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Root Barrier and Fertilizer Effects on Soil CO_2 Efflux and Cotton Yield in a Pecan-Cotton Alley Cropping System in the Southern United States

Kye-Han Lee* and **Kiwan An**

Department of Forestry, Chonnam National University, Gwangju 500-757, Korea

Abstract : Little information is available on soil CO_2 efflux and crop yield under agroforestry systems. Soil CO_2 efflux, microbial biomass C, live fine root biomass, and cotton yield were measured under a pecan (*Carya illinoinensis* K. Koch)-cotton (*Gossypium hirsutum* L.) alley cropping system in southern USA. A belowground polyethylene root barrier was used to isolate tree roots from cotton which is to provide barrier and non-barrier treatments. The barrier and non-barrier treatment was randomly divided into three plots for conventional inorganic fertilizer application and the other three plots for organic poultry litter application. The rate of soil CO_2 efflux and the soil microbial biomass C were affected significantly ($P < 0.05$) by the fertilizer treatment while no significant effect of the barrier treatment was occurred. Cotton lint yield was significantly ($P < 0.01$) affected by the root barrier treatment while no effect was occurred by the fertilizer treatment with the yields being greatest (521.2 kg ha^{-1}) in the root barrier×inorganic fertilizer treatment and lowest (159.8 kg ha^{-1}) in the non-barrier×inorganic fertilizer treatment. The results suggest that the separation of tree-crop root systems with the application of inorganic fertilizer influence the soil moisture and soil N availability, which in turn will affect the magnitude of crop yield.

Key words : *agroforestry, belowground process, CO_2 efflux, microbial biomass*

Introduction

Alley cropping is an agroforestry practice on purpose of growing trees/shrubs with rows creating alleys where crops are produced. The purpose is to enhance or maintain soil fertility and productivity, and to add income diversity. In aspect of sustainable soil fertility, one of major roles of trees in agroforestry systems is the organic matter input into the system through the turnover of leaves and roots (Thevathasan and Gordon, 1997; Jose *et al.*, 2000). Thus, by adopting suitable agroforestry systems on agriculture-dominated landscapes, there is a large potential for sequestering carbon in soil. In addition, the soil organic matter in temperate agroforestry systems could represent an important reservoir for carbon.

Although there are a number of studies describing below-ground interactions such as competitions for water and nutrients between trees and crops in agroforestry systems (Jose *et al.*, 2000; Allen *et al.*, 2004; Wanvestraut *et al.*, 2004), only a few studies are available to characterize soil CO_2 efflux and microbial biomass under alley cropping systems (Tufekcioglu *et al.*, 2001; Amatya *et al.*, 2002, Lee and Jose, 2003). Thus, information describing the effect of tree component in alley cropping systems on the below-ground processes such as soil CO_2 efflux, microbial biomass, and fine root biomass is useful for understanding nutrient dynamics in these systems, and assessing the carbon storage capacity. Furthermore, in agroforestry, the impact of fertilizer management on those below-ground processes and on crop yield is unclear.

The overall objective of this study was to examine the below-ground tree-crop interactions on soil CO_2 efflux and microbial biomass C with different fertilization practices in an pecan-cotton alley cropping system. The specific objectives were: 1) to determine the effect of pecan tree root system in soil CO_2 efflux and microbial biomass C in the alley cropping soil using root barrier method, 2) to examine the influence of two commercial fertilizers on soil CO_2 efflux and microbial biomass C, and 3) to examine the effect of the below-ground competition between tree and crop on cotton lint yield.

