Effects of *Persicaria thunbergii* on Nitrogen Retention and Loss in Wetland Microcosms

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습지 미소생태계에서 질소 보유와 제거에 대한 고마리(*Persicaria thunbergii*)의 효과

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ABSTRACT

Growth and nitrogen retention of *Persicaria thunbergii* were investigated in the wetland microcosms which contained the plants growing on soil bed. Nitrogen solution was supplied to the microcosms with the same amount of NH_4^+-N and NO_3^--N at the rates of 0.00, 0.78, 1.57, 3.14g $N \cdot m^{-2} \cdot wk^{-1}$ from May 1 to August 31, 1995. The solution was detained for 5 days to react with soil and plant and then allowed to leach. The contents of NH_4^+-N and NO_3^--N in the leachate, total Kjeldahl nitrogen, plant biomass, and soil characteristics were determined. Nitrogen retained by plant was estimated as the increment of TKN in plant biomass.

The addition of 0.78 and 1.57g $N \cdot m^{-2} \cdot wk^{-1}$ resulted in significant increase of plant biomass. However, plant growth was inhibited when nitrogen was added at the rate of 3.14g $N \cdot m^{-2} \cdot wk^{-1}$. Overall, the plant biomass was positively correlated with the amount of nitrogen retained by plant and soil system. The amounts of NO_3^--N leached from the microcosms were 5~10 times higher than those of NH_4^+-N. While total nitrogen added ranged from 143.2 to 576.5g N/m^2, total leaching loss of inorganic nitrogen and nitrogen retained by plant was as little as 1.04~22.71g N/m^2 and 5.46~12.91g N/m^2, respectively. Then, the plant seemed to contribute to chemical and microbial immobilization of nitrogen in the soil. Finally, it is suggested that a large portion of nitrogen added was lost into the air by denitrification and volatilizaton, and /or leached in organic forms.

Key words: Microcosm, NH_4^+-N, NO_3^--N, Nitrogen loss, Nitrogen retention, *Persicaria thunbergii*, Riparian system, Wetland

INTRODUCTION

Riparian areas have been recognized as a control of non-point source pollutants, such as nitrogen, phosphorus and insecticides (Cooper *et al.* 1986, Richardson and Nichols 1985). Plant uptake and denitrification are suggested to be primary mechanisms responsible for N removal in the systems. Hence, these two processes of riparian systems may largely contribute to amelioration of aquatic environments by lowering nitrogen availability (Haycock 1993).

Many studies have addressed nutrient retention in riparian ecosystems. For instance, Gumbricht (1992, 1993) examined nutrient retention in non-harvested root-zone wetlands covered with reeds and cattails. The retention efficiencies of nitrogen and phosphorus were esimated 70% and 67% during summer and 32% and 58% during winter, respectively. Richardson and Nichols (1985) presented that 60% of phosphorus and 80% of nitrogen were removed in wetland ecosystems and long-term application of higher loads resulted in removal less than 40% due to nutrient saturation and loss of permeability in soil. Although denitrification accounts for the loss of $NO_3^- - N$ in riparian area, it may take place in the narrow range (Cooper *et al.* 1986, Holland *et al.* 1990).

Vascular aquatic plants have been increasingly used for removal and uptake of nitrogen, phosphorus and other nutrients from domestic and agricultural wastes (Tourbier and Pierson 1976, O'Brien 1981, Wolverton 1982, Xu *et al.* 1992). In addition to direct uptake of nutrients, vegetation of riparian zone stimulates denitrification by providing organic carbon and surfaces inhabiting microorganisms (Weisner 1994). For instance, an aquatic macrophyte, *Phragmites australis*, has been successfully employed to purify waste water in reed ponds (de Jong 1976) and natural marshes (Toth 1972, Wathugala *et al.* 1987). In Korea, *Salvinia natans* and *Oenanthe javanica* were also examined for the same purpose (Ahn 1993, Ahn 1994).

Gumbricht (1992, 1993) explained that 20% of phosphorus and 10% of nitrogen removed in riparian zone were found in harvested plant biomass and the rest were controlled by the processes in sediments (or soils) or on plant surfaces (sedimentation of particles, denitrification, adsorption, precipitation). Nitrate removal is enhanced and stabilized by vegetatiton in riparian zone as plant uptake and denitrification of soil microbes compensate for seasonal variation.

