Seasonal Changes in Soil Ammonium and Nitrate in Relation to Crop Production

Paibool Wivutvongvana and Suchart Jiraporncharoen*

Department of Soil Science and Conservation, Faculty of Agriculture, Chiang Mai University, Chiang Mai 50200, Thailand

**Corresponding author. E-mail: agsci005@chiangmai.ac.th*

ABSTRACT

Twelve on-farm experiments (sites) were conducted throughout the "Thai Family Research Project" area in four provinces (three sites per province) during 2001 growing season. Upland rainfed corns (Zea mays L.) were planted on Typic Calciustolls soil in Lopburi, whereas lowland paddy rices (Oryza sativa L.) were grown on Typic Tropaquepts in Chachoengsao and on Aeric Paleaquults in Buriram and Sisaket. The main purpose was to investigate seasonal changes in soil exchangeable NH_4^+ and NO_3^- in relation to farmers' conventional practices of fertilization (F) and a control-modified treatment (C). The amount of fertilizer in the C was approximately half of the F plot.

Except only one site of corn, monthly concentrations of exchangeable NH_4^+ and NO_3^- at two soil depths (0-20 and 50-70 cm) were not significantly different between the C and F treatments. For corn, soil NH_4^+ varied slightly during the growing period whereas concentrations of NH_4^+ in paddy soil increased considerably depending upon soil fertility after planting (soil submergence) and then decreased gradually until rice harvest. Concentrations of nitrate, particularly under flooded rice soil depleted rapidly after flooding.

In addition to soil fertility and cultivation practices, seasonal changes in soil NH_4^+ and NO_3^- concentrations were closely related to plant uptake (hence planting date, moisture availability and plant growth performance). Considering the very low concentrations of NH_4^+ and NO_3^- in the flooded water as well as in both the upper and lower soil depths, the application methods and fertilizer rate used in the present investigation were unlikely to have any adverse effect on the environment.

Key words: Ammonium, Nitrate, Soil, Seasonal changes

INTRODUCTION

Plants absorb nitrogen in inorganic forms, NH_4^+ and NO_3^- from soil solution. If plant uptake and losses (e.g., by leaching and denitrification) are excluded, the amounts of inorganic nitrogen present in the soil are the net result of nitrogen mineralization and immobilization. Both processes are mediated by soil microorganisms utilizing organic matter which is the major pool of soil-N as energy sources (Norton, 2000). Concentrations of soil exchangeable NH_4^+ and NO_3^- in soil solution are frequently used as an important index of N availability (Blackmer, 2000; Sim, 2000).

Both inorganic forms of nitrogen, especially NO_3^- are very mobile and may show a marked seasonal change in concentrations during the growing season when soil moisture and temperature are suitable for microbial activities. In addition, in well-to moderately well-drained soils, most NH_4^+ will be nitrified fairly rapidly into NO_3^- and subjected to losses (mainly by leaching) from the soil system. On the other hand, under submerged condition (e.g., paddy rice cultivation) NH_4^+ tends to accumulate with time of submergence due to lack of O_2 for nitrification. Nitrate (if presents) is depleted rapidly within a week after flooding due to denitrification (Ponnamperuma, 1972; Patrick and Jugsujinda, 1992). Thus while nitrate is the main form of leaching losses in upland soils, leaching of NH_4^+ ion is an important mechanism in flooded soils with substantial water movement.

Informations and particularly on-farm research work concerning changes in soil NH_4^+ and NO_3^- during the cropping season of major crops in Thailand (e.g., field corn and flooded rice) as well as their impacts on environment are very limited. The present investigation aims at providing these interesting and useful informations. Regarding to farmers' adoption and participation, the experiments involved are practical and appropriate for local farmers. This paper is a part of the research entitled "Fertilizer response and seasonal changes in soil ammonium and nitrate in relation to crop production" supported by Chicago University via the "Thai Family Research Project" in Thailand (Department of Soil Science and Conservation, 2002).

