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Behavior of Nitrate Nitrogen in an Andisol Following Intensive Fertilizer Regimes in Arable Lands

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Abstract

The impact of inorganic N fertilization and organic N fertilization on nitrate leaching in Andisol (volcanic ash soil) exposed to extreme rainfall was examined, with regard to different vegetables present. Soil water was collected, using ceramic porous cups installed in different soil layers, and analyzed for NO_3-N. Immediately after extreme rainfall, the NO_3-N concentrations in soil water at 50 cm depth were markedly increased compared with that of soil water at 100 cm and 200 cm depth, most likely due to the rapid leaching of fertilizer nitrogen caused by downward movement of water through the soil. Nitrate leaching in fields amended with inorganic N fertilizer was greater than in fields amended with organic fertilizers. Soil, treated mainly with organic fertilizers showed higher nitrification activities and to a lesser extent denitrification activities than soils supplied mainly with inorganic N. It was concluded that the rapid nitrate leaching from inorganic fertilizer application in the experimental fields was induced by occasional single event of rainfall.

Key words : fertilizer regimes, nitrate leaching, nitrification, denitrification, Andisol, rainfall

INTRODUCTION

Groundwater is an extreamly valuable resource and therefore pollution of groundwater by nitrate following intensive agricultural practices is a matter of serious concern throughout the world. According to the World Health Organization (WHO) Guidelines, maximum admissible concentration of nitrate is 10 mg l^{-1} as nitrogen (45 mg l^{-1} nitrate) to be safe for drinking water. It was predicted that groundwater would reach to 34 to 45 mg l^{-1} NO_3-N (150 to 200 mg l^{-1} NO_3^-) in the future if present agricultural losses remain unchanged[1)].

In actual fact, the removal of nitrates from water is expensive[1, 2)], therefore, key concern should be directed to preventing contamination of water resources by nitrates. More and more, the ability to predict the risk of nitrate leaching is necessary in order to make recommendations for minimizing N-losses into the subsurface environment. A number of factors and practices can influence the nitrate concentration in soil and consequently in groundwater. Pertinent factors include precipitation or irrigation[3, 4)], soil type[5-8)], nitrification and denitrification, and non-agricultural sources in the subsurface environment. Pertinent practices include fertilizing intensity and crop type[4, 9)].

Rainfall is one of the predominant factors

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for nitrate leaching. Most of the Asian countries including Japan receive annual rainfall around 1200 mm or more, which is nearly about two times higher than that of European countries (500-800 mm). Most possible reason for such higher annual rainfall in Asia is typhoons or cyclones or monsoon rains, which brings extreme rain within a very short period.

Andisol is a kind of volcanic ash soil, which covers about 51% of upland agricultural lands in Japan. Most of the agricultural lands of Andisols are exposed to heavy rains from typhoons, which equate to nearly 25% of the annual rainfall of Japan. Volumetric water holding capacity of Andisols is comparatively higher than that of other soils[4] and water flux through soil increases when the rainfall intensity increases[10,11]. In addition, Andisols are volcanic ash soils and hence the anion exchange capacities are higher than other soils[12]. Hence tendency of leaching of NO_3 interferes differently with N-cycle and N-transport. This affects to the fertilizers, which is usually applied before the autumn rainfall and none of the study was carried out to assess the risk of nitrate leaching in such arable lands following the single event of extreme rainfall.

Fertilizer type is also a predominant factor of nitrate leaching. Use of inorganic fertilizers is conventional, however the substitution of slow-release organic fertilizers or manures for inorganic fertilizers is becoming popular, as consumers increasingly prefer products grown with organic fertilizers. Further more, composting of livestock waste (manure) has been recognized as a promising alternative to waste management[13] as utilization of live stock waste compost could be substituted for inorganic fertilizer.

Although several studies have documented that nitrate leaching in several soils[1, 14-16], none have particularly concentrated on the nitrates exhibited in arable soils when inorganic fertilizer is substituted with livestock waste under an extreme rainfall event. Hence, it is of the utmost importance to understand the fertilization-dependent nitrate behavior in soils and nitrate leaching properties related to the occurrence of heavy rainfalls in arable lands in order to assess their contribution to reduce leaching of nitrate when they are treated with organic fertilizer and inorganic fertilizer.