Understanding processes in riparian zone is critical when naturalization of artificial stream channels is desired. The knowledge should help make the system stable in structure and function. When biological as well as hydrological and chemical processes at landscape level are integrated, the system may be restored with self-maintenance.

The major objective of this study was to understand the effect of an aquatic plant (*Persicaria thunbergii*) on nitrogen retention in riparian zone.

MATERIALS AND METHODS

Plant and soil

Seedlings of *P. thunbergii* and soil were taken from a riparian area of Kyungan stream on May 1, 1995. It is supposed that in the Korean riparian systems the plant largely contributes to removal of nutrients through sedimentation and denitrification as well as direct uptake by fine roots which are extensively distributed. The stream is located in the upstream of Han River and designated as a protective area as water supply source. It has been known that large amounts of nutrients flow into the stream from agricultural land and stock farms which occupy considerable area of the surrounding watershed.

Microcosm and experimental design

A plastic pot (17cm×17cm×20cm) was filled with 2.7 kg of the soil to allow leaching at the bottom. Three seedlings of *P. thunbergii* were planted in each of 12 pots and no seedling in the other 12 pots. The pots were kept in a greenhouse.

Two hundred milliliters of nitrogen solutions, which contained NH_4^+-N and NO_3^--N in the same amount, were supplied to the microcosms. Nitrogen was added at the rates of 0.00, 0.78, 1.57, and 3.14 g N/m^2 every week. The solution was detained in the pots for 5 days to react with the soil and plant, and then leaching was allowed. There were three replicates for each treatment. Hoagland solution was added once every three weeks to supply other essential nutrients except for nitrogen. The microcosms were placed in a greenhouse till August 31, 1995.

Plant growth

In the place where plant and soil materials were taken, the numbers of leaves and stems, and length of stem of the plant were determined. The plant was clipped, dried at 80℃ for 48 hours, and weighed. An equation to describe the relationship of the dry weight and parameters was derived from correlation analysis and multiple regression. Then, plant biomass was estimated by measuring the parameters 6 times over the period of experiment.

Chemical Analyses

1) Plant and Soil

Total Kjeldahl nitrogen (TKN) of the plant was analyzed using micro-Kjeldahl method (Jackson 1967). The soils, air-dried and sieved through a 2mm screen, were analyzed both before and after nitrogen treatment. Soil pH (soil:distilled water 1:5, w/v) was measured using a pH meter (Fisher 230A). Total Kjeldahl nitrogen (TKN) was determined using the micro-Kjeldahl method with 1 g of air-dried soil (Jackson 1967). Ammonium-N and

$NO_3^- - N$ were measured colorimetrically using the phenate method (Strickland and Parsons 1972) and the cadmium reduction method, respectively (APHA 1981). Contents of ions of K^+ and Na^+ were determined with a flamephotometer (Coleman 1951). Available phosphorus was extracted with 0.01 N NH_4F + 0.025 N HCl solution, and was measured colorimetrically at 700nm using the ascorbic method (APHA 1989). Organic matter (OM) was determined with ignition method.

2) Leachate

Ammonium and nitrate of leachate were determined with the phenate method (Strickland and Parsons 1972) and hydrazine sulfate reduction method, respectively.

RESULTS AND DISCUSSION

Biomass and TKN of plant

1) Biomass

Multiple regression equation of dry weight against number of leaves and length of stems was derived (as shown in Table 1).

In general, plant biomass increased with nitrogen supply during the experiment, ranging from 500 to 2000 g/m² (Fig. 1). However, in the case of 3.14 g $N \cdot m^{-2} \cdot wk^{-1}$ biomass increased during the first 7 weeks and then decreased, indicating that excess nitrogen may inhibit plant growth.

2) TKN

Total Kjeldahl nitrogen of plant material were considerably different among treatments (Fig. 2). TKN of plant with 1.57 g $N \cdot m^{-2} \cdot wk^{-1}$ showed the highest value. Nitrogen retention by the plant may be represented by multiplying the value by plant biomass.