MATERIALS AND METHODS

On-farm experiments were undertaken throughout the "Thai Family Research Project" area located in the four provinces: Lopburi, Chachoengsao, Buriram, and Sisaket during 2001 cropping season. Three representative farmer fields in each province were carefully selected for the experimental sites (a total of 12 sites). These sites are the typical farmer fields in the village regarding to soil characteristics, crop species, cultivation practices and crop yield performance. The preliminary study (Department of Soil Science and Conservation, 2002) indicated that soils of the three experimental sites in each province were very similar and belong to the same Great Group (Soil Survey Staff, 1975; 1998). The test soil in Lopburi was a Typic Calciustolls, whereas Chachoengsao soil was classified as a Typic Tropaquepts. Both soils in Buriram and Sisaket were in the same Great Group, Aeric Paleaquults. Chemical analysis results of the surface soil samples (0-20 cm depth) taken before planting and fertilization were not much different among sites in each province. Their averaged values are given in Table 1. Upland rainfed corns (*Zea mays* L.) were planted in Lopburi, while lowland paddy rices (*Oryza sativa* L.) were grown in the other three provinces. By a close cooperation with the Thai Family Research Project, all management and cropping practices were carried out by the farm owners at each site.

Table 1. Average chemical analyses of the surface soil samples (0-20 cm depth) taken from the experimental plots before planting in each province.

Province	pH[1/]	%O.M.[2/]	P[3/] (mg kg^{-1})	Extractable (mg kg^{-1})[4/]				
				K	Ca	Mg	Fe	Mn
Lopburi	7.7	2.3	17.5	143.7	8667	101.7	3.75	0.10
Chachoengsao	4.7	2.2	19.5	289.0	1292	666.7	163.2	23.83
Buriram	5.0	0.9	3.0	25.5	208.3	11.67	230.8	5.00
Sisaket	4.5	0.9	3.1	49.3	166.7	13.33	155.4	10.25

[1/] Soil : H_2O = 1:1 [2/] Walkley & Black method [3/] Bray II method [4/] 1M NH_4OAc, pH 7.0 extraction

To avoid complexities in farmers' operation as well as to fulfill the objectives, a very simple experimental design consisting of two treatments in a randomized complete block with three replications was used in the study for all sites (3 sites in each province). The designation and description of the two treatments are:

F : The farmers' conventional practices of fertilization. In most cases, the crops were fertilized twice, first at planting and 2-3 weeks later for the second application.

C : A control-modified treatment in which the crop was fertilized only once at the second application of the F plot. The first application as done for the F plot was omitted in the C treatment.

An individual plot size was 5 m x 5 m with an area of 2 m x 2 m in the middle of the plot for soil samplings and crop harvesting. Corns were seeded with plant spacings approximately 75 cm between rows and 10-15 cm within the row. Rices were either transplanted (25 cm x 25 cm spacing) with 30-40 day-old seedlings or direct seeded at a rate of 95-125 kg ha^{-1}. Some important cropping data for each experimental site in each province are given in Tables 2-5.

To examine seasonal changes in NH_4^+/NO_3^-, representative soil samples at two soil depths, 0-20 cm and 50-70 cm of both C and F designated plots for all replications were collected monthly at each site. After sampling collection, the field-moist samples were immediately air-dried. To facilitate the drying, each soil sample was thinly spread over a clean plastic sheet in a well ventilated room. Then the air-dried soil samples were packed and transported to Chiang Mai University. Soil extractable NH_4^+/NO_3^- in KCl solution were analysed by steam distillation method (Mulvaney, 1996). In addition, in the case of paddy rice, surface water samples from both C and F plots were taken three times during July-October (rainy season). When it was available, depending upon locations, water in the pond/reservoir nearby the experimental plots was also sampled simultaneously. All water samples were kept refrigerated in a cooler container (0-5˚c) during the transportation to the University for NH_4^+/NO_3^- determinations.

Table 2. Some important cropping data for each experimental site at Tumbol Chorn-Maung, Ban Mi district, Lopburi province.