This study was carried out to determine the effect on nitrate leaching in arable soil (Andisol) with inorganic fertilizer, and organic fertilizer substituted (live stock waste compost) for inorganic fertilizer following extreme rainfall. The conventional fertilizer treatment of the study area consists of mainly inorganic fertilizer. Substitution of organic fertilizer for inorganic fertilizer associated with 4 years of crop rotation was introduced for contributing to livestock waste management in the area with out affecting to crop yield.

The authors also have considered the pertinent factors of nitrate leaching such as crop sequence and rotations, nitrification and denitrification activities, in the instance when arable land was treated with mainly organic fertilizers and inorganic fertilizers (ammonium sulfate).

MATERIALS AND METHODS

Field history A field study was conducted at the Nippon Agricultural Research Institute (NARI) in Kukisaki in Ibaraki Prefecture, Japan. The average depth of the groundwater table in this area is about 5 m, however the water table is known to fluctuate during the rainy seasons. The soil is Andisol, which has the unique physical characteristics of low density, high porosity, large surface area, and high soil water retention capacity even at low matric potentials[12]. The surface soil to a depth of 18 cm was dark brown in color (7.5 YR 3/4) with 5-10% humus. Depths from 18 cm to 25 cm showed that a plowsole was present, and below the plowsole the color of soil was brown (7.5 YR 4/6) with 2.5% humus. Some physico-chemical characteristics of the plow layer (0-18 cm) and the sub soil (18-25 cm) prior to the start of crop rotation are given in Table 1.

Fertilizer Treatments Originally the experiment field was established to examine the effect of substitution of organic fertilizer for inorganic fertilizer on the growth, yield and quality of the crops. The six cultivated crops with rotation were crops, Italian rye

Table 1 Physiochemical characteristics of plow layer soil and subsoil of an Andisol at NARI(Ibaraki, Japan) before crop rotation and fertilizer applications

Soil characteristics	Plow layer soil (0～18cm)	Sub soil (18～25cm)
Physical characteristics		
Sand(%)	16.0	25.0
Silt(%)	33.8	30.0
Clay(%)	50.2	45.0
Air conductivity(m*l*/min)	750	30
Hydraulic conductivity(cm/sec)	0.0058	0.0069
Volumetric water capacity(%)	40	50
Chemical characteristics		
pH(in water)	6.4	6.4
Total N(mg/gDW)	5.6	5.5
Total C(mg/gDW)	66.6	62.9
C : N ratio	13.9	13.3
CEC[a](me/100g dry soil)	30	30

[a]cation exchange capacity

grass, radish, potato, barley, Chinese cabbage, and peanuts.

For this study four test fields were selected; A, B, C and D. Amounts of applied fertilizer and cultivated crops for all the fields are shown in Table 2. In field A and field C, cattle manure was the main fertilizer source, while in field B and field D inorganic fertilizer (ammonium sulfate) was the main source. Fertilizer treatment of B and D represents the conventional fertilizer treatment used in this area. NO_3 leaching at the four agricultural fields A to D was investigated in the fourth year from the start of the treatment. Cattle manure prepared by NARI was used for this research. It consisted mainly of cow dung and wooden chips and had a total N content of 0.5 %. The amount of cattle manure to be applied to each crop depended on the total nitrogen concentration of cattle manure. The cattle manure supplemented the applied inorganic fertilizer, until the total nitrogen was half

Table 2 Seasonal nitrogenous fertilizer application rates and planted crops in 4 agricultural test fields with Andisol at NARI(Ibaraki, Japa) from spring 1993 to autumn 1996

Agricultural Field		Field A		Field B		Field C		Field D	
Type of Fertilizer	Season	Inorganic fertilizer (N kg ha^{-1})	Organic fertilizer (N kg ha^{-1})	Inorganic fertilizer (N kg ha^{-1})	Organic fertilizer (N kg ha^{-1})	Inorganic fertilizer (N kg ha^{-1})	Organic fertilizer (N kg ha^{-1})	Inorganic fertilizer (N kg ha^{-1})	Organic fertilizer (N kg ha^{-1})
1993	[a]Spring	*Peanuts*				*Potato*			
		NA	150	30	NA	60	200	120	NA
	[b]Autumn	*No crop*				*Barley*			
		NA	NA	NA	NA	NA	200	53	100
1994	[a]Spring	*Italian rye grass*				*No crop*			
		NA	200	80	NA	NA	NA	NA	NA
	[b]Autumn	*Radish*				*Chinese cabbage*			
		60	200	150	100	120	200	240	100
1995	[a]Spring	*Potato*				*Peanut*			
		45	100	120	NA	NA	100	30	NA
	[b]Autumn	*Barley*				*No crop*			
		NA	200	53	100	NA	NA	NA	NA
1996	[a]Spring	*No crop*				*Italian rye grass*			
		NA	NA	NA	NA	NA	200	80	NA
	[b]Autumn	*Chinese cabbage*				*Radish*			
		120	200	240	100	75	150	150	100
	Total	225	1050	673	300	255	1050	673	300