*Corresponding author
E-mail: khL@jnu.ac.kr

Materials and Methods

1. Study site

This study was conducted at the University of Florida's West Florida Research and Education Center (WFREC) research farm in Jay, Florida (30° 46'N, 87° 13'W), USA during the 2002 growing season. The climate is temperate with mild winter and hot, humid summer. The soil at the site is characterized as a well-drained, Redbay sandy loam (a fine-loamy, siliceous, thermic Rhodic Paleudult) formed in thick beds of loamy marine deposits with an average water table depth of 1.8m. The main chemical and physical characteristics of the soil are summarized in Table 1 representing the soil properties before the experiment. For this study, a pecan-cotton alley cropping system was initiated in spring 2001 from an existing pecan orchard established in 1954. Pecan trees were spaced at 10.6 m (intra row) × 18.3 m (alley row). Average height and DBH of pecan trees were 18.5 m and 68.2 cm. For this study, 12 plots were laid out within the alley cropping system and arranged into a two-way factorial complete randomized design with three replications. The two factors, root barrier and different fertilizers were randomly assigned (described below) in each plot to measure the effects on soil CO_2 efflux, microbial biomass, fine root biomass, and cotton yield. The plot size was 27.4 m long and 18.3 m wide and consisted of two rows of pecan trees. Each plot was separated from its adjacent plot by a buffer zone of the same dimensions. Cotton was planted in May 2002 in each alley, and each alley had 16 rows of cotton with 0.9 m row spacing. The site had remained abandoned for at least 29 years before the alley cropping trial began.

2. Treatments

In March of 2001, twelve plots were randomly divided into six barrier plots and six non-barrier plots. For the barrier treatment, 20 cm wide trenches were dug down to 120 cm at a distance of 150 cm away from the trees. A double layer of 0.15 mm thick polyethylene sheeting was then inserted into the ditches prior to mechanical backfilling. It is believed that the barrier treatment effectively separates the belowground root interaction between pecan trees and cotton crops, while the belowground interaction exists in non-trenched plots.

The different fertilizer treatment (conventional inorganic fertilizer vs. organic poultry litter) was to assess differences in soil CO_2 efflux, microbial biomass, fine root biomass, and cotton yield. The barrier and non-barrier treatment plots was randomly divided into three plots for conventional inorganic fertilizer application and the other three plots for organic poultry litter application. A 3-9-18 fertilizer blend was applied at a rate of 89.6 kg N ha^{-1} on 5 June 2002. 2/3 rate of the organic poultry litter (Black Gold Compost Co., Oxford, Florida) was distributed on 5 June, and 1/3 rate was distributed on 24 June using a rotary manure spreader. Conventional insecticide and herbicide were applied during the growing season as recommended.

3. Soil CO_2 efflux measurement

An Infra-red gas analyzer (IRGA) (Li-Cor 6400 potable photosynthesis system fitted with a 6400-09 soil CO_2 flux chamber, LI-COR Inc., Lincoln, Nebraska) was used to measure the rates of soil CO_2 efflux as in Lee and Jose, (2003). During the cotton growing season, the rates of soil CO_2 efflux were measured monthly from July to September 2002 at four locations in the cotton alley at distances of 2, 4, 6, and 8 m from a randomly selected pecan tree. One cylindrical soil collar, 5 cm tall and 10.2 cm in diameter, was placed in each measurement location and was kept in the same location for all measurements. Collars were installed seven days prior to the first measurement. The IRGA measurements were conducted from 10:00 am to 12:00 noon and an average of three consecutive IRGA measurements was taken as a sample in each measurement. Soil temperature was measured at 12 cm depth adjacent to each chamber during the soil CO_2 efflux measurement. Volumetric soil moisture content was measured at 12 cm depth by using a Hydrosense soil moisture meter (Campbell Scientific, Inc. Logan, UT).

4. Microbial biomass C and live fine root biomass

Soil microbial biomass C and fine root biomass were measured from soil core samples taken during each soil CO_2 efflux measurement. Two soil cores (35 cm deep × 5 cm diameter) were taken from each location that followed the same sequence as the soil CO_2 efflux measurement using a soil core sampler. Each soil sample for microbial biomass C analysis was passed through a 4 mm mesh sieve to separate roots and debris. One soil core was used for soil microbial biomass C analysis, and the other for fine root biomass measurement. Soil microbial biomass C was determined through chloroform fumigation-extraction method (Vance *et al.*, 1987). Dissolved organic carbon (DOC) was analyzed by using a Phoenix 8000 autoanalyzer (Tekmar-Dormann, Cincinnati, OH). Microbial biomass C was calculated as follows:

Microbial biomass C (mg C kg dry $soil^{-1}$) =
[(DOC in fumigated sample − DOC in control)/0.33]
/(Soil dry weight)

A correction factor (0.33) was used to convert DOC to microbial biomass C, which also accounts for the efficiency of extracting DOC and lysis by fumigation (Dictor *et al.*, 1998).