Table 1. Multiple regression equation for plant biomass estimation

Equation		$Y = a + b\chi_1 + c\chi_2$
		Y : plant biomass
		χ_1 : number of leaves
		χ_2 : length of stems
R-square		0.9804
Parameter estimates	a	-0.8670 (T for H_0 : Prob$\rangle$|T| = 0.0397)
	b	0.0708 (T for H_0 : Prob$\rangle$|T| = 0.001)
	c	0.1238 (T for H_0 : Prob$\rangle$|T| = 0.0037)

Soil

1) Characteristics of soil

Some chemical properties of the original soil including, pH and the contents of $NO_3^- - N$, $NH_4^+ - N$, TKN, K^+, Na^+, and organic matter, are summerized in Table 2. Concentration of $NH_4^+ - N$ was approximately 4 times higher than that of $NO_3^- - N$.
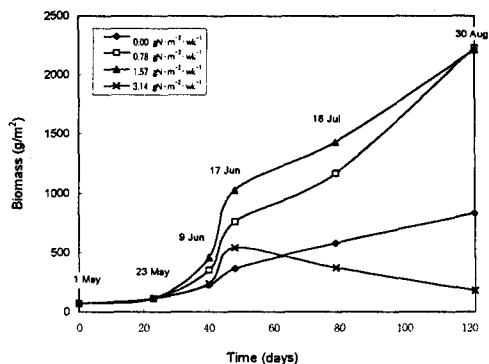
Fig. 1. Growth of *Persicaria thunbergii* in microcosms to which nitrogen was added at the rates of 0.00, 0.78, 1.57, and 3.14 g/m² every week.
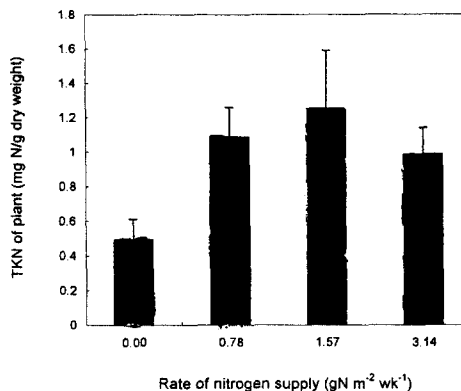

Fig. 2. Total Kjeldahl nitrogen of plant biomass at the end of 4 month incubation.

Table 2. Physico-chemical properties of initial soil

NH_4^+−N (μg/g soil)	NO_3^-−N (μg/g soil)	TKN (mg/g soil)	PO_4^{3-}−P (μg/g soil)	K (μg/g soil)	Na (μg/g soil)	pH	Organic matter(%)
24.2	6.43	0.15	7.22	182	39.2	6.5	5.73

2) pH

Soil pH ranged from 6.0 to 6.5. Overall, soil pH decreased over the period of experiment. In general, microbial respiration and nitrification can cause lower soil pH by producing carbonic acid and nitric acid, respectively.
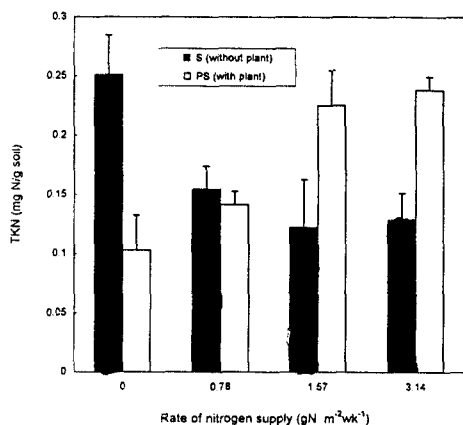

Fig. 3. Total Kjeldahl nitrogen of soils with and without plant at the end of 4 month incubation. The value of the original soil was 0.15 mg N/g soil.

3) TKN

Total Kjeldahl nitrogen of soil ranged from 0.13 to 0.25 mg N/g soil. When higher amount of nitrogen was added, TKN tended to decrease in the soil without plant, while the value increased in the soil with plant (Fig. 3).