[a] spring : 16 March-15 June, [b] autumn : 16 September-15 December,
NA = no application

that of the recommended by conventional fertilizer regimes per each agriculture in the Ibaraki prefecture (Table 2).

Annual rainfall The annual rainfall of this area is in between 1000-1500 mm, which mainly depends on the rains brought by typhoons. Typhoons generally occur in September to October and contribute to nearly 25% of annual rainfall.

The meteorological division of the National Institute of Agro-Environmental Sciences, Tsukuba, Japan, provided annual rainfall data (Fig. 1) and temperature fluctuations (Fig. 6) of the area.

Soil water extraction using porous cups Porous cups were used for sampling soil water in the four experimental fields. The sampling units consisted of three parts: a porous suction cup (20mm o.d., 50mm length), a connecting hollow wire and PVC pipe (20 mm i.d). Suction cups are constructed of hydrophilic ceramic materials with fine pores (1-2 μm). The soil water collecting units were installed at depths of 50 cm, 100 cm and 200 cm. Each porous cup was mounted on a PVC pipe and a hollow tube of 1 mm diameter placed into the inner bottom of the porous cup to take out accumulated soil water. The PVC pipe supporting the ceramic porous cup protected the hollow tube, which carried water to ground level. For each depth 2 units were installed along a straight line in every field, with a distance of 15 m between units.

Before installation, each cup was washed with 10% HCl solution and then rinsed with deionized water until the conductivity of the rinsing water to fell below 6 $\mu S\ cm^{-1}$. A 50 cm deep trench was dug to install the porous cups. For installation at 100 cm and 200 cm depth holes were drilled in the bottom of the trench, with a hand auger with diameter slightly over 20 mm. Hydraulic-continuum was ensured by carefully filling the narrow gap between the cups and soil with fine soil particles. Side leakage was prevented by also carefully filling the gap between soil and PVC pipe. After installation the trench was filled with the original soil.

Sampling was performed once per two weeks from March 1996 to April 1997. A flask with an air stopper and a hand-operated pressure-vacuum pump were used for sampling. The hollow sampling tube was connected with a needle to the stopper on the flask. Porous cups were operated under a falling head of 80 kPa, which was sufficient to collect volume of water for analysis using a handy suction pump (DIK-3910, Daiki Rika Kogyo, Japan). The water samples were filtered through a 0.4 μm membrane filter and were analyzed for NO_3-N. The analyses were carried out using ion chromatography (Dionex 2010i, Germany).

Soil sampling and analysis Soil samples were collected every 10 cm, from the surface to 50 cm depth, in February 1997 after the harvest of Chinese cabbage and radish. Sampling was done at either end of the imaginary line joining the positions of the ceramic cup in each field.

The soil samples were ground to pass a 2-mm sieve, packed in poly-ethylene bags and stored at 4℃ till analysis. The moisture content of each sample was measured, and pH (water) determined (1:5 soil:water) using a glass pH electrode. Fresh soil ($\approx$12g) was shaken with 90 ml 10% (w/w) KCl solution for 60 min. The suspension was filtered and the filtrate was analyzed colorimetrically for NO_3-N and NH_4-N with TRAACS 800 autoanalyzer (BRAN+LUEBBE TRAACS). Parts of the soil samples were allowed to dry at ambient temperature crushed to finer powder and analyzed for total N and total C using an ANCA-SL mass spectrometer (Europe Scientific Crew, UK) in the single C/N mode.