Soil core samples for estimating live fine root biomass were wet sieved through a fine mesh screen (2 mm), and root fragments were hand-sorted. Fine roots (< 2 mm diameter) were classified as live or dead fractions based on the elasticity of their tissues and the color of the cortex (Fahey and Hughes, 1994). Live fine roots were dried at 70°C for 48 h and weighed to ± 0.1 mg.

5. Statistical analyses

The effect of treatment on soil CO_2 efflux, microbial biomass C, fine root biomass, and cotton yield was tested using General Linear Model procedure of SAS (SAS, 1990). If significant treatment effects were revealed ($\alpha = 0.05$), Tukey's studentized range test was used for mean separation. Possible effects of soil microbial biomass C, live fine roots biomass, and soil organic matter on soil CO_2 efflux rates were evaluated using correlation analysis.

Results and Discussion

The rate of soil CO_2 efflux was significantly ($P < 0.01$) affected by the fertilizer treatment while root barrier treatment did not significantly affect the rate of soil CO_2 efflux (Figure 1 and Table 2). No interaction between the fertilizer and root barrier treatment occurred for the rate of soil CO_2 efflux and rates of soil CO_2 efflux were varied significantly ($P < 0.05$) among measurements (Table 2). Mean soil CO_2 efflux rate was highest (5.57 $\mu mol\ m^{-2}\ s^{-1}$) in the non-root barrier× poultry litter treatment, and lowest (3.74 $\mu mol\ m^{-2}\ s^{-1}$) in the root barrier×inorganic fertilizer treatment (Table 3). The spatial variation in soil CO_2 efflux in cotton rows did not occur under all treatments (data not shown).

Soil microbial biomass C was affected significantly ($P < 0.05$) by the fertilizer treatment while no significant effect of the barrier treatment was occurred (Figure 1 and Table 2). No interaction of treatments between the fertilizer and root barrier occurred for microbial biomass C, and amounts of microbial biomass C were varied significantly ($P < 0.01$) among measurements (Table 2). Soil microbial biomass C was greatest (522.0 mg C kg^{-1}) in the root barrier× poultry litter treatment and lowest (428.7