4) Available phosphorus

When higher amount of nitrogen was added, phosphorus availability increased with one exception (Fig. 4). Increased phosphorus availability might be attributed to less adsorptivity of phosphorus due to acidification. In general, calcium phosphate
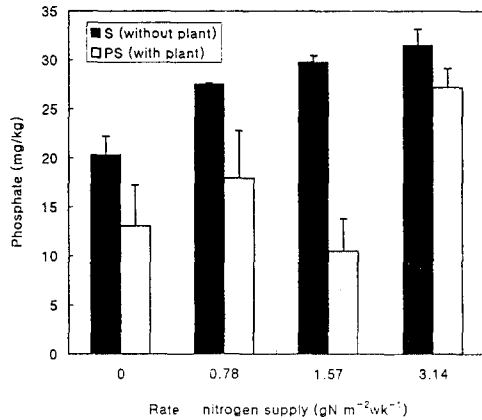
Fig. 4. Available phosphorus in soils with (light) and without (dark) plant at the end of 4 month incubation. The value of original soil was 7.22 μg P /g soil.

phosphate compounds are solubilized as nitrification promotes soil acidity. Howerver, it should be noted that nitrogen addition can cause less phosphorus availability in soil to stimulate microbial uptake of phosphorus, and acidification enhances phosphours adsorption onto aluminun and iron compounds.

Phosphorus availability was lower in soil with plant than in soil without plant. Plants might have absorbed phosphorus up from soil obviously. In addition, plants contribute to high redox potential of soil and hence promote phosphate adsorptivity. Ferric state of iron (Fe^{3+}) is hardly soluble, while ferrous form (Fe^{2+}) is easily mobilized (Brown *et al.* 1989).

5) Organic matter

The contents of soil organic matter decreased by approximately 2% during the experiment. Nitrogen addition could have made microbial consumption of organic carbon outgo the supply by root exudaton. There was no significant difference among treatments.

$NH_4^+ - N$ and $NO_3^- - N$ in leachates

Concentrations of $NH_4^+ - N$ and $NO_3^- - N$ of leachates are presented in Fig. 5 and 6. While $NH_4^+ - N$ kept being leached, amounts of $NO_3^- - N$ in the leachates were initially low and then almost undetected 7 weeks after the microcosm experiment began. It seems that $NH_4^+ - N$ was a dominant form of inorganic nitrogen under such a reduced condition.

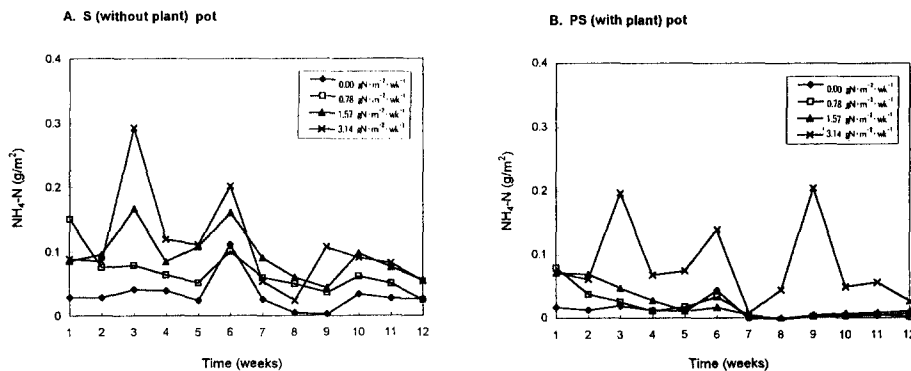**Fig. 5.** Content of $NH_4^+ - N$ in leachates of soils with and without plant.

A. S (without plant) pot

B. PS (with plant) pot

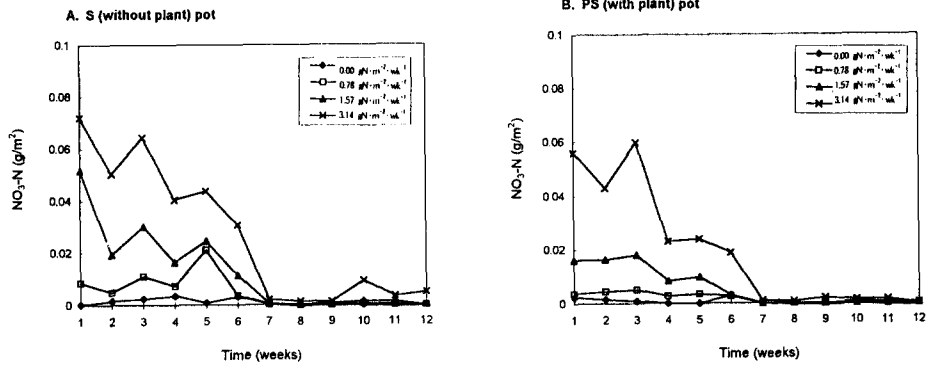**Fig. 6.** Content of $NO_3^- - N$ in leachates of solis with and without plant.

