nitrate leaching loss was highly observed in urea plot. Nitrate leached from urea plot in NM and PFM were 90 mg L^{-1} and 27 mg L^{-1}, while in SRF was 70~82% and 9~48% of that in urea plot, respectively. On the whole, slow release fertilizer on reduction of nitrate leaching showed great impact in non-mulched soil. Yields of sesame in NM plot were about half level compared with those in PFM. Especially, application of SRF in PFM and NM plot increased yield up to 3~7% and 5~22% compared with urea, respectively. N recovery by SRF compared with urea in sesame plant increased to 2~18% and 5~18% in PFM and NM, respectively. As a result, compared with urea application, SRF application contributed to the retention of more mineral N, which resulting in reduced nitrate leaching, increasing N efficiency, and sesame yield.

ACKNOWLEDGMENT

This study was supported by Post Doctoral Course Program of Yeungnam Agricultural Research Institute, Rural Development Administration, Republic of Korea.

REFERENCES

Bowen, P. and B. Frey. 2002. Response of plastic cultured bell pepper to staking, irrigation frequency and fertigated nitrogen rate. Hort. Science. 37(1) : 92-94.

Chang, C. and T. Entz. 1996. Nitrate leaching losses under repeated cattle feedlot manure applications in Southern Alberta. Journal of Environmental Quality. 25(1) : 145-153.

Choi, Y. M., J. N. Lee, J. T. Lee, G. O. Cho, and W. B. Kim. 2000. Yield and storability of onion (*Allium cepa* L.) according to application of controlled-release fertilizer in alpine area. J. Korean. Soc. Hort. Sci. 41 : 499-502.

Lim, D. K., Y. K. Chung, D. H. Choi, and K. S. Seong. 1995. Property of controlled release compound fertilizer for upland crops. RDA. J. Agri. Sci. 37 : 213-219.

Minami, K. 1992. Effects of nitrification inhibitors and slow released fertilizer on emission of nitrous oxide from soil. Res. Rep. Div. Environ. Planning (NIAES). 8 : 137-146.

Morihiro, M., Z. Bingzi, O. Yasuo, and Y. Tadakatsu. 2003. Nitrate leaching in an andisol treated with different types of fertilizers. Environment pollution. 121 (477-487).

NIAST. 2000. Chemical analysis of soil and plant. National Institete of Agricultural Science and Technology, Rural Development Administration, Suwon, Korea.

Oh, D. S., Y. W. Kwon, J. N. Im, and K. S. Ryu. 1996. Actual evapotranspiration of sesame crop cultured with and without transparent plastic film mulch. J. Korean Soc. Soil Sci. Fert. 29(1) : 34-43.

Reynolds, C. M., D. C. Wolf, and J. A. Armbruster. 1985. Factors related to urea hydrolysis in soils. Soil Sci. Soc. Am. J. 49 : 104-108.

Rhee, K. M., J. H. Yoon, and J. K. Park. 1990. Effect of polyethylene film mulching on the change of soil chemical properties during the sesame cropping season. Res. Rept. RDA (S&F). 32(3) : 38-45.

Schmidt, J. R. and J. W. Worthington. 1998. Modifying heat unit accumulation with contrasting colors of polyethylene mulch. Hort. Science. 33(2) : 210-214.

Seong, K. S., B. J. Kim, and J. S. Shin. 1991. Development of slow release compound fertilizer used urea-resin for upland crop. II. Effect of slow release compound fertilizer on Chinese cabbage. J. Korean Soc. Soil. Sci. Fert. 24 : 50-54.

Thomsen, I. K., J. F. Hansen, V. Kjellerup, and B. T. Christenson. 1993. Effects of cropping system and rates of nitrogen in animal slurry and mineral fertilizer on nitrate leaching from a sandy loam. Soil Use and Management. 9(2) : 53-58.

Unger, P. W. 1975. Role of mulches in dryland agriculture. In Gupta, U. S. (Ed), Crop Physiology. Oxford/IBH Publishing Co. New Delhi, pp. 237-260.