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Soil CO_2 Evolution and Nitrogen Availability on Abandoned Agricultural Fields at Mt. Kumdan

Yowhan Son[1], Jiyeon Ban[1], Rae-Hyun Kim[1] and Joon Kim[2]
[1]*Division of Environmental Science and Ecological Engineering, Korea University, Seoul 136-701, Korea*
[2]*Department of Atmospheric Sciences, Yonsei University, Seoul 120-749, Korea*

검단산 한계농지에서의 토양발생 CO_2 및 질소 유효도

손요환[1] · 반지연[1] · 김래현[1] · 김 준[2]
[1]고려대학교 환경생태공학부
[2]연세대학교 대기과학과

ABSTRACT

The influence of abandonment of agricultural fields on soil carbon and nitrogen dynamics is rarely addressed due to lack of appropriately paired sites. In this study, we identified three sites that have native forest and abandoned rice and crop fields at Mt. Kumdan near Seoul. Currently the vegetation of indigenous forest and the abandoned rice field is deciduous hardwood forest, while that of the abandoned crop field is deciduous shrub. We measured soil CO_2 evolution and inorganic N availability for the three sites from 25 July 2002 through 24 January 2003. Soil CO_2 evolution tracked seasonal soil temperature. Mean soil CO_2 evolution (g $CO_2/m^2/hr$) for the study period was 0.42 for the rice field to forest, 0.50 for the crop field to shrub, and 0.41 for the indigenous forest, respectively. Soil CO_2 evolution and soil temperature were not different among the sites; however, soil water content was significantly different. Soil water content had a very weak influence on soil CO_2 evolution. Inorganic resin N availability differed among the three sites and seemed to be related to soil moisture.

Key words : **abandoned agricultural fields, nitrogen availability, soil CO_2**

I. INTRODUCTION

Over the past several decades, Korean forests have experienced human-induced disturbances such as agriculture. However, abandonment of croplands is rapidly increasing throughout the country because of urbanization and industrialization, and consequently, in recent years successional development of vegetative communities is occurring (Ministry of Agriculture and Forestry 2002). Abandonment of croplands is one of seven types of land-use change for carbon stock changes, and abandonment of cultivated lands may result in recovery of shrub or forest at a rate determined by local conditions (Watson *et al.* 2000). Soils are the major reservoir of terrestrial carbon (C). Soil C storage is dependent on environmental and land-management factors. Changes in land use can have a marked effect on soil C contents (Ross *et al.* 1999). When croplands are allowed to revert to natural vegetation, changes in soil C and soil temperature and moisture occur. Soil CO_2 evolution may be the consistent indicator of soil condition and metabolic activity in the soil. The common limitation of N for plant and microbial growth suggests that soil CO_2 evolution and soil N availability

Corresponding Author: Yowhan Son(yson@korea.ac.kr)

should be closely related. Although the effects of cultivation and harvesting of crop fields or forest lands on soil C and nitrogen (N) changes are well studied, studies of soil CO_2 evolution and N availability by conversion of agricultural fields to natural vegetation are very limited (Aweto 1981, Brown and Lugo 1990, Knops and Tilman 2000, Post and Kwon 2000). Our major objective in the current study was to investigate the difference in soil CO_2 evolution and N availability for the three land use changes during conversion of cultivated agricultural fields to natural vegetation in Mt. Kumdan.

II. MATERIALS AND METHODS

2.1. Study site

The site was located at Mt. Kumdan near Seoul (37°27'N, 127°16'E). The meterological data collected between 1991 and 2000 showed that precipitation averaged 1300 mm/yr and that average annual temperature was 10.8°C. Three types of land-use change (indigenous forest, rice field to forest, crop field to shrub) were selected at the site. A detailed site description is provided by Chung *et al.* (1998), Son and Lee (2001) and Son *et al.* (2003). Briefly, the indigenous forest was dominated by *Quercus mongolica* Fisch., *Q. variabilis* Bl., *Prunus sargentii* Rehder, and *Fraxinus rhynchophylla* Hance. Abandonment of the rice field and the crop field took place about 20 years ago, based on the periodic aerial photographs of the region. Current plant species of the rice field to forest site included *Salix glandulosa* Seem., *S. koreensis* Anderss., and *Acer ginnala* Max. *Spiraea prunifolia* for. *simpliciflora* Nakai, *Lespedeza bicola* Turcz, and *Pueraria thunbergiana* Benth were dominant at the site of crop field to shrub. All sites had the southern aspect and similar elevation. However, the rice field to forest site was relatively flat and located near a water catchment valley. Three plots were located within each land use change type for this study.