	Site 1	**Site 2**	**Site 3**
Hybrid corn cultivar:	CPDK 888	CPDK 888	CPDK 888
Planting date:	May 14	May 16	May 31
Fertilizer Application:			
(F treatment)[1/]			
1st Application:	May 14	May 15	May 31
Grade/type	15-15-15	Chicken manure	16-16-8
Rate (kg ha^{-1})	(8.13)	(62.5)	(78.2)
2nd Application:	June 9	June 16	June 26
Grade/type	15-15-15	16-16-8; 46-0-0	16-20-0; 46-0-0
Rate (kg ha^{-1})	(125)	(62.5) (93.8)	(93.8) (62.5)
Harvesting date:	September 28	September 27	October 11

[1/] For the C treatment, the plot was fertilized only once by the same method as indicated in the 2nd application for the F treatment.

Table 3. Some important cropping data for each experimental site at Tumbol Bang-Kra-Hai, Maung district, Chachoengsao province.

	Site 1	**Site 2**	**Site 3**
Rice cultivar:	Suphan 90	Pathum 60	Suphan 90
Planting date:	June 8	June 3	June 6
	(Direct seeding)	(Direct seeding)	(Direct seeding)
Fertilizer Application:			
(F treatment)[1/]			
1st Application:	July 2	June 25	June 29
Grade/type	16-20-0	16-20-0	46-0-0
Rate (kg ha^{-1})	(117.5)	(125)	(106.3)
2nd Application:	August 10	August 2	–[/2]
Grade/type	16-20-0	16-20-0	
Rate (kg ha^{-1})	(116.3)	(148.8)	
Harvesting date:	September 25	October 2	September 25

[1/] For the C treatment, the plot was fertilized only once by the same method as indicated in the 2nd application for the F treatment.

[2/] At Site 3, the crop was fertilized only once for the F plot. No fertilizer was applied for the C treatment.

Table 4. Some important cropping data for each experimental site at Tumbol Ban-Gruod, Ban-Gruod district, Buriram province.

	Site 1	Site 2	Site 3
Rice cultivar:	KDML 105	KDML 105	KDML 105
Planting date:	August 11 (Transplanting)	June 1 (Direct seeding)	July 29 (Transplanting)
Fertilizer Application: (F treatment)[1/]			
1st Application:	August 11	August 5[2/]	August 7
Grade/type	16-16-8	16-16-8	16-16-8
Rate (kg ha^{-1})	(117.5)	(87.5)	(125)
2nd Application:	August 29	-	September
Grade/type	16-16-8		16-20-0
Rate (kg ha^{-1})	(116.3)		(125)
Harvesting date:	November 8	November 18	November 20

[1/] For the C treatment, the plot was fertilized only once by the same method as indicated in the 2nd application for the F treatment.

[2/] For Site 2, both F and C were fertilized only once, but the C plot received only half the amount of the F plot.

Table 5. Some important cropping data for each experimental site at Tumbol Seaw, Pho-Suwan district, Sisaket province.

	Site 1	Site 2	Site 3
Rice cultivar:	KDML 105	KDML 105	KDML 105
Planting date:	July 24 (Transplanting)	July 24 (Transplanting)	August 7 (Transplanting)
Fertilizer Application: (F treatment)[1/]			
1st Application:	September 11	August 7	September 11
Grade/type	15-15-15	16-16-8	15-15-15
Rate (kg ha^{-1})	(100)	(100)	(100)
2nd Application:	September 25	September 18	October 2
Grade/type	15-15-15	16-16-8	15-15-15
Rate (kg ha^{-1})	(100)	(100)	(100)
Harvesting date:	November 20	November 20	November 20

[1/] For the C treatment, the plot was fertilized only once by the same method as indicated in the 2nd application for the F treatment.

RESULTS AND DISCUSSION

In Relation to Upland-Corn Production

Except in July at Site 3 (Lopburi province), results indicated that concentrations of NH_4^+ and NO_3^- in each soil depth under the corn crop production were not significantly different between the C and F fertilizer treatments throughout the growing season. It was also found that the amounts of ammonium and nitrate nitrogen determined monthly were not much different between Sites 1 and 2. Thus the concentrations were averaged from the two sites for each soil depth and presented graphically in Figure 1.

