JOURNAL OF
ECOLOGY AND ENVIRONMENT
http://www.jecoenv.org

Research Paper

J. Ecol. Environ. 38(4): 425-436, 2015

Budget and distribution of organic carbon in *Quercus serrata* Thunb. ex Murray forest in Mt. Worak

Seung-Hyuk Lee[1,2], Rae-Ha Jang[1], Kyu-Tae Cho[1] and Young-Han You[1,*]

[1]Department of Biology, Kongju National University, Gongju 32588, Korea
[2]National Institute of Ecology, Seocheon 33657, Korea

Abstract

The carbon cycle came into the spotlight due to the climate change and forests are well-known for their capacity to store carbon amongst other terrestrial ecosystems. The annual organic carbon of litter production, forest floor litter layer, soil, aboveground and belowground part of plant, standing biomass, net primary production, uptake of organic carbon, soil respiration, etc. were measured in Mt. Worak in order to understand the production and carbon budget of *Quercus serrata* forest that are widely spread in the central and southern part of the Korean Peninsula. The total amount of organic carbon of *Q. serrata* forest during the study period (2010-2013) was 130.745 ton C ha^{-1}. The aboveground part of plant, belowground part of plant, forest floor litter layer, and organic carbon in soil was 50.041, 12.510, 4.075, and 64.119 ton C ha^{-1}, respectively. The total average of carbon fixation in plants from photosynthesis was 4.935 ton C ha^{-1} yr^{-1} and organic carbon released from soil respiration to microbial respiration was 3.972 ton C ha^{-1} yr^{-1}. As a result, the net ecosystem production of *Q. serrata* forest estimated from carbon fixation and soil respiration was 0.963 ton C ha^{-1} yr^{-1}. Therefore, it seems that *Q. serrata* forest can act as a sink that absorbs carbon from the atmosphere. The carbon uptake of *Q. serrata* forest was highest in stem of the plant and the research site had young forest which had many trees with small diameter at breast height (DBH). Consequentially, it seems that active matter production and vigorous carbon dioxide assimilation occurred in *Q. serrata* forest and these results have proven to be effective for *Q. serrata* forest to play a role as carbon storage and NEP.

Key words: allometric equation, biomass, deciduous forest, net ecosystem production, temperate seasonal change

INTRODUCTION

Climate change, desertification, melting ice caps, rising sea level, and destruction of ecosystem have been under progress as global warming continued to accelerate since mid-1980s. The increase of CO_2 concentration was noted as the main cause of mentioned phenomena (Jones et al. 1986, Cannell et al. 1992, Kim 2012). The global CO_2 concentration increased by 40% from 278 ppm (1975) to 390.5 ppm (2011) (Ciais et al. 2013). The main cause of this global increase was the usage of fossil fuels which significantly contributed to changes in land-use (IPCC 2007). Therefore, much attention is paid to the forest ecosystem which is a carbon sink (Hu and Wang 2008) and to the change and role of carbon cycle. The carbon cycle of terrestrial ecosystem was significantly disturbed after the industrialization. The carbon emission during 1980-1990 was 140 billion tons C ha^{-1} and carbon absorption was only 101

http://dx.doi.org/10.5141/ecoenv.2015.045

Received 16 May 2015, **Accepted** 29 July 2015

***Corresponding Author**
E-mail: youeco21@kongju.ac.kr
Tel: +82-41-850-8508

pISSN: 2287-8327 eISSN: 2288-1220

billion tons C ha^{-1} resulting with surplus of 39 billion tons C ha^{-1} (Sabine et al. 2004). The carbon storage of terrestrial ecosystem can be mainly divided into forest and soil (Lee 2010). The carbon cycle starts by fixing carbon from the atmosphere through photosynthesis of plants and they are absorbed into the soil in form of organic matter such as leaves, woods, and fruits. The accumulated carbon in the soil is then released into the atmosphere through plant, microbial decomposition and respiration. Thus, further research on forest matter production is required in order to analyze their carbon absorption, emission, and storage.