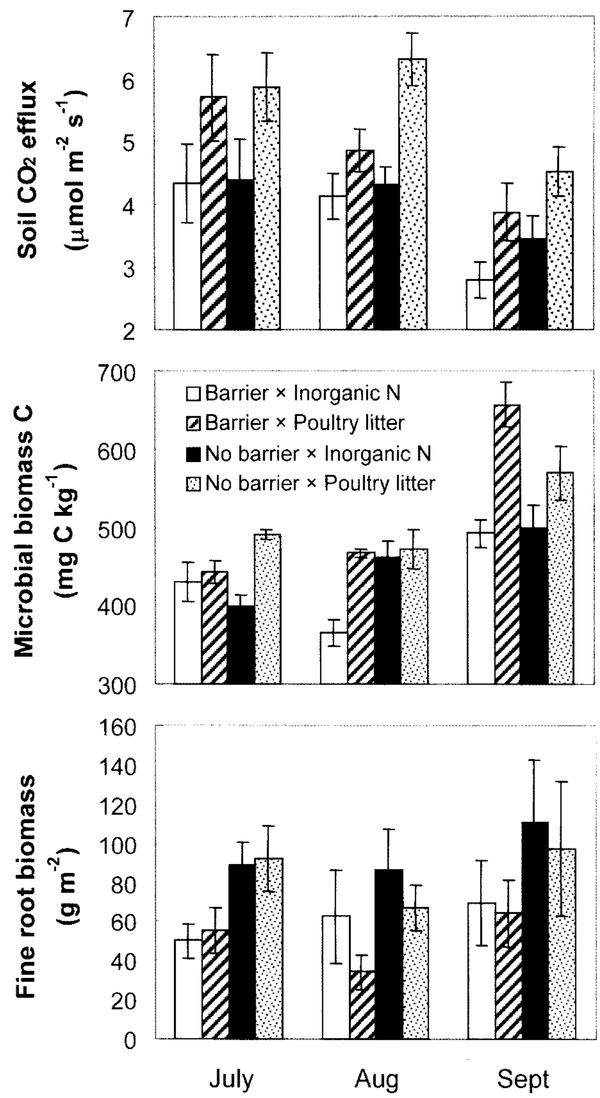

Figure 1. Temporal variations in soil CO_2 efflux, microbial biomass C, and live fine root biomass in the two factors (root barrier and fertilizer treatments). Error bars represent one standard error of the mean.

Table 1. Chemical and physical properties of the upper 10 cm soils in a pecan-cotton alley cropping system in northwest Florida, USA.

Treatment	SOM[1] (%)	Total N (%)	CEC[2] (cmol kg^{-1})	pH	Sand (%)	Silt (%)	Clay (%)	Bulk density (g cm^{-3})
Barrier × Inorganic N	2.57	0.14	20.80	6.33	73	16	11	1.20
Barrier × Poultry litter	2.56	0.15	23.17	6.77	77	15	8	1.31
No barrier × Inorganic N	2.70	0.16	22.03	6.80	75	14	11	1.27
No barrier × Poultry litter	2.65	0.15	22.70	6.73	75	16	9	1.23

[1]SOM: Soil organic matter.
[2]CEC: Cation exchange capacity.

Table 2. *F*-values from ANOVA test for the effects of two different fertilizers and root barrier on soil CO_2 efflux, microbial biomass C, live fine root biomass, and cotton yield in a pecan-cotton alley cropping system in northwest Florida, USA.

Effect	DF	Soil CO_2 efflux	Microbial biomass C	Live fine root biomass	Cotton yield
Fertilizer	1	9.3**	6.7*	0.3 NS	0.7 NS
Barrier	1	1.5 NS	0.1 NS	4.0*	18.3**
Time	2	4.4*	6.6**	0.6 NS	NA
Fertilizer × Barrier	1	0.3 NS	0.4 NS	0.0 NS	2.3 NS

*$P < 0.05$, **$P < 0.01$, NS = not significant, NA= not available.

Table 3. Effects of root barrier and different fertilizers on soil CO_2 efflux, microbial biomass C, live fine root biomass, and cotton yield in a pecan-cotton alley cropping system in northwest Florida, USA. Values are means (n=9) with standard errors in parenthesis. Values with the same lower case letter are not significantly different ($P < 0.05$).

Treatment	Soil CO_2 efflux ($imol\ m^{-2}\ s^{-1}$)	Microbial biomass C ($mg\ C\ kg^{-1}$ dry soil)	Live fine root biomass ($g\ m^{-2}$)	Cotton yield ($kg\ ha^{-1}$)
Barrier × Inorganic N	3.74 (0.28) c	428.7 (14.3) c	60.7 (11.0) ab	521.2 (70.6) a
Barrier × Poultry litter	4.81 (0.32) ab	522.0 (19.2) a	51.2 (7.6) b	374.5 (97.7) ab
No barrier × Inorganic N	4.04 (0.27) bc	452.4 (14.6) bc	95.0 (13.1) a	159.8 (23.4) b
No barrier × Poultry litter	5.57 (0.29) a	510.6 (15.6) ab	85.6 (13.1) ab	201.0 (24.0) b

mg C kg^{-1}) in the root barrier×inorganic fertilizer treatment (Table 3).