Results showed that concentrations of soil exchangeable NH_4^+ were relatively higher in the upper (0-20 cm) as compared to the lower (50-70 cm) soil depths throughout the investigation period. This was mainly due to a higher content of organic matter in the surface soil which contributed to higher cation exchange capacity and a greater rate of nitrogen mineralization. Nevertheless, concentrations of exchangeable NH_4^+ were considerably stable and varied slightly from approximately 5 to 10 in the upper and 5 to 7 mg N kg^{-1} in the lower soil depths throughout the growing season (May-October). After corn harvesting (late September, see Table 2), the ammonium concentration tended to increase slightly as recorded in late December (Figure 1).

Similar results were obtained regarding to seasonal changes in nitrate nitrogen. However, the amounts of nitrate were very low ranging from almost zero to approximately 3 mg N kg^{-1} in both soil depths at Sites 1 and 2 throughout the investigation period (Figure 1).

Theoretically, in a well-to moderately well-drained soil including the one (Typic Calciustolls) grown with corns in the present study, NH_4^+ should be nitrified fairly rapidly into NO_3^-. However, the present result indicated a very low concentration of NO_3^- in both surface and subsoils at Sites 1 and 2. Thus it is likely that most of the mineralized NH_4^+ (or from the added fertilizer) was taken up rather fast by corn plants during the growing season. It should be noted that soil samples taken for NH_4^+ and NO_3^- determination in the present study were carried out only once a month. Particularly, the first sampling was done just before the basal application of fertilizer prior to planting (May 15). Then the second soil sampling was made one month later when the corn plants (at Sites 1 and 2) were about four weeks old. Therefore most of the mineralized and added nitrogen was taken up by the plants which grew vigorously at Sites 1 and 2. These results were supported by that obtained from Site 3 and will be discussed later. Consequently, relatively low concentrations, especially nitrate nitrogen in the soil were detected and no differences in concentration were observed between the June and July samplings in both C and F treatments. On the other hand, if soil samplings were carried out more frequently, a higher fluctuation in NH_4^+ and NO_3^- concentrations might be detected.

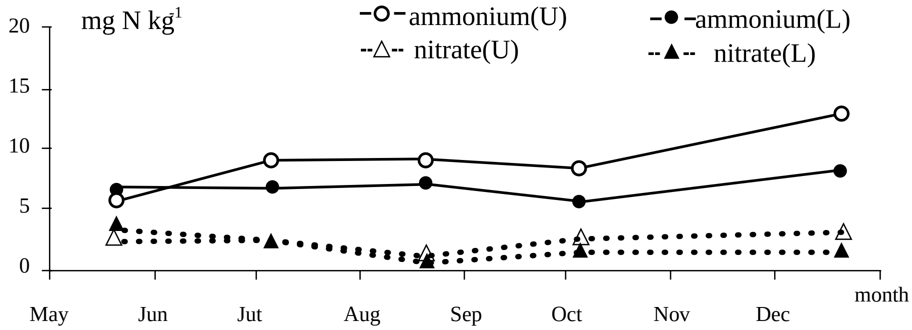

Figure 1. Seasonal changes in ammonium and nitrate nitrogen in the upper (U) and lower (L) soil depths averaging from Sites 1 and 2 of both C and F experimental plots in Lopburi province.