The matter production is a result of growth of communities within the forest that are formed by the interaction between environment and vegetation. The research has a significant meaning in a way that it revaluates forest resources by investigating and estimating the productivity, ecological properties, and carbon fixation in the forest (Park et al. 2005). The forests have different carbon storage capacity depending on physical, chemical, and biological environment such as dominant tree species, forest age, locational condition, and climate. However, it has been reported that forest ecosystem is responsible for 90% of aboveground carbon storage and 40% of belowground carbon storage (Waring and Schlesinger 1985). The standing biomass of plant communities becomes an index for matter production within the ecosystem and biomass allocation is an important factor in analyzing the feature and type of matter accumulation in the ecosystem (Whittaker and Marks 1975). The estimate of standing biomass can be calculated by using diameter at breast height (DBH) of trees and allometric equation between each organs (Kittredge 1944, Shidei 1960). It has been reported by Kim and Kim (1988) in the domestic forestry research that belowground biomass increases with the increase in aboveground biomass and that belowground biomass accounts for 20-30% of aboveground biomass.

The organic carbon in soil accounts for approximately more than 50% of total Earth's carbon (Vitousek 1991) and it is crucial to investigate the carbon accumulation in soil and carbon emission from soil to atmosphere. Therefore, the ecosystem and climatic condition must be investigated because carbon cycle of soil is controlled by such factors (Lee et al. 2010), and recently temperature and moisture correlation data, which is the environmental factors of soil respiration, have been required (Shutou and Nakane 2004). Alkali absorption method which applies CO_2 absorbing chemicals such as lime and potassium hydroxide under closed chamber conditions were used in the beginning to measure soil respiration but Infrared Gas Analyzer (IRGA) is used today (Lee et al. 2010). The litter production is a fundamental process in maintaining the functions of forest ecosystem and it is determined by factors such as temperature, rainfall, insects, tree density, and climate (Bray and Gorham 1964). The accumulated organic matter on the forest floor of forest ecosystem mostly consists of tree leaves that form the forest (Ovington and Heitkamp 1960), and CO_2 is released again during the absorption process in the soil when plants are decomposed (Berg and Agren 1984). Hence, the litter production is an important factor that controls the primary production of the forest (Cole and Rapp 1981, Meentemeyer et al. 1982).

In this way, the forest carbon distribution, absorption, and emission can be determined through estimated carbon budget by quantifying the amount of carbon in each factor. It was purported that temperate forest ecosystem plays an important role in decreasing the atmospheric carbon (Tans et al. 1990), and *Quercus* spp., which are deciduous trees, dominate south central regions of Korea (Kim et al. 1981). Worak National Park situated in central Korea was the 17th National Park selected and it is situated at 128°02′-128°21′ East longitude, and 36°47′- 36°58′ North latitude having total area of 287,977 km^2. There has not been a research on carbon budget of *Q. serrata* forest even though there were researches on *Pinus koraiensis* S. et Z. plantation by Pyo et al. (2003), *Q. variabilis* BL. Forest by Choi (2007) and Namgung (2010) at Worak National Park, *Q. mongolica* FISCH. Forest by Shin (2012), and *P. densiflora* S. Et Z. forest by Lee (2014a) with regards to carbon budget of domestic forest ecosystem. *Q. serrata* Thunb. ex Murrayis recognized as climax species of forest vegetation succession as well as the potential natural vegetation (Lee and You 2012), and it is widely distributed across central lowlands and southern regions of Korea (Chung and Lee 1965).

This research investigated the main plant community, *Q. serrata* forest amongst *Quercus* forests which represents temperate deciduous forests of Korea, in Worak National Park from 2010 to 2013. The following areas were studied in order to explain the matter production of forest ecosystem, budget and distribution of carbon: annual litter production, litter organic carbon, standing biomass, net primary production, organic carbon in plants and soil, organic carbon in litter on forest floor, and soil respiration.