Determination of nitrification and denitrification capacities Nitrification capacity of each soil was determined by measuring NO_2-N and NO_3-N accumulations during incubation in a buffer containing NH_4-N[17]. In a 250 ml flask 20 g of fresh soil, 0.15 g $CaCO_3$ and 50 ml medium were placed. One liter of medium (pH 7.5) contained 330 mg $(NH_4)_2SO_4$, 140 mg K_2HPO_4 and 27 mg KH_2PO_4. Samples were shaken at 150 rpm at 25℃. One-milliliter samples were taken after 1 hr and 8 hrs incubation and analyzed for NO_2^- and NO_3^- by ion chromatography. Preliminary experiments with hourly samplings had demonstrated linear production of NO_2^- and NO_3^- up to 9 hrs of incubation. Per soil sample the average of three replicates was obtained.

The denitrification potential of each soil sample was measured by the acetylene inhibition method[18], with minor modifications. 20 g of fresh soil was placed in a 100 ml glass bottles and 20 ml 10mM KNO_3 solution was added before capping the bottles gas tight with rubber stoppers. To create anaerobic conditions, the air in the flasks was evacuated and replaced by Argon gas. This procedure was repeated three times. To inhibit reduction of N_2O gas to N_2, 10% of the gas phase in the bottles was replaced by C_2H_2 gas[19]. Samples were incubated at 25℃. 0.5 ml samples of the gas phase in the bottles were taken through the septum with an air-tight micro-syringe and analyzed for N_2O gas using a gas chromatograph (Shimadzu 14B, Japan). Sampling was done after 1, 4 and 12hrs.

Determination of nitrifiers and denitrifiers The method of determination of nitrifiers and denitrifiers is set out in JIS (Japan Industrial standards) K0102 and has been used for enumeration of the nitrifiers in several soils including Andisols[20]. To count the populations of NH_4^+ oxidizing bacteria and NO_2^- oxidizing bacteria an immuno latex detection kit called "kensyutukun" (Yakult Co., Japan) was used. The detection kit includes all necessary buffers for detecting NH_4^+ and NO_2^- oxidizing bacteria within 30 hrs. The detection limit of NH_4^+ oxidizing bacteria and NO_2^- oxidizing bacteria by this method is 6×10^4 and 1×10^5, respectively. Samples were prepared uniformly by mixing fresh soil (equivalent to 1g of dry weight) with 9 ml 5 mg l^{-1} sodium tri-polyphosphate buffer (TPB) of pH 7. The mixture was treated with ultrasonic waves for 15 min using a sonicator (UD201: Tomy, Japan) and the resulting supernatant was diluted 10 times with TPB. Following the instructions of the manufacturer, NH_4^+ and NO_2^- oxidizing bacterial populations were counted separately according to the most probable number (MPN) method.

The population size of denitrifying bacteria was estimated by the MPN method, using the medium (8 g nutrient broth and 1 g KNO_3 per liter)[21]. Fresh soil was mixed (equivalent to 10g of dry weight) with 90 ml phosphate buffered saline (PBS). One milliliter of each soil sample was added to 9 ml PBS-buffer in order to make a series of dilutions. A further 10 ml of sample was placed into a tube with an inverted Durham tube. A series of 10^1 to 10^{10} time dilutions of the original soil mixture were obtained. Three replicate dilution series were prepared for the each soil sample. The test tubes were capped well to make an anaerobic gas phase and incubated at 28 ℃. A positive score was found when gas production in the inverted Durham tubes was observed after 14 days.

RESULTS AND DISCUSSION

Variation in NO_3-N concentrations at three depths in agricultural fields Fig. 1 shows the changes of soil water NO_3-N concentrations at 50, 100, 200 cm depths in all four fields from late February 1996 to April 1997. Due to insufficient rainfall, in some instances no soil water could be extracted for analysis in the first few months. In the beginning of the study, fields A and C, which were fertilized mainly with organic fertilizer, showed high NO_3-N concentrations at the depth of 100 cm (Fig. 1 A and 1C) most likely due to the fertilization from previous years, when compared to fields B and D (Fig. 1B and 1D), which received mainly inorganic N. The NO_3-N concentrations at 200 cm depth were found to be constant at a low value of around 20 mg l^{-1} in comparison to other depths. At 50 cm depths, NO_3-N concentrations decreased and then dramatically increased just after the typhoon on September 22, 1996. This Typhoon brought a single event of heavy rainfall of 193 mm day^{-1}. The dramatic increase of NO_3-N in all four fields was approximately 70 mg l^{-1} or more. This event occurred after the fertilizer application at the end of August. The trends in NO_3-N concentrations of the soil water were similar for sites amended with organic and inorganic fertilizers. However, no dramatic increase in NO_3-N occurred at 100 and 200 cm depths in all sites after the typhoon, rather a decrease at 100 cm depth was observed. The detected NO_3-N concentrations of fields A and C at 50 cm depth were lower than the fields with conventional inorganic treatment (fields B