2.2. Soil CO_2 Evolution

Soil CO_2 evolution was measured monthly with a soil respiration chamber (EGM-2, PP Systems Inc. UK) from July 2002 through January 2003. The chamber was gently inserted into the mineral soil to a depth of less than 0.5 cm, and five randomly selected sample points per plot were measured in each site. Soil temperature was measured with a soil temperature probe (PP Systems Inc. UK) at a 15 cm depth, and volumetric soil water content was measured at the same depth with a soil water sensing probe (HydroSense, Campbell Scientific Inc. USA). Also, gravimetric soil water content was determined, based on five replicates per plot. The wet soil samples were weighed, then dried to constant weight. Gravimetric soil water content was expressed as percent of dry weight.

2.3. Inorganic soil N Availability

Ion exchange resin bags were used as a field index method to assess inorganic soil N availability (Binkley *et al.* 1994). Five resin bags were placed beneath the forest floor at one meter intervals in a randomly chosen transect through each plot. The resin bag included 14 m*l* of anion (Sybron IONAC ASB-1P OH^-, Sybron International, Milwaukee, Wisconsin, USA) and 14 m*l* of cation (Sybron IONAC C-251 H^+) exchange resins in separate compartments in a nylon stocking (Son and Kim 2000). After an incubation period of 16 weeks (25 July - 24 November 2002), the resin bags were retrieved, air-dried, and extracted with 100 m*l* of 2M KCl. The extracts were analyzed colorimetrically for NH_4^+-N and NO_3^--N on a Lachat continuous flow ion analyzer (QuickChem AE, Milwaukee, Wisconsin, USA). Results were expressed as milligrams of N per bag (NH_4, NO_3, or total N).

2.4. Data Analysis

Statistical significance of land use change effects on soil CO_2 evolution and inorganic N availability were determined using analysis of variance. Analyses were performed for individual measuring months and for data pooled across the period. In the pooled analysis, sampling period was included as an independent variable. The general linear model procedure was used for all data analyses (SAS 1988). Regression analysis was used to analyze the relationships between soil CO_2 evolution and soil moisture, soil temperature, and N availability.

III. RESULTS AND DISCUSSION

3.1. Soil CO_2 Evolution

Soils under the different land use changes have been reported to differ markedly in their properties (Ross *et al.* 1999). A basic assumption in the comparative study is that the soils were initially similar in each ecosystem. Although we are unable to test this assumption, it is likely that the soils were very similar, having originated from the same parent rock. Any differences that may have developed before the land use changes should have been small and would possibly have been associated with soil material movements on the catchment slopes.

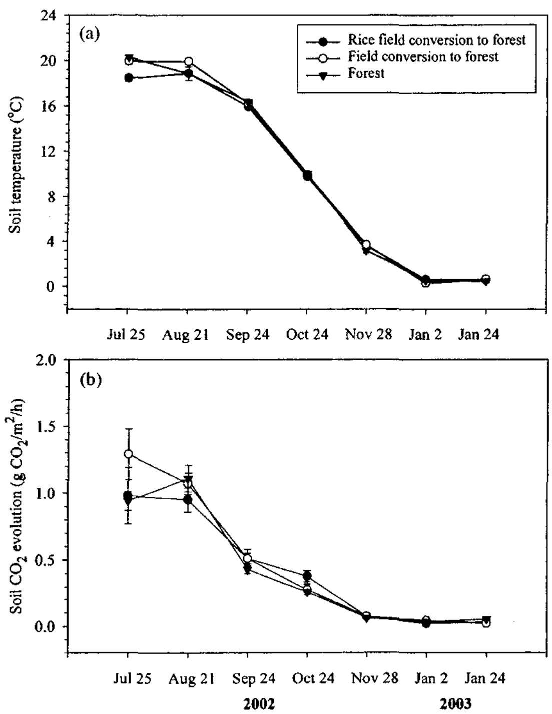

Fig. 1. Seasonal soil temperature and soil CO_2 evolution for the three study sites at Mt. Kumdan.