MATERIALS AND METHODS

Research site

Worak National Park consists of following main vegetation: 32.4% deciduous forests, 16.7% *Pinus-Quercus* forests, and 12.4% *Q. mongolica* forest (Oh et al. 2005). It has continental climate as it is situated in southern central regions of Korean Peninsula and it also reflects some of the features of mountain climate because it is surrounded by rugged mountain ranges. It has relatively heavy rainfall affected by the orographic rainfall of Taebaek, Sobaek, Charyeong, and Noryung mountain ranges.

In November 2009, 20 m × 20 m permanent quadrat (N 36°50′08.5″, E 128°17′27.4″) was installed in the research site for *Q. serrate* community. It is located in Dongsa-myeon, Moonan-gol of Mt. Worak 398 m above sea level with the slope of 22°. The average forest age was 18.4 years, average height was 12.7, average DBH was 14.2 cm, and tree density was 1200 tree/ha. *Staphylea bumalda* DC., *Securinega suffruticosa* (Pall.) Rehder, and *Weigela subsessilis* (Nakai) L. H. Balley were distributed in the shrub layer whereas Carex siderosticta Hance, *Lespedeza maximowiczii* C.K. Schneid, and Atractylodes ovata (Thunb.) DC. were found in the herb layer. It was found that annual average temperature was 12.4℃ and rainfall was 1258.9 mm with reference to 30 years of climatic data stored at Jecheon Meteorological Observatory 20 km away from the research site. The annual average temperature was 9.63-10.11℃ and annual average rainfall was 1381.30-2230.50 mm (Korea Meteorological Administration 2010, 2011, 2012, 2013) during the study period (2010-2013) but exceptionally high rainfall was observed in 2011.

Standing biomass and annual net primary production

The harvesting method is the best method to measure the standing biomass of tree layer after felling the forest (Kang and Kwak 1998) but allometric equation which can be applied to each plant was used instead to measure the standing biomass as felling is prohibited in National Parks. The diameter at breast height (D) and height (H) of the trees with diameter greater than 3.0 cm within the permanent quadrat of the research site were measured every April from 2010 to 2013. Allometric Equation of *Q. serrata* Thunb. ex Murray (Koh 2002), *Q. mongolica* (Kim and Yoon 1972), *Q. variabilis* (Kang and Kwak 1998), and *P. sargentii* (Kwak et al. 2004) were used to estimate the standing biomass. The annual litter production collected from the litter trap was used to calculate the standing biomass of leaves and reproductive organs.

The standing biomass of shrub layer was estimated by installing three quadrats (2 m × 2 m) around permanent quadrat in the region of same community and leaves and twigs produced in that year were collected. The same procedure was conducted for herb layer by installing three quadrats (1 m × 1 m). The collected samples were weighed after being dehydrated at 60℃ in the dryer until it reached constant weight and then the standing biomass per area unit was calculated. It was reported that the proportion of belowground standing biomass in woody plants in general accounts for 15-35% of entire standing biomass depending on forest age and environment (Rodin and Bazilevich 1967).This research estimated and applied 25% as the ratio of belowground standing biomass (roots) to aboveground standing biomass (shoots) (Johnson and Risser 1974).

The annual net primary production ($\triangle W = W2 - W1$) was calculated by subtracting current year's standing biomass (W1) from next year's standing biomass (W2). The annual net primary production of leaves and reproductive organs were calculated using the annual litter production collected from the litter trap because they wither in same year they are produced. The net primary production of shrub and herb layer was used the standing biomass.

Plant organic carbon and uptake of organic carbon

The plant organic carbon was estimated to be 45% of dehydrated plant mass in tree, shrub, and herb layer (Houghton et al. 1983). The absorption of organic carbon by plants was calculated based on organic carbon found in plants which was measured. The annual uptake of organic carbon ($\triangle C = C2 - C1$) was calculated by subtracting current year's organic carbon (C1) from next year's organic carbon (C2).