Live fine root biomass was only affected significantly ($P < 0.05$) by the root barrier treatment (Table 2) being greatest (95.0 g m^{-1}) in the no-root barrier treatment× inorganic fertilizer treatment and lowest (51.2 g m^{-1}) in the root barrier×poultry litter treatment (Table 3).

Results of this experiment showed that soil CO_2 efflux rate and microbial biomass C were increased with the poultry litter application compared to those with the inorganic fertilizer application and there was no differences in fine root biomass between the two fertilizer applications (Figure 1 and Table 3). As the result expected, the root barrier treatment decreased fine root biomass without changing CO_2 efflux rate and microbial biomass C.

Soil CO_2 efflux originates from autotrophic live roots and heterotrophic microbial respiration in the rhizosphere (Buchmann, 2000). Higher soil CO_2 efflux rate under the no-root barrier× poultry litter treatment indicates the possible alteration of factors affecting soil CO_2 efflux by the trees and the fertilizer treatment. The higher rates of soil CO_2 efflux may be attributed to higher live fine root biomass in the soil (Table 3). Even though distinguishing the live fine roots of cotton crops and pecan trees was not available in this study, the live fine roots found in the root barrier treatment could be presumed as only cotton roots because the barrier must have prevented pecan tree roots entering the alleys. Increased microbial biomass C in the poultry litter treatment compared with the inorganic fertilizer treatment (Table 3) may also be one of reasons for the higher soil CO_2 efflux in the no-root barrier×poultry litter treatment. Many studies have showed that applications of organic fertilizer have increased soil CO_2 efflux and microbial biomass (Borken *et al*., 2002; García-Gil *et al*., 2000).

The type of fertilizer applied had a significant influence on soil CO_2 efflux and microbial biomass C (Table 2), with the plots that received poultry litters having higher soil CO_2 efflux and microbial biomass C than those that received inorganic fertilizer (Figure 1 and Table 3). The difference may be due to the extra C source added with the poultry litters provided fuel for microbial respiration and biomass. Schindler *et al.* (1997) found similar result that plots received organic fertilizers had higher soil CO_2 efflux rates and microbial biomass than those that received inorganic fertilizers, but the stimulatory effect did not persist into the late autumn and did not carry over to the following spring.

It may be deduced that the application of poultry litter has a beneficial effect on soil microbes in the alley cropping system due to the increase in nutrient availability. However, it may also increase the competition between crop roots and soil microbes for nutrients resulting reduced crop yield. Because soil microbial biomass act as sink and source for plant nutrients, increased microbial biomass with the poultry litter application in this study may increase long-term nutrient availability in the system.

Several mechanisms may explain the differences in soil CO_2 efflux rates with the root barrier treatment. Soil CO_2 efflux can be reduced not only because the roots component is lacking, but also because trenching prevents belowground carbon input for microbes (Buchmann, 2000).

Table 4. The relationships among soil CO_2 efflux, microbial biomass C, live fine root biomass, soil moisture, and cotton yield in a pecan-cotton alley cropping system in northwest Florida, USA. Values are Pearson correlation coefficients (r) with *P* values in parenthesis (n=12).

Variables	Microbial biomass C	Live fine root biomass	Soil moisture	Cotton yield
Soil CO_2 efflux	0.436 (0.157)	0.442 (0.151)	- 0.545 (0.067)	- 0.195 (0.543)
Microbial biomass C		0.201 (0.531)	- 0.383 (0.219)	- 0.600 (0.039)
Live fine root biomass			- 0.656 (0.021)	- 0.628 (0.029)
Soil moisture				0.733 (0.007)

Many studies have used the root barrier method to separate the root system between tree and crop in alley cropping systems with results that the root barriers were effective in reducing or eliminating below-ground competition for water and nutrient resulting in higher soil water levels and greater crop yields in the alleys with the root barrier treatment compared to the no-barrier treatment (Jose *et al.*, 2000; Miller and Pallardy, 2001; Wanvestraut *et al.*, 2004).