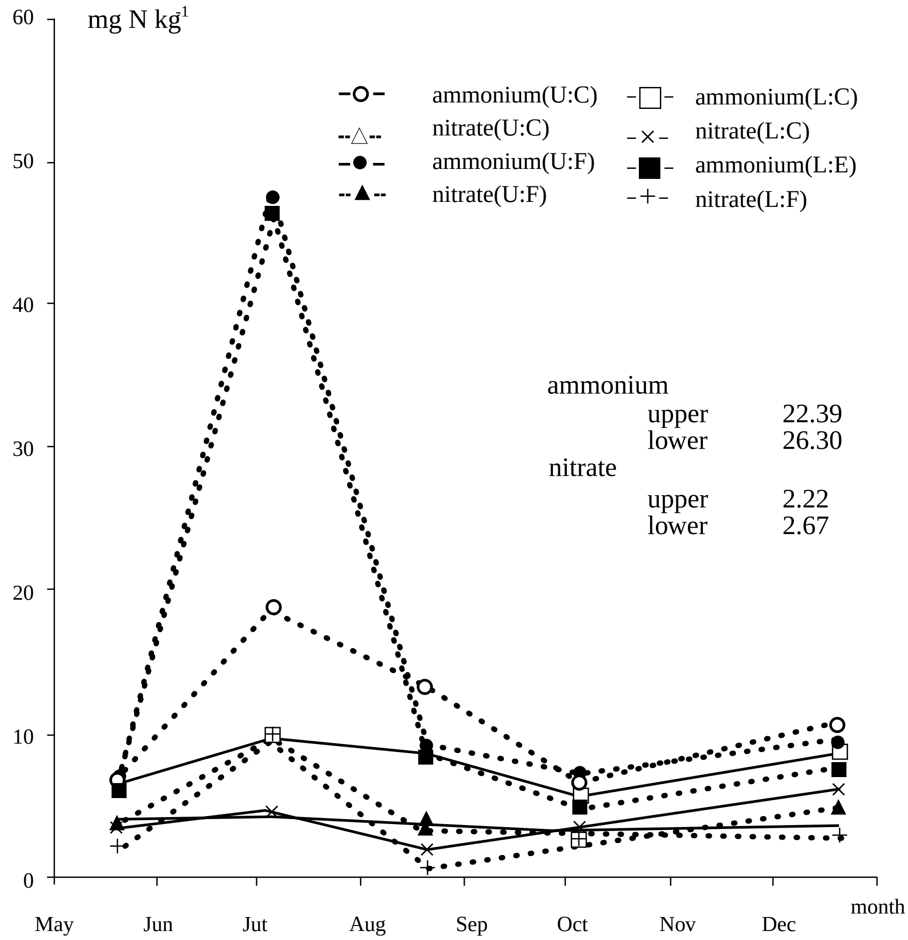

Figure 2. Seasonal changes in ammonium and nitrate nitrogen in the upper (U) and lower (L) soil depths as influenced by fertilizer treatments (C:control-modified treatment) (F:farmers' conventional practices of fertilization at Site 3 in Lopburi province.

According to Bundy and Meisinger (1994), the pre-sidedress soil nitrate test (PSNT) showed a critical level around 25 mg NO_3^--N kg^{-1} for corns grown in a wide range of conditions. Soil samples for PSNT were taken when corn plants were about 15-30 cm tall. Thus it seems that soils under the present investigation had a much lower NO_3^- concentration (0-3 mg N kg^{-1}). However, if soil exchangeable NH_4^+ (5-10 mg N kg^{-1}) was included, the total concentration of NH_4^+ + NO_3^- should be very close to the PSNT critical level (1 mg NH_4^+-N ≈ 3.4 mg NO_3^--N). Corn grain yields obtained from Sites 1 and 2 in the present study were moderately high and no significant differences were noted between the C and F treated plots. The average grain yields from both treatments were 6400 and 6156 kg ha^{-1} for Sites 1 and 2, respectively (Department of Soil Science and Conservation, 2002).

For Site 3, except in July, seasonal changes in soil exchangeable NH_4^+ and NO_3^- tended to follow the same pattern as observed at Sites 1 and 2. However, a strikingly different result was noted in early July at Site 3. Results showed that concentrations of inorganic nitrogen especially NH_4^+ in the F treated plot (fertilizer applied at planting) increased sharply from June to July in both the upper and lower soil depths as compared to a slight increase in concentrations in the C treatment (Figure 2). This implies that most of the fertilizer applied at planting was not utilized by corn plants. It was observed earlier that when the drought came during mid-June to early July, the corns with a late planting at Site 3 (May 31, see Table 2) were about two weeks old. Thus most plants were still small with less developed roots and subjected to a severe moisture stress. As a consequence, most of the added fertilizer was still remained and a high concentration of soil exchangeable NH_4^+ was detected in early July for the F treatment. High concentrations of NO_3^- in the fertilized F plots were also noted but with a smaller extent (Figure 2). Plant growth performance was rather poor throughout the growing season. No differences in corn yield were detected between the C and F treatments with very low grain yields, averaging 2,619 kg ha^{-1}. It is obvious that the changes in soil NH_4^+ and NO_3^- were quite different from those observed at Sites 1 and 2. This was mainly due to the plant uptake particularly during early vegetative growth of corns in June-July as discussed earlier.