Annual litter production

The litter was collected in intervals of two months (excl. winter season) from March 2010 to December 2013 by installing three 1 m × 1 m litter trap 1 m above ground in November 2009 to measure the litter production. The collected litter was classified into leaf, stem (bark and branch), reproductive organs (flower and seed), and miscellaneous (other trees etc.) which were then weighed after being dehydrated at 60℃ condition in the dryer for more than 48 hours. Subsequently, the litter production per area unit was calculated using the litter collected from the litter trap. The organic carbon of litter production was estimated at 45% of dehydrated mass (Houghton et al. 1983).

Litter on forest floor

Four 25 cm × 25 cm small quadrats were installed outside the permanent quadrat and the litter on forest floor was collected after classifying the layer into Litter and Fermentation layer. It was then weighed after being dehydrated in the dryer at 65˚C condition for 48 hours in the laboratory. The organic carbon of forest floor litter was estimated at 45% of dehydrated mass (Houghton et al. 1983).

Soil organic carbon

The soil was collected in 10 cm intervals until it reached 50 cm in depth at three random points outside the permanent quadrat and it was taken to the laboratory sealed in plastic bags. The collected soil was used to analyze organic matter content, organic carbon content, accumulated organic carbon content, and rock volume. The soil was collected in 10 cm intervals up to 50 cm by using a soil sampler which is a stainless cylinder 5 cm in diameter and 10 cm in height. It was taken to the laboratory sealed in plastic bag to be weighed after being dehydrated at 105˚C condition in the dryer until it reached constant weight. The measured weight value was then divided by the volume in order to calculate soil bulk density. The rock volume was calculated by dividing the weight of particles greater than 2 mm by the total weight after filtering the dehydrated soil particles with 2 mm filter sieve. The 5.000 g air dried fine soil in porcelain crucible was weighed after being dehydrated in the dryer at 105˚C condition for 48 hours and it was heated in electric furnace at 600˚C condition for six hours. The ash content was subtracted from the dry mass and it was then divided by 1.724 in order to convert the value into soil organic carbon content (Black 1965). The following equation was used to calculate accumulated organic carbon content according to the method proposed by Wang et al. (2002) considering the rock volume ratio:

Soil organic carbon (SOC) (kg / m^2) = bulk density (ton / m^3) × organic carbon content (g / kg) × soil thickness (cm) × (1-rock volume ratio)

Soil respiration

A portable measuring device, EGM-4 (PP Systems, Amesbury, UK), was used to measure the soil respiration. The measuring method of this device is one of the SRC-1 (PP Systems) based on closed method and it was easy to measure with infrared gas analyzer at the measuring point using portable battery. The soil respiration was measured by CO_2 released from the soil into the closed chamber (g CO_2 m^{-2} hr^{-1}) according to elapsed time after removing the litter layer and fixing a cylinder chamber on the soil surface. The root respiration was calculated by 46% of estimated value after estimating the soil respiration using the correlation between soil respiration and soil temperature excluding the maximum and minimum value measured quarterly at 10 random points in the permanent quadrat of this research site (Koo et al. 2005).

Net ecosystem production

The quantification of carbon budget using biometric method is a method of completing the entire frame of carbon budget by quantifying the carbon mass of each factor within the ecosystem and the carbon transfer process (Lee et al. 2010). The net ecosystem production (NEP), a carbon budget at ecosystem level, is calculated by subtracting heterotrophic respiration (HR), which releases carbon into the atmosphere through animal and microbial carbon decomposition process, from net primary production (NPP).

$$NEP (C) = NPP (C) – HR (C)$$

RESULT AND DISCUSSION

Standing biomass, net primary production, plant organic carbon, and uptake of organic carbon