Many studies have shown that soil temperature and soil water content are the most important factors affecting soil CO_2 efflux rates (Raich and Potter, 1995; Buchmann, 2000). It is well known that soil temperature and soil moisture have pronounced influence on the seasonal dynamics of soil CO_2 efflux (Carlyle and Than, 1988). Recent research shows that soil CO_2 efflux is influenced more by soil temperature than soil moisture (Fang *et al.*, 1998; Wagai *et al.*, 1998), if soil moisture is between the permanent wilting point and the field capacity. Wagai *et al.* (1998) suggested that the two environmental factors might have a confounding effect on soil CO_2 efflux rates, because soil temperature tended to be high when the soil moisture was low and *visa versa*. This was apparent in this study as well (Figure 2). However, soil temperature was not well correlated with soil CO_2 efflux rate in this study while soil water content was correlated (Table 4). This might be due to the less variation in soil temperature (26 to 28°C) than soil water content (15 to 22%) (Figure 2). Results from this study indicated that soil water was one of primary competing resources between trees and crops in this temperate alley cropping system (pecan/cotton).

Cotton lint yield was significantly ($P < 0.01$) affected by the root barrier treatment while no effect was occurred by the fertilizer treatment (Table 2). Cotton lint yield was greatest (521.2 kg ha^{-1}) in the root barrier× inorganic fertilizer treatment and lowest (159.8 kg ha^{-1}) in the non-barrier× inorganic fertilizer treatment (Table 3). Cotton yield was correlated positively with soil water content ($r = 0.73$, $n = 12$, $P < 0.007$), correlated negatively with microbial biomass C ($r = -0.60$, $n = 12$, $P < 0.039$) and live fine root biomass ($r = -0.63$, $n = 12$, $P < 0.029$) (Table 4).

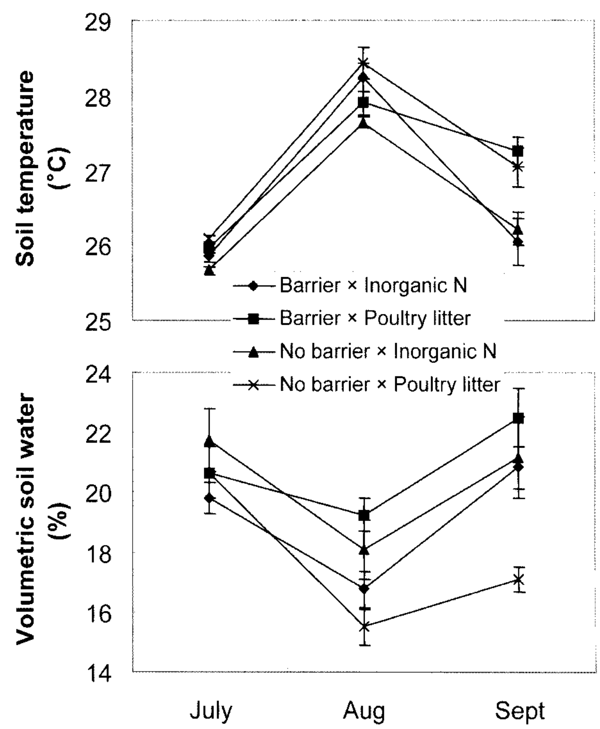

Figure 2. Temporal variations in soil temperature and volumetric soil water measured at the depth of 10 cm.

The results of this study show that crop yields can be increased by separating established roots systems of trees from crop roots indicating periodic tree root pruning practice may require to force strict spatial partitioning of tree roots to a portion of the soil unavailable to the crop. However, the long-term impacts of repeated tree root pruning in alley cropping systems are not known, although periodic root pruning in orchards has been used to manage fruit production.

Overall, our results suggest that the separation of tree-crop root systems with the application of inorganic N fertilizer influence the soil moisture and soil N availability, which in turn will affect the magnitude of crop yield, while the application of poultry litter temporarily decreases the N availability in the soil resulting the low crop yield. Because microbial biomass act as sink and source for plant nutrients, increased microbial biomass with the poultry litter application in this study may increase long-term nutrient availability in the system.

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