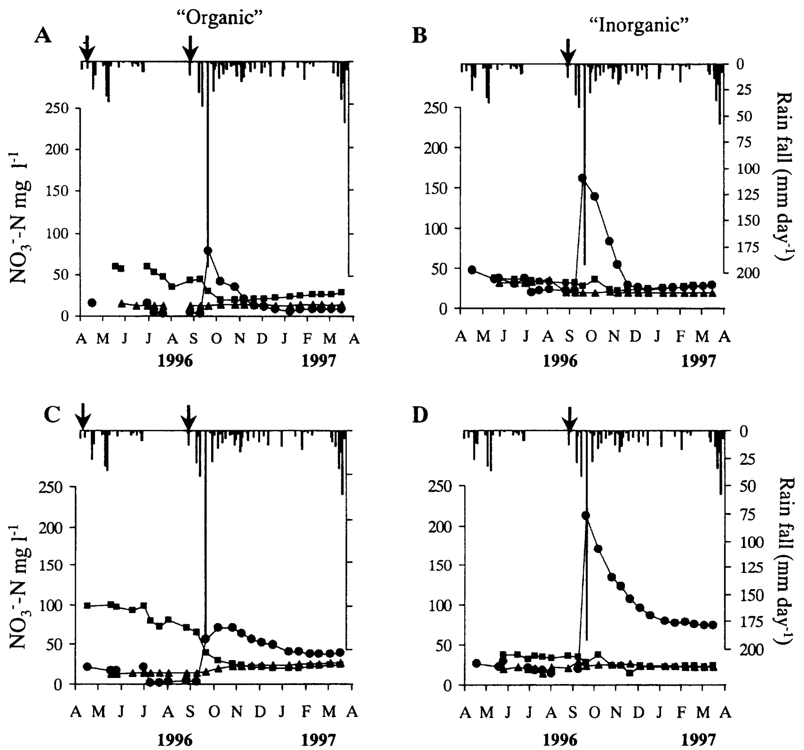

Fig. 1 Amounts of precipitation (mm day-1) and changes in NO3-N concentrations in soil solution collected from three soil depths in four fields (A, B, C and D) from 1996 March through 1997 April. 50 cm (●), 100 cm (■), and 200 cm (▲). (A) mainly organic fertilizer, cabbage (B) mainly inorganic fertilizer, cabbage (C) mainly organic fertilizer, radish (D) mainly inorganic fertilizer, radish; Arrows (↓) indicate fertilizer applications.

and D). The circumstances may be attributed to the slow-release organic fertilizers. Thus, it can be explained that NO_3^- at surface soils, which are received from fertilizers gradually move downward with the water flow when rainfall occurs.

In this study fertilizer regimes followed by a single event of rainfall affected the NO_3-N concentration in soil solution contrasting to the observation made by some reporters[22]. These authors showed that the fluctuations in NO_3-N concentrations were generally influenced by seasonal variation such as temperature rather than the fertilizer treatments accounting for make the higher level of NO_3^- in the soils. Although, some researchers[14-16] also observed maximum N leaching in late summer and early autumn as does this study. These authors too suggested that weather conditions such as temperature were one of the main factors by influencing nitrification in the soil, and as a result increasing NO_3-N concentrations. However, in this study, reduction of NO_3-N concentrations was observed in all fields during the summer (Fig. 1). Hence it is suggested that the temperature (Fig. 6) was not the main factor for accumulation of NO_3-N before the particular rainfall but rather the fertilizer regime.