The standing biomass of the research site was 122.626, 133.625, 144.233, 155.528 ton/ha for 2010, 2011, 2012, 2013, respectively, and total average over the study period was 139.003 ton/ha. The plant organic carbon was 55.182, 60.131, 64.905, 69.988 ton C ha^{-1} , respectively, and total average over the study period was 62.551 ton C ha^{-1}. In addition, the standing biomass and organic carbon increased annually (Table 1).The research results related to standing biomass of *Q. serrata* forest were reported as follows: Koh (2002) reported aboveground biomass of 52.631 ton/ha at Mt. Songgwang, and *Q. serrata* forest of 94.20

ton/ha at Mt. Songni; Park and Lee (2002) reported 56.07 ton/ha of 34 year old *Q. serrata* forest at Gwangyang, 44.00 ton/ha of 25 year old *Q. serrata* forest at Muju, and 86.32 ton/ha of 37 year old *Q. serrata* forest in Pohang region; and lastly, Park and Moon (1994) reported 115.3 ton/ha of 26-29 year old *Q. serrata* forest at Mt. Mohu in Jeollanam-do. The standing biomass of above-mentioned sites were lower than the standing biomass of this research but the standing biomass (221 ton/ha) of *Q. serrata* forest in Bukhansan National Park estimated by Lee (2011) and standing biomass (261.2 ton/ha, 1,473 trees/ha) and organic carbon (136 ton C ha^{-1}) of deciduous forest (*Q. serrata* dominant) in Gwangneung estimated by Lim et al. (2003) were higher than this research result.

The annual net production was 10.999, 10.608 and 11.295 ton $ha^{-1}yr^{-1}$ for 2010, 2011, 2012, respectively, and total average was 10.967 ton $ha^{-1}yr^{-1}$ (Table 1). This result was similar to the result (11.36 ton $ha^{-1}yr^{-1}$) reported by Chang and Kim (1983) for *Q. serrata* forest in Mt. Jiri. However, it was higher than 4.870 ton $ha^{-1}yr^{-1}$ of *Q. serrata* forest in Suncheon reported by Lim (1985), and estimates reported by Park and Lee (2002) in Gwangyang (6.18 ton $ha^{-1}yr^{-1}$), Muju (6.53 ton $ha^{-1}yr^{-1}$), and Pohang region (7.66 ton $ha^{-1}yr^{-1}$). Nonetheless, the result was slightly lower than 14.5 ton $ha^{-1}yr^{-1}$ of Park and Moon (1994). The standing biomass and plant organic carbon show similar trends in their correlation. The reason why standing biomass, annual net production, and plant organic carbon show different values to other research is because forest age and tree density of different research sites have influenced the study. Kimmins (1987) stated that the standing biomass and net production increases with aging of the forest in case of young forests given that community structure of the forest is similar and Ohtsuka et al. (2010) also reported that the increase of biomass and net production of younger forest is greater than the older forest. In addition, the NPP of forest ecosystem typically changes with the forest age, and it starts to decrease once dense pioneer community reaches its peak (Marks 1974, Smith and Long 2001, Binkley et al. 2002). Kang and Kwak (1998) reported that there could be a difference in matter production as it is influenced by tree density, forest age, and locational condition even though *Quercus* spp. consist of same species. Furthermore, Kwak and Kim (1992) reported that the change in annual net production of tree layer has a close connection to changes in tree density, death rate, and production cycle rate. Thus, the research result was higher than the other research results because the forest was younger and tree density was higher.

The uptake of organic carbon was 4.949, 4.774, 5.083 ton C $ha^{-1}yr^{-1}$ for 2010, 2011, 2012, respectively, and the average was 4.935 ton C $ha^{-1}yr^{-1}$ (Table 1). The research result showed similar result to 4.3 ton C $ha^{-1}yr^{-1}$ of deciduous forest in Gwangneung reported by Lim et al. (2003) and it was higher than 1.834 ton C $ha^{-1}yr^{-1}$ uptake of organic carbon at Mt. Songgwang in Suncheon reported by Lim (1985). The previously mentioned differences in forest age, tree density, and high NPP of young forest seem to affect the uptake of organic carbon as well. In particular, there was a tree in this community damaged by wild animals in 2012 but it was recovering very fast. The uptake of organic carbon in this community seems to be higher than other communities as Ohtsuka et al. (2010) states that the damage recovery is faster in younger forests which affects the production.