The present findings have demonstrated a significant influence of plant uptake (hence planting dates, moisture availability and plant growth performance) on the net concentration of inorganic nitrogen present in an upland soil. For instance, if the plants grow vigorously, most of the applied nitrogen should be absorbed by extensive plant roots. As a result, concentrations of inorganic nitrogen in the soil would be low and nonsignificant amount of nitrogen would be lost (e.g. by leaching) from the soil system.

In Relation to Lowland-Paddy Rice Production

Seasonal changes in soil exchangeable NH_4^+ and NO_3^- in relation to lowland-paddy rice production were investigated through all sites in Chachoengsao, Buriram, and Sisaket provinces (3 sites in each province). Though a slight but significant differences in grain yields were detected at two of the nine sites, concentrations of NH_4^+ and NO_3^- between the two treatments were not statistically different for all locations (Department of Soil Science and Conservation, 2002). Nevertheless, it is interesting to examine the seasonal pattern of NH_4^+ and NO_3^- changes in soils under paddy rice cultivation. Thus monthly concentrations of NH_4^+ and NO_3^- in each soil depth were averaged from the C and F treated plots and presented graphically in Figure 3, a-c for each province.

Results showed that seasonal changes in soil exchangeable ammonium under paddy rice cultivation were similar for all the three provinces. Ammonium concentrations, especially in Chachoengsao surface soil increased markedly from approximately 5 to 18 mg N kg^{-1} after planting (after soil submergence). From July-August depending upon locations, when the rice plants were about one month old, concentrations of ammonium decreased gradually owing mainly to the plant uptake and then the concentrations slightly increased again after rice harvesting (after drainage, October). It should be noted that monthly concentrations of ammonium were considerably higher in Chachoengsao soil as compared to those observed in Buriram and Sisaket. These were mainly due to the higher organic matter content in the former soil (see Table 1). With the same reason, concentrations of ammonium in the top soil (0-20 cm) were consistently higher than those detected in the lower soil depth (50-70 cm) for all the investigated locations (Figure 3, a-c).

For nitrate nitrogen, on the other hand, its concentration decreased rapidly after soil submergence for all sites. The amounts of nitrate in both surface and subsoils were depleted to almost zero mg N kg^{-1} throughout the growing season (Figure 3, a-c). These losses of NH_4^+ and NO_3^- under the submerged condition were mainly due to denitrification process.

Results of the present investigation have demonstrated that nitrogen mineralization in the soil also occurs under submergence, but it stops at the ammonification step (conversion of organic-N to NH_4^+-N) owing to lack of O_2 for nitrification. Although the decomposition of organic matter proceeds at a slower rate in flooded than in aerobic conditions, anaerobic decomposition proceeds at lower energy levels and therefore requires less nitrogen. Thus the net amount of nitrogen mineralized is higher under soil submergence and NH_4^+-N tends to accumulate after flooding provided that there is no loss of ammonium nitrogen (e.g., by plant uptake). De Datta (1981) also reports that the availability of nitrogen is higher in flooded soils because of the lower immobilization (assimilation) of inorganic nitrogen by microorganisms.

Nitrogen Application-Environmental Impacts

In addition to soil samples, concentrations of inorganic nitrogen in the surface water of the C and F treated plots as well as the water in the pond/reservoir nearby were also determined periodically. Results indicated that the amounts of both NH_4^+ and NO_3^- nitrogen were very low and almost undetectable for all the investigated locations. Thus considering the very low concentrations of inorganic nitrogen, especially NO_3^--N in the water as well as in both the upper and lower soil depths under the upland corn crop (except at Lopburi Site 3) and lowland paddy rice productions, the application methods and fertilizer rate used in the present study were unlikely to have any adverse effect on the environment. The United States and United Kingdom set a pollution limit of 10 mg NO_3^- -N L^{-1} in the ground water (Miller and Miller, 2000).