Soil temperature changed from 0.3°C to 20.3°C at single spots, with a clear seasonal trend of peaks either in July or August depending on land use change type, decreases from late summer throughout the winter, and a slight increase from late January ($p<0.05$) (Fig. 1a).

Soil CO_2 evolution fluctuated between 0.02 and 1.29 g $CO_2/m^2/hr$, and showed a clear seasonal variation, which was related to soil temperature (Fig. 1b). These seasonal patterns of soil CO_2 evolution were consistent with those observed in other deciduous forests in the region (Moon *et al.* 2001, Son and Lee 2001). Soil CO_2 evolution was higher at higher soil temperature, and gravimetric soil water content explained a very low fraction of the variance in soil CO_2 evolution (Table 1). However, other factors such as volumetric soil water content, inorganic resin NH_4, NO_3, and total inorganic N concentrations did not influence soil CO_2 evolution. A strong correlation between soil CO_2 evolution and soil temperature was also reported from the other coniferous and deciduous forests in the region (Son and Kim 1996, Son *et al.* 1994). Although it was known that soil CO_2 evolution was related to soil moisture when soil moisture was low (Conant *et al.* 2000, Maier and Kress 2000), soil moisture seemed to have a minor influence on soil CO_2 evolution in most temperate regions (Bridgham and Richardson, 1992, Mathes and Schriefer 1985, Thuille *et al.* 2000, Widen and Majdi 2001).

Mean soil CO_2 evolution (g $CO_2/m^2/hr$) during 7

Table 1. Correlation analysis of potential factors influencing soil CO_2 evolution. Abbreviation: SE = soil CO_2 evolution (g $CO_2/m^2/hr$), ST = soil temperature (°C), GWC = gravimetric water content (%), VWC = volumetric water content (%) NO_3 = inorganic resin NO_3 concentration (mg-N/bag), NH_4 = inorganic resin NH_4 concentration (mg-N/bag), and TNA = total N availability (mg-N/bag). The p values are below the correlation coefficient

	SE	ST	GWC	VWC	NO_3	NH_4	TNA
SE		0.6529 <0.0001	0.0159 0.0281	0.0066 0.1616	0.2177 0.2054	0.2998 0.1270	0.0733 0.4809
ST			0.0673 <0.0001	0.0246 0.0062	0.5257 0.0271	0.0000 0.9859	0.5484 0.0225
GWC				0.2704 <0.0001	0.3943 0.0702	0.0294 0.6594	0.3295 0.1061
VWC					0.5510 0.0220	0.0158 0.7476	0.5014 0.0328
NO_3						0.0497 0.5641	0.8710 0.0002
NH_4							0.0202 0.7156

Table 2. Mean soil CO_2 evolution, soil temperature and soil moisture (volumetric and gravimetric) for the three land use change types during the study period. Numbers in parentheses denote the standard error. Significant differences among the types at the p=0.05 level are indicated by different letters

	Rice field to forest	Crop field to shrub	Indigenous forest
Soil CO_2 evolution	0.42 (0.05) a	0.50 (0.06) a	0.41 (0.04) a
Soil temperature	9.66 (0.75) a	10.08 (0.80) a	9.95 (0.79) a
Gravimetric water content	30.74 (0.95) a	20.87 (0.42) c	24.29 (0.39) b
Volumetric water content	27.76 (1.52) a	12.99 (0.32) b	14.22 (0.33) b

months was 0.42 for the rice field conversion to forest site, 0.50 for the crop field conversion to shrub site, and 0.41 for the indigenous forest site, respectively (Table 2). These values were not significantly different among the sites; however, they were significantly related to month and site x month interaction ($p<0.001$).

Average soil temperature for the study period was 9.7°C for rice field to forest, 10.1°C for crop field to shrub, and 10.0°C for indigenous forest, respectively, and was not different among the land use change types (Table 2). However, soil temperatures were different among the three sites in July and September, and differences in light interception by overstory vegetation might influence soil temperature. Either gravimetric or volumetric soil water content was significantly higher at the rice field to forest site than the other two sites (Table 2). Topographical position and flat soil surface of the rice field forest site might influence soil moisture conditions.