Some reporters stated that the percolation rate of water in soils depends on inter-granular spaces[22] and the magnitude and duration of the soil water flux are strongly influenced by the water transmission properties of the soil[10]. Furthermore it was reported that due to the high transmission properties of Andisols, water infiltrates uniformly into that soil, without water accumulation on the surface. Another study

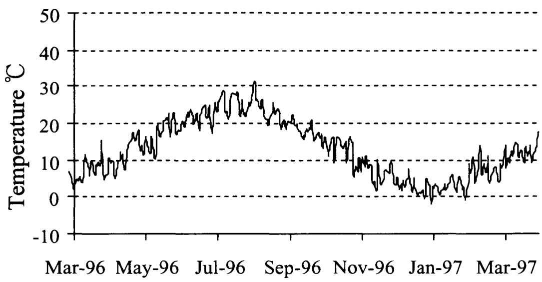

Fig. 6 Daily average temperatures around NARI from March 1996 to April 1997.

carried out in a Andisol[11] proved the infiltrating water flow highly depends on the rainfall intensity, as it increases matric potential within the soil. The water holding capacity of the Andisols are about 40-50%[11, 24]. Hence for 193 mm rainfall the water can be moved down to about 39 - 48 cm. Apparently, there is no doubt that high rainfall intensity induces a fast downward water movement in soil, and thereby increasing the water soluble nitrate transport and amount of water reaching to the maximum depth of 50 cm.

According to some reports the average rate of water movement through soil profile would be about 30 to 40 cm annually for silt loam or fine textured soils[25]. Further some have showed that climatic condition highly influences nitrate leaching through soils by controlling the soil water content of the soil[26]. In addition, a heavy rainfall event would carry nitrates derived from inorganic fertilizer to deep soil consequently to groundwater. There are similar results to this study, which clarified that nitrate leaching seems to increase when the amount of rainfall increases in structured soil[27].

For the present experiment fields, inorganic fertilizer ($(NH_4)_2SO_4$) was applied 2 weeks prior to the start of rainy season. 2-3 weeks after the fertilizer application onto the agricultural soils, NH_4^+ form fertilizer actively converts to NO_3^- under favorable conditions such as temperature, and organic carbon[28]. Therefore, the authors infer that the NH_4^+fertilizer of our agricultural fields was already converted to NO_3^- before the heaviest rainfall, which optimized the conditions for leaching.

Even though there was no NO_3-N peak found at about 100 cm during the experimental period the decrease of NO_3-N level was observed after the heavy rainfall in Figure 1 (A and C). This could be considered, as the denitrification or NO_3^- movement induced by the downward movement of water, but not by uptake of plants. By that time, the plants were small, as they had been planted one week before the typhoon. In addition, while nitrates were passing through the soil it could also be diluted in the soil waters. Therefore no peak at 1m was noticed during the entire period.

Nitrate concentrations along the soil profile varied greatly between N treatments (Table 3). Except for the top-soil of field A, NO_3-N concentrations in all four fields were highest in the 40-50 cm layer (Table 3). The C & N concentrations and C:N ratios changed along the soil profile and reflected the degrees of decomposition, mineralization and the loss N from organic compounds. The topsoil layers (0 -10 cm and 10-20 cm) of all sites contained higher total carbon and nitrogen contents. The relatively higher C:N ratios at 40-50 cm depth suggest the presence of undecomposed organic material in that layer. However, the C:N ratios before the crop rotation was introduced (Table 1) was slightly higher than the presence value.

When considering the crop yield, there was relatively no difference between the organic fertilizer substituted fields and inorganic fertilizer mainly applied conventional fields. In spring of 1996, field C and field D gave the yield of Italian rye grass 78.2 t ha^{-1} and 76.4 t ha^{-1} respectively. In autumn the yield of radish was 59 t ha^{-1} and 55 t ha^{-1} respectively. In field A and B the yield of Chinese cabbage was 72.1 t ha^{-1} and 67 t ha^{-1} respectively. Consequently the yield was slightly higher in the organic fertilizer substituted fields

Nitrification and denitrification

Nitrification and denitrification capacities (Fig. 2 and 3) were measured for each soil at 5 depths with 10 cm intervals. It was conclusive that nitrification and denitrification capacities at 0-10 cm depth in field A (which was fertilized with mainly organic

Table 3 Physical and chemical characteristics of 5 soil layers in the experimental fields after 3 years of crop rotation and different fertilizer treatments.(n=3)

Field	Siol depth(cm)	Water content(%)	pH 1 : 5 (soil : H_2O)	Total C (mg g^{-1}DW)	Total N (mg g^{-1}DW)	C/N	NH_4-N (μg g^{-1}DW)	NO_3-N (μg g^{-1}DW)
Field A	0-10	36.9	6.8	57.0	4.92	13.53	2.3	187.1
	10-20	39.6	6.8	57.3	5.17	12.95	3.1	32.7
	20-30	40.8	6.3	48.2	4.04	13.88	2.3	16.9
	30-40	45.4	6.7	41.1	3.41	14.12	2.4	36.2
	40-50	50.4	6.8	23.4	1.66	16.45	2.2	70.1
Field B	0-10	39.2	5.4	47.9	3.85	14.46	3.2	5.6
	10-20	40.8	5.4	47.3	4.00	13.76	2.2	11.5
	20-30	42.4	5.5	49.6	4.04	14.35	2.0	8.8
	30-40	43.2	6.3	44.7	3.68	14.12	2.6	13.5
	40-50	50.5	6.7	21	1.59	15.48	2.7	66.4
Field C	0-10	37.7	6.6	51.4	4.45	13.53	2.9	12.2
	10-20	39.6	6.4	49.9	4.60	12.59	3.7	15.4
	20-30	40.0	6.3	53.5	4.28	14.58	3.1	18.2
	30-40	43.3	6.4	53.6	4.68	13.42	3.3	41.8
	40-50	51.3	6.7	32.3	2.46	15.28	1.9	92.7
Field D	0-10	37.2	5.8	47.9	4.41	12.72	2.1	10.3
	10-20	38.2	6.0	46.3	4.21	12.83	3.8	9.6
	20-30	40.2	6.3	45.0	3.85	13.65	2.6	18.9
	30-40	43.1	6.7	28.6	2.25	14.82	1.9	47.6
	40-50	50.4	6.8	15.7	1.22	15.05	2.9	113.9

Soils were sample in 1997 February

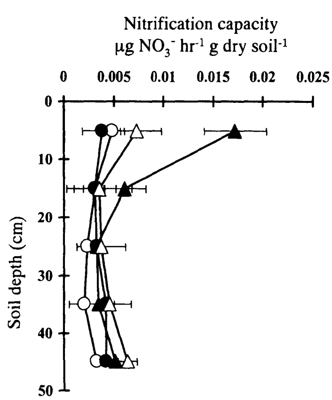

Fig. 2 Nitrification capacity of soils at the different soil depths. ▲: field A, △: field B, ●: field C, ○: field D. Soil sampling was done on 17th of February 1997, after the harvest of chinese cabbage and radish. Each value represents mean ± SD (n = 3).

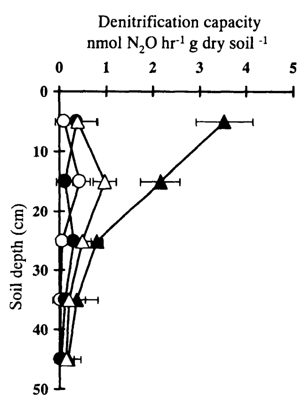

Fig. 3 Denitrification capacity of soils at the different soil depths. ▲: field A, △: field B, ●: field C, ○ : field D. Soil sampling was done on 17th of February 1997, after the harvest of chinese cabbage and radish. Each value represents mean ± SD (n = 3).

fertilizer) were higher than capacities at the same depth in the other three agricultural fields. However in spring season of 1996, field C was also treated mainly with organic fertilizer. The agriculture at field C was Italian rye grass, which is usually used as the clear crop. Root system of Italian rye grass is ramified, which go deeply through the soils and could absorb the N. This may also a reason for the lesser value of nitrification and denitrification in field C as it absorbed N from the top-soil layers.

Inorganic fertilizer treated fields B and D are showed slightly lower pH than organic fertilizer amended fields A and C. The above fact is contradictory to the results of nitrification shown in Fig. 2 and 4 that is difficult to give an explanation. However, the maximum-recorded pH for the topsoil profile (from 0-10) cm in all four plots was almost neutral, which is generally very suitable for nitrification and denitrification. Apart from the favorable pH, the 0-10 cm top soil from field A had the advantage that cabbage had relatively profusely ramified fine root system, which has more C while field C had radish which has very poorly ramified root system.