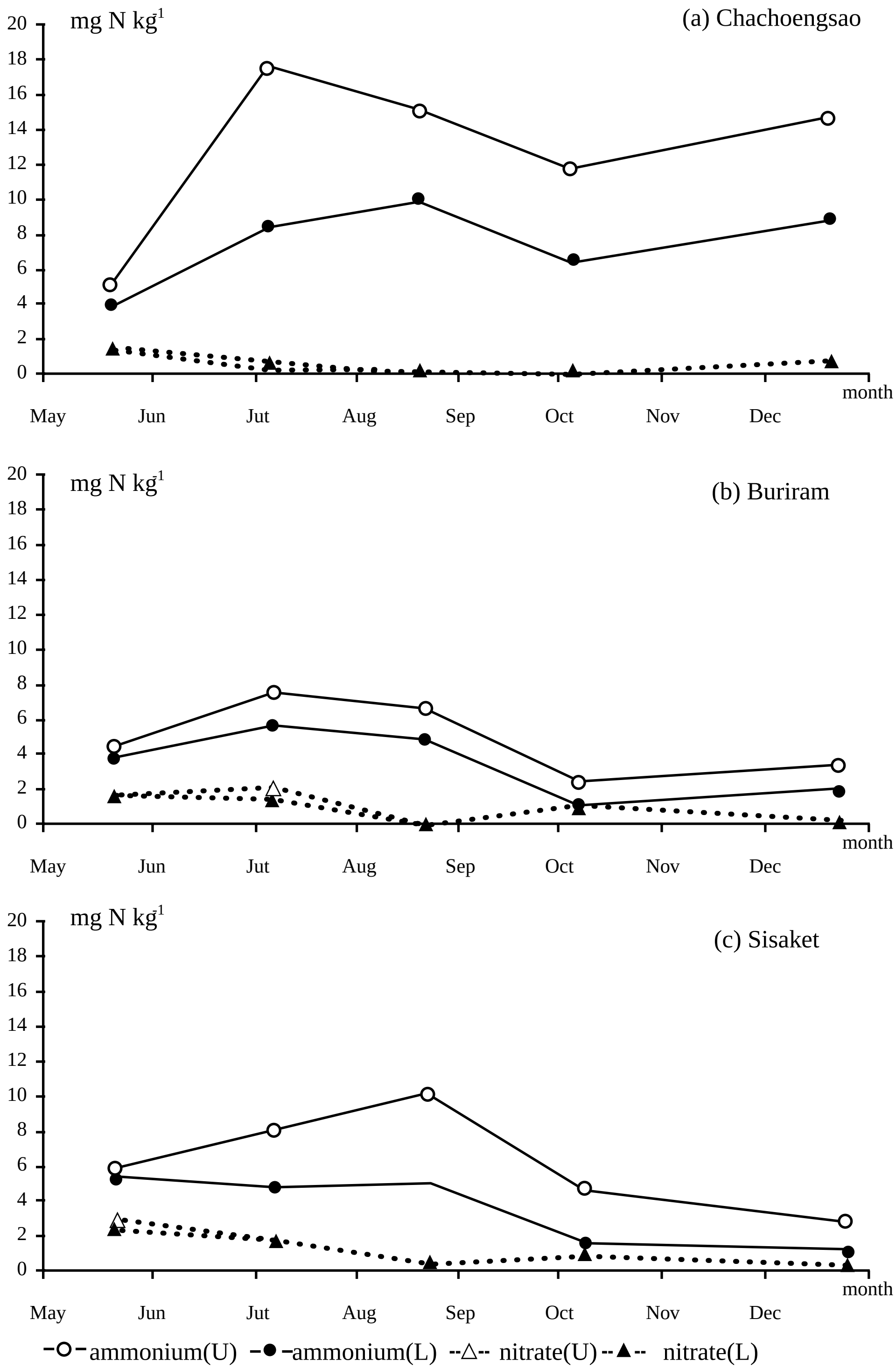

Figure 3. Seasonal changes in ammonium and nitrate nitrogen in the upper (U) and lower (L) soil depths averaging from the three sites of both C and F experimental plots in Chachoengsao (a), Buriram (b), and Sisaket (c) provinces.

CONCLUSIONS

Except only one (corn crop) of the 12 experimental sites, monthly concentrations of soil exchangeable NH_4^+ and NO_3^- between the control-modified treatment (C) and the farmers' conventional practices of fertilization (F) were not significantly different. In addition to soil fertility level (e.g., organic matter content) and cultivation practices (e.g., upland-corn crop and lowland-paddy rice), results showed that seasonal changes in soil NH_4^+ and NO_3^- concentrations were closely associated with plant uptake (hence planting date, moisture availability and plant growth performance). Considering the very low concentrations of NH_4^+ and NO_3^- in the flooded water or the pond water nearby as well as in both the upper and lower soil depths under the upland-corn crop and lowland-paddy rice productions, the application methods and fertilizer rate used in the present study were unlikely to have any adverse effect on the environment.

ACKNOWLEDGEMENTS

The authors would like to thank Director Sombat Sakuntasathien and Manager Songrat Wilairat of the Thai Family Research Project (TFRP) for their kind assistance and collaboration in conducting the research work. Financial support from Chicago University via the TFRP is most grateful and highly appreciated.

REFERENCES

Blackmer, A.M. 2000. Bioavailabity of nitrogen. p. D 3-18. In M.E. Sumner (ed) Handbook of soil science. CRC Press LLC. Boca Raton, FL, USA.

Bundy, L.G., and J.J. Meisinger. 1994. Nitrogen availability indices. p. 951-984. In R.W. Weaver (ed) Methods of soil analysis. Part 2: Microbiological and biochemical properties. Soil Science Society of America, Madison, WI, USA.

De Datta, S.K. 1981. Principles and practices of rice production. John Wiley & Sons Inc., NY, USA.

Department of Soil Science and Conservation. 2002. Fertilizer response and seasonal changes in soil ammonium and nitrate in relation to crop production. Report submitted to the Thai Family Research Project. Faculty of Agriculture, Chiang Mai University, Thailand.

Miller, D.M., and W.P. Miller. 2000. Land application of wastes. p. G 217-245. In M.E. Sumner (ed) Handbook of soil science. CRC Press LLC. Boca Raton, FL, USA.

Mulvany, R.L. 1996. Nitrogen-inorganic forms. p. 1123-1184. In D.L. Sparks, A.L. Page, P.A. Helmke, R.H. Loeppert, P.N. Soltanpour, M.A. Tabatabai, C.T. Johnston, and M.E. Sumner (eds) Methods of soil analyses. Part 3-Chemical methods 3rd ed. SSSA Book Series : 5. Soil Science Society of America Inc. & American Society of Agronomy Inc. Madison, WI, USA.

Norton, J.M. 2000. Nitrogen mineralization immobilization turnover. p. C 148-160. In M.E. Sumner (ed) Handbook of soil science. CRC Press LLC. Boca Raton, FL, USA.

Patrick, W.H. Jr., and A. Jugsujinda. 1992. Sequential reduction and oxidation of inorganic nitrogen, manganese, and iron in flooded soil. Soil Sci. Soc. Am. J. 56:1071-1073.

Ponnamperuma, F.N. 1972. The chemistry of submerged soils. Adv. Agron. 24:29-96. Sims, J.T. 2000. Soil fertility evaluation. p. D 113-153. In M.E. Sumner (ed) Hand book of soil science. CRC Press LLC. Boca Raton, FL, USA.

Soil Survey Staff. 1975. Soil taxonomy. Agricultural handbook No. 436. USDA-SCS. US Government Printing Office, Washington DC, USA.

Soil Survey Staff. 1998. Keys to soil taxonomy. 8th ed.USDA-NRCS, US Government Printing Office, Washington DC, USA.