3.2. Nitrogen Availability

Inorganic N concentrations of the ion exchange resin bags for the incubation period were presented in Table 3. These values were slightly lower than those measured for other coniferous and deciduous forests in central Korea (Son and Kim 2000, Son and Lee 2001), and the differences might be derived from the changes in incubation season and period. There were significant differences in NH_4^+-N, NO_3^--N and total inorganic N concentrations for the three land use change types. In rice field to forest and crop field to shrub sites, NO_3 and total N concentrations were similar in resin bags. However, these values in both sites were significantly greater than those in the indigenous forest site. These differences were a function of the NO_3 concentration of the bags rather than NH_4. In addition, the retention of NH_4 by the resin bags was less than that of NO_3. During the incubation period, the amount of retained NH_4 was 20 to 39% of the total N retained. High nitrification was common in the region (Son and Lee 1997, Son *et al.* 1999), and especially the ratio was high at the rice field to forest site. It implied that NO_3 leaching loss at the site might be more important than the crop field to shrub and indigenous sites, since NO_3 is much more mobile in soil solution than NH_4. It appeared that soil temperature and volumetric soil water content influenced the resin NO_3 concentration for the three sites (Table 1). In a separate study, Son *et al.* (2003) found that soil moisture was a limiting factor of litter decomposition for the area. Higher soil moisture at the rice field to forest site appeared to result in a higher resin NO_3 concentration at the site.

Soil C and N dynamics are regulated by a complex set of interactions that change during successional development of vegetative communities. Soil C and N availability are ultimately controlled by the formation of organic matter through primary production and its loss through the activities of decomposing organisms (Zak *et al.* 1990). There is too little information at this point to conclude the effects of land use change on soil

Table 3. Soil inorganic N availability measured by ion exchange resin bags for the three land use change types. Numbers in parentheses denote the standard error. Significant differences among the types at the p=0.05 level are indicated by different letters

Land use change type	NO_3	NH_4	Total
Rice field to forest	2.23 (0.45)a	0.58 (0.16)b	2.81 (0.45)a
Crop field to shrub	1.45 (0.22)ab	0.94 (0.13)a	2.38 (0.29)ab
Indigenous forest	1.03 (0.18)b	0.40 (0.07)b	1.42 (0.22)b

CO_2 evolution and inorganic N availability. Data over the short duration of this experiment underscored the need for further and long-term research on soil carbon and N cycling including above- and belowground production, decomposition and respiration during the conversion of agricultural lands to natural vegetation.

적 요

한계농지 토양 내의 탄소와 질소의 동태에 관한 연구는 적절한 연구 대상지의 부족으로 지금까지 폭 넓게 이루어지지 못했다. 본 연구에서는 서울 근처의 검단산 일대에서 지속적으로 산림이었던 지역, 과거 논으로 이용되었던 지역, 과거 밭으로 이용되었던 지역 등 세 곳의 연구 대상지를 선정하고 여기에서 2002년 7월 25일부터 2003년 1월 24일까지 토양 발생 CO_2와 무기태 질소의 유효도를 측정하였다. 현재 지속적으로 산림이었던 지역과 과거 논으로 이용되었던 지역은 낙엽활엽수림이고, 과거 밭으로 이용되었던 지역은 낙엽성 관목이 주 식생을 이루고 있다. 토양 발생 CO_2는 토양 온도의 계절적 변화에 따라 차이를 보였다. 본 연구 기간동안 토양 발생 CO_2량 (g $CO_2/m^2/hr$)의 평균은 각각 과거 논으로 이용되다 산림으로 변한 지역이 0.42, 과거 밭으로 이용되다 관목으로 변한 지역이 0.50, 지속적으로 산림이었던 지역이 0.41로 나타났다. 토양 발생 CO_2와 토양 온도는 연구 지역간에 차이가 나타나지 않았으나 토양 습도는 주목할 만한 차이를 보였고, 토양 발생 CO_2에 대해 토양 습도는 매우 약한 상관관계를 나타냈다. 무기태 질소의 유효도는 세 곳의 연구 대상지에 따라 차이를 나타냈으며 이는 토양 수분과 관련이 있는 것으로 보인다.

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