Plants did not have any significantly different effect on leaching loss of inorganic nitrogen, indicating that removal of nitrogen is largely attributed to soil processes. Unfortunately, total loss of the nutrient could not be estimated since content of organic nitrogen was not determined for the leachates.

Nitrogen retention in plant-soil system

1) Estimation of plant contribution to nitrogen removal

Contribution of *P. thunbergii* to the removal of nitrogen from nutrient solution applied to the microcosms is represented by the differences of $NH_4^+ - N$ and $NO_3^- - N$ in the leachates taken from the corresponding soil with plant and soil without plant. The cumulative differences were plotted in Fig. 7. Apparently, plants contributed to less leaching loss of nitrogen. Negative effect of excess nitrogen on plant growth might cause less nutrient removal when nitrogen was added at the rate of $3.14 \text{ g N} \cdot \text{m}^{-2} \cdot \text{wk}^{-1}$. It is noted
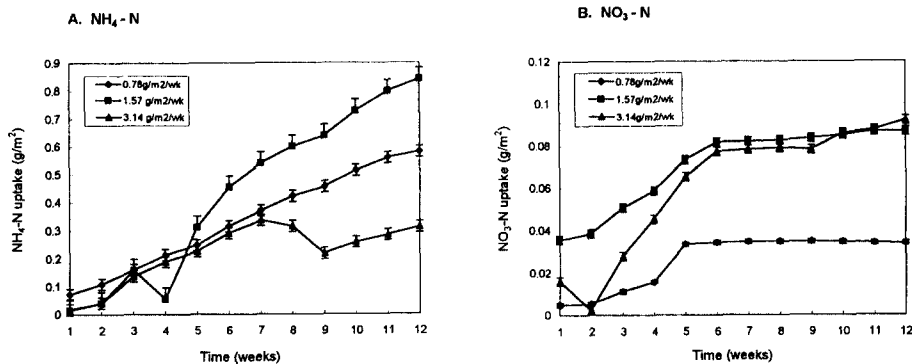
A. $NH_4 - N$

B. $NO_3 - N$

Fig. 7. Effects of *Persicaria thunbergii* on the removal of inorganic nitrogen from nutrient solution applied to the microcosms. The removal is represented by the cumulative differences of $NH_4^+ - N$ and $NO_3^- - N$ contents, respectively, in solution passed through soils with and without plant.

that in the cases of moderate inputs the effects of plants on ammonium removal was maintained, but not on $NO_3^- - N$ removal from 5 or 6 weeks.

2) Mass balance of nitrogen

Nitrogen retained by plants was estimated as the increment of TKN in plant biomass during experimental period. Then, mass balance of nitrogen in the microcosms was compared as shown in Table 3.

Total leaching loss of inorganic nitrogen ranged from 1.04 to 22.71 g N/m². Note that total nitrogen added ranged from 143.20 to 576.50 g N/m². Although nitrogen content in leachate of no plant pot was to some extent higher than the other, and nitrogen retention by plant was recognized, most of the retention was ascribed to the soil rather than the plant. Nonethelss, plant might indirectly contribute to less leaching loss of nitrogen by causing chemical and microbial immobilization in the soil. In addition, it was speculated that a large portion of nitrogen added was lost by denitrification and volatilizaton, and/or leached in organic forms.

Table 3. Mass balance of nitrogen in the microcosms (unit : g N/m²)

	Treatment*					
	S1	S2	S3	PS1	PS2	PS3
Total input	143.20	286.40	576.50	143.20	286.40	576.50
Net increment in plant				12.73	12.91	5.46
Net increment in soil	19.46	−45.14	−32.30	−6.42	161.50	187.40
Leaching loss of $NH_4^+ - N$ and $NO_3^- - N$	10.37	17.86	22.71	1.04	3.17	18.93
Total output**	123.74	331.54	608.80	136.89	111.99	383.64

* The symbols of 'S' and 'PS' represent 'soil only', 'soil with plant', respectively. The figures of 1, 2, 3 following the symbols indicate the rates of nitrogen addition of 0.78, 1.57, and 3.14 g $N \cdot m^{-2} \cdot wk^{-1}$, respectively.
** Total output is given as the difference between total input and sum of net increments in both plant and soil, and hence includes net gaseous and leaching losses.