Organic carbon of litter production

The amount of annual organic carbon accumulating on the forest floor from the litter production was 1.834, 1.769, 1.440, 1.641 ton C $ha^{-1}yr^{-1}$ during study period (2010-2013) and total average was 1.671 ton C $ha^{-1}yr^{-1}$ (Fig. 1). The organic carbon of litter showed significant annual change. The organic carbon decreased sharply in 2012 but it increased again. The sharp decrease seems to be from the damage on leaf and stem of trees caused by the typhoon (Bolaven). The high ratio of stands that have low DBH and fast recovery of young *Q. serrata* forest seem to have affected the increase in the production and uptake of organic carbon. The leaves had the highest distribution of organic carbon on forest floor each year and the rest were in following order: stem, reproductive organ, then

Table 1. Standing biomass (ton/ha), plant organic carbon (ton C ha^{-1}), net primary production (ton ha^{-1} yr^{-1}) and uptake of organic carbon (ton C ha^{-1} yr^{-1}) of *Quercus serrata* forest from 2010 to 2013

	2010	2011	2012	2013
Standing biomass (ton/ha)	122.626	133.625	144.233	155.528
Plant organic carbon (ton C ha^{-1})	55.182	60.131	64.905	69.988
Net primary production (ton $ha^{-1}yr^{-1}$)	10.999	10.608	11.295	
Uptake of organic carbon (ton C $ha^{-1}yr^{-1}$)	4.949	4.774	5.083	

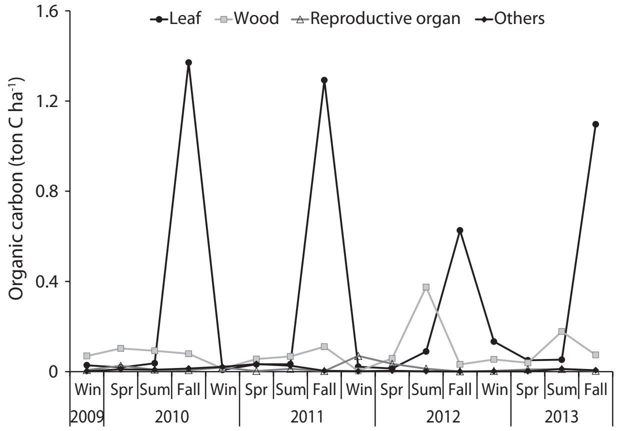

Fig. 1. Seasonal fluctuations of litter production (ton C ha^{-1}) in *Quercus serrata* forest from 2009 to 2013. Win, winter; Spr, spring; Sum, summer.

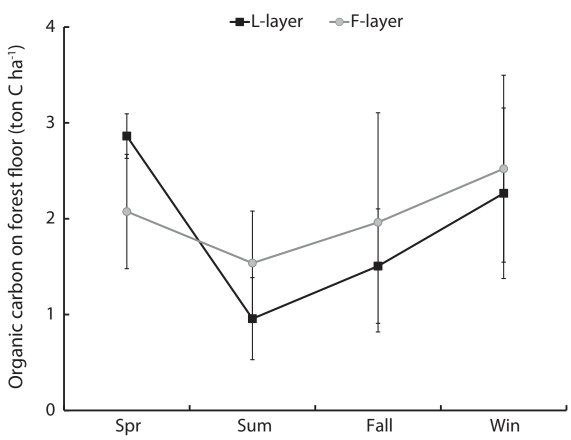

Fig. 2. Seasonal fluctuations of organic carbon (ton C ha^{-1}) on forest floor of *Quercus serrata* forest during the study period. Spr, spring; Sum, summer; Win, winter.