In field A, combined effects of acidity of soil (Table 3) and the relatively profusely ramified root system of cabbage may have caused these high nitrification and denitrification capacities. It is worth noticing that a small denitrification capacity was found for soil below 40 cm. A high rate of denitrification could occur in sub-soils if there was a supply of organic matter[29]. The occurrence of denitrification may depend on the presence of sufficient organic matter in the subsurface layers, to induce to formation of an anaerobic environment. Although, this generalization has been accepted for many years, useful quantitative relationships have not been established. Also, the increase of organic C by frequent application of the organic fertilizers increases the number of heterotrophic microorganisms[30-31], of which large numbers are able to denitrify under anaerobic conditions. Soil denitrification capacity usually decreases with depth, mainly due to a decrease in organic C materials with depth[32]. Accordingly, it can be expected that the higher organic fertilizer application in field A and C was the cause of slightly higher nitrification and denitrification capacities in those fields, when compared to fields B and D. Field A showed the highest capacity among all.

As shown in Fig. 4, the MPNs of nitrifying bacteria in the 40-50 cm soil stratum of all the fields showed significantly higher values when compared to the other soil strata. Fig. 5 illustrates the variation in denitrifying bacterial population of the same soils. Contrary to the nitrifying population, the denitrifying population of soil decreases following the soil profile. Maximum denitrifying bacterial population was recorded in the top layers of fields that were fertilized with organic fertilizer (A and C). Fluctuations in the denitrifying bacterial populations were observed in the fields mainly supplied with inorganic fertilizers. But in general, denitrifying populations were within a narrow range (10^4 to 10^6), being significantly higher in surface soil than in deeper soil layers.

Generally, denitrification is considered to be an anaerobic process, occurring in the presence of NO_3^- and the absence of molecular oxygen. However, most of the organism known to denitrify, are not strict

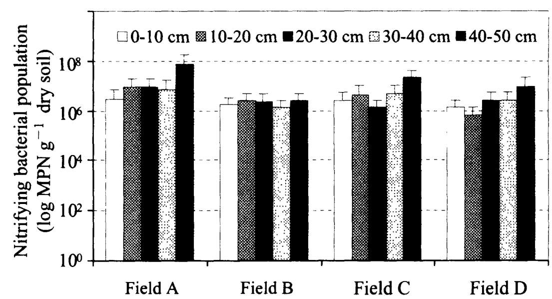

Fig. 4 Size of nitrifying bacterial populations of soils from 5 depths of four fields (A, B, C and D). Each value represents mean ± SD (n = 3).

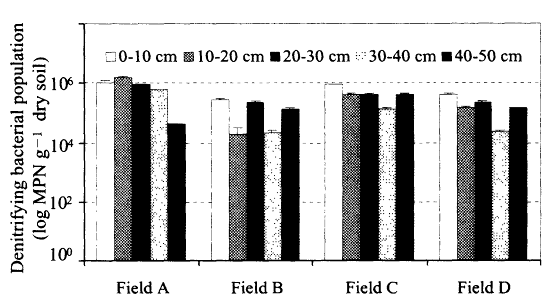

Fig. 5 Denitrifying bacterial populations of soils from 5 depths of four fields (A, B, C and D). Each value represents mean ± SD (n = 3)

anaerobes, but rather facultative organisms[33]. Thus, it is not surprising to find a large denitrifying population in the top layers of these agricultural fields. Accordingly, it can be concluded that nitrification and denitrification capacities of arable soils were promoted by organic fertilizers rather than by inorganic fertilizers.

In this study we have been considering the effect of substitution of organic fertilizer on the agricultural lands. Figures of N-cycle microbial population distribution along the soil profiles indirectly support the field data as they show the snap shot of microbial population involve with the N cycle. Accordingly, it is worthwhile to have a knowledge on influencing factors of nitrification and denitrification, such as microbial population, in arable fields.

CONCLUSIONS

This study has focused on the effects of a single event of heavy rainfall on nitrate leaching from arable land of Andisol that had been mainly fertilized by inorganic fertilizer and organic fertilizer (live stock compost). Substitution of organic fertilizer for inorganic nitrogenous fertilizer would reduce rapid NO_3^- leaching in soils of high water holding capacity under a single event of extreme rainfall. However, organic fertilizer may increase NO_3^- concentration in deeper soils over a prolonged period. It is recommended that further studies in this context are necessary.

Nitrification and denitrification processes in N-cycle were slightly enhanced by substitution of organic fertilizer application. Thus, understanding of subsurface nitrogen dynamics and influencing factors such as single event of rainfall effects help us to delineate appropriate fertilizer management to minimize further soil and groundwater pollution by nitrates.

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