CONCLUSIONS

Nitrogen is supplied to riparian ecosystems in various ways. They include surface and ground water inflows, wet and dry deposition, and N fixation. Vegetation may contribute to trapping of suspended solids and stabilization of system in riparian zone, where denitrification becomes catalyzed. This study was conducted to understand the effects of an aquatic plant, *Persicaria thunbergii* on the fate of nitrogen added to riparian ecosystems. The plant is extensively and intensively distributed along most riparian zone in Korea.

It was noted that plant biomass of *P. thunbergii* could be reliably estimated from the

number of leaves and length of stems. When nitrogen was added to the soil and plant microcosms at the rates of less than 1.57 g N/m² every week, plant growth was largely enhanced. However, a negative effect was observed with excess nitrogen of 3.14 g N · m⁻² · wk⁻¹.

Plants lowered level of phosphorrus availability in soil and leaching loss of inorganic nitrogen by retaining or transforming the nutrients in biomass and soil. While soil TKN without plant decreasd as amounts of nitrogen added increased, there was an opposite tendency with plant (Fig. 6), suggesting that the the plant supported nitrogen retention of soil. It was exceptional that nitrogen loss was higher in microcosms with plant than without plant only when 0.78 g N · m⁻² · wk⁻¹ was added. Although nitrogen content in leachate of no plant pot was to some extent higher than the other, and nitrogen retention by plant was recognized, most of the removal was attributed to the soil rather than the plant. In addition, it appears that a large portion of nitrogen added was lost by denitrification and volatilizaton, and /or leached in organic forms. In the future, relevant retention mechanisms should be better understood to improve effectiveness of nutrient removal in riparian system. Although some ot recent works have addressed the role of riparian buffer strips in water quality management, some questions such as the optimal width, most efficient type of vegetation, saturation of riparian zone and seasonal variations remain unanwsered.

ACKNOWLEDGMENTS

적 요

고마리(*Persicaria thunbergii*) 군락의 영양염 보유 및 제거능을 평가하기 위해 1996년 5월 1일 유식물과 토양을 실험실에 옮겨와 8월 31일까지 온실 모의실험을 실시하였다. 식물-토양계에 질산염과 암모늄염을 1:1로 혼합하여 0.00, 0.78, 1.57, 3.14g N · m⁻² · wk⁻¹ 의 네 가지 다른 수준으로 질소를 첨가하고 5일 동안 체류시킨 다음 식물-토양계를 통과하는 침출수를 받아 분석하였다. 식물체를 배양하면서 식물의 생장량을 추정하였고 실험 전후의 식물 및 토양의 성분을 분석하였다.

질소를 각각 0.78 g N · m⁻² · wk⁻¹, 1.57 g N · m⁻² · wk⁻¹ 공급했을 때 식물의 생장량은 질소의 첨가량에 비례하여 증가하였지만 3.14 g N · m⁻² · wk⁻¹의 공급에서는 오히려 식물생장이 억제되었다. 습지 미소생태계에 의해서 보유되는 질소량은 식물 생장과 양의 상관관계를 보였다. 전체적으로 질산염의 침출량은 암모늄의 침출량보다 5~10배 가량 높았다. 침출수에서 암모니아성 질소와 질산성 질소의 양은 식물구와 무식물구 모두 1.04~22.71g N/m² 였으며, 식물의 생물량으로 보유되는 양도 5.46~12.91g N/m² 으로서 공급된 총질소량에 비해 매우 작았다. 그러나 식물은 토양 또는 미생물에 의한 질소 보유에 공헌하는 것으로 나타났다. 그럼에도 불구하고

공급된 질소의 많은 양이 토양내에서 일어나는 휘산이나 탈질화작용으로 대기중으로 소실되었거나, 유기질소 형태로 용탈된 것으로 사료된다.

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