miscellaneous. The litter production and organic carbon was always high during fall and it was the lowest during winter each year except in 2012 (Fig. 1). A similar trend was observed in the period and change in litter production of *P. densiflora*, *Q. mongolica*, and *R. pseudoacacia* forests in Namsan (Jeong et al. 2013). *Q. serrata* forest, representative *Quercus* forest in Mt. Worak, showed the lowest organic carbon though *P. densiflora* forest of Lee (2014a) in the same Mt. Worak showed a similar value of 1.68 ton C ha^{-1}yr^{-1}, whereas *Q. mongolica* forest of Shin (2012) was 2.59 ton C ha^{-1}yr^{-1}, and *Q. variabilis* forest of Namgung and Mun (2009) was 2.42 ton C ha^{-1}yr^{-1}. In the other regions, Gwangneung deciduous forest (*Q. serrata* dominant) was 2.10 ton C ha^{-1}yr^{-1} (Lee 2009) and Geumsan *Q. serrata* forest was 2.323 ton C ha^{-1}yr^{-1} (Kim et al. 2013) showing higher value than this research. It is known that there can be changes in litter production because it has significant relation to temperature, rainfall, and pests unless there is a disturbance such as typhoon (Lousier and Parkinson 1975, Li et al. 2005, Kim et al. 2013).

Organic carbon of forest floor

The organic carbon of forest floor in the *Q. serrata* forest during the study period was on average 1.959 ton C ha^{-1} for L layer, 2.115 ton C ha^{-1} for F layer, and total average was 4.075 ton C ha^{-1} (Fig. 2).The organic carbon of F layer was always greater than L layer except during spring and it decreased from spring to summer but it increased from summer to winter (Fig. 2). Decomposition of forest floor litter is affected by animals as well as microbes in soil and they are affected by moisture, temperature and chemical properties of leaves (Rochow 1974, Singh and Gupta 1977, Meentemeyer 1978, Leirós et al. 1999, Mun 2004). It seemed that there are seasonal differences inorganic carbon of forest floor because the decomposition process accelerates during summer due to high temperature and rainfall.

The organic carbon of forest floor in Gwangneung deciduous forest was 5.4 ton C ha^{-1} (Lee et al. 2010) and *Q. serrata* forest of Piagol in Mt. Jiri was 4.29 ton C ha^{-1} (Chang and Kim 1983) which showed higher values than this research. However, similar or higher values of 3.97, 3.58, and 4.96 ton C ha^{-1} (National Institute of Environmental Research 2013) were observed during the same period (2010-2013) in the long-term ecological research of *P. densiflora*, *A. holophylla*, and *Q. mongolica* in Mt. Jeombong. The difference in organic carbon of forest floor seems to be from the differences in environmental factors of each community. Namgung and Mun (2009) stated that the difference is affected by the slope, forest age, tree density, and size of the leaf, etc. In addition, the differences in litter on forest floor seem to be caused by wild animals and artificial disturbances as well apart from natural phenomena. The research site is in the region where landslide often occurs and litter on forest floor was often lost in each investigation due to landslide and wild animals (boars etc.). There were significant differences in forest floor litter in comparison to other researched forests because the soil was bear and likewise for organic carbon. The naturally damaged deadwoods (stem etc.) and fallen leaves have high nutrient content and they can be leached fast which influences the increase of distribution and production of carbon as it accumulates on the forest floor in a long term. Moreover, Triska and Cromack (1980) stated that deadwoods enhance species diversity as they provide microhabitats. Therefore, more research

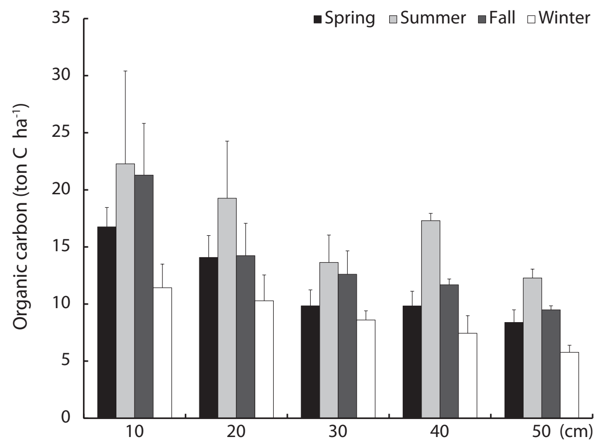

Fig. 3. Seasonal fluctuations of organic carbon (ton C ha^{-1}) along the soil depth of *Quercus serrata* forest during the study period.

on forest floor litter is required in order to understand the status of organic carbon and carbon cycle of forest ecosystem (Mun 2004).

Organic carbon in soil

The organic carbon in soil which was measured up to 50 cm in depth during the study period in *Q. serrata* forest was in total 64.119 ton C ha^{-1}yr^{-1}and the average was 12.824 ± 2.097 ton C ha^{-1}yr^{-1} (Fig. 3). The organic carbon in soil decreased as it went deeper from top soil (17.937 ton C ha^{-1}yr^{-1}) to 50 cm (8.981 ton C ha^{-1}yr^{-1}) in depth except at 40 cm (11.564 ton C ha^{-1}yr^{-1}) (Fig. 3). The seasonal accumulated organic carbon content in soil decreased as soil depth increased except in summer. Spring season was 8.390-16.759 ton C ha^{-1}yr^{-1}, summer season was 12.279-22.275 ton C ha^{-1}yr^{-1}, fall season was 9.490-21.286 ton C ha^{-1}yr^{-1}, and winter season was 5.765-11.426 ton C ha^{-1}yr^{-1}. Summer season had the highest value and the value decreased in order of fall, spring, and winter season. Also, summer season was highest and then fall, spring, and winter with regards to the depth of the soil showing similar trend (Fig. 3). This is a similar trend to *Q. serrata* forest in Bukhansan National Park where amount of carbon decreases according to depth of the soil. The total organic carbon was 49 ton C ha^{-1}yr^{-1} (Lee 2010) which was lower than this research but *Q. serrate* dominant forest in Gwangneung had 92 ton C ha^{-1}yr^{-1} which was higher than this research (Lim et al. 2003).The organic carbon in soil is affected by amount of plants falling on the soil and it is different depending on seasonal variation without doubt (Leirós et al. 1999). The decomposition occurred very well in the forest floor layer due to high temperature and rainfall of summer season. It seemed that carbon storage of soil was the highest during summer season because decomposed carbon and organic matters accumulated in soil which showed a change of seasonal difference. In addition, storage capacity of organic carbon in soil is different by region and age classes (Jeong et al. 1998). There are significant amount of nutrient, and carbon amongst aboveground matter production, that moves belowground (Chen et al. 2000). Therefore, the decomposition of fine roots and roots increase organic carbon in soil and it seems that differences in organic carbon in soil is caused by biological factors such as production and decomposition of litter and environmental factors such as temperature, soil depth, and locational conditions. The organic carbon of *Q. serrata* forest in Mt. Bukhan had the lowest amount of organic carbon in soil due to shallow soil depth in comparison to other research sites within the National Park (Lee 2011). It seems that such result is different from this research because it has lower tree density (800 tree/ha) than *Q. serrata* forest in Mt. Worak.

Soil respiration

The organic carbon from soil respiration of *Q. serrata* forest was 7.338, 7.544, 7.183 ton C ha^{-1} yr^{-1} for 2010, 2011, 2012, respectively (Fig. 4), root respiration was 3.375, 3.470, 3.304 ton C ha^{-1} yr^{-1}, annual microbial respiration was 3.962, 4.074, 3.879 ton C ha^{-1} yr^{-1}, and total average was 3.972 ton C ha^{-1} yr^{-1}. The annual soil respiration was highest in 2011 and lowest in 2012. The soil respiration in each year was highest during summer season in August, lowest in January in 2010 and 2011, but it was lowest in February in 2013 (Fig. 4). With regards to research on soil respiration of *Q. serrata* forest, Lee (2009) reported 3.65 ton C ha^{-1}yr^{-1} for *Q. serrata* and *C. laxiflora* communities (80-200 years) using Open Flow (OF) method, and Chae et al. (2003) reported 4.13 ton C ha^{-1}yr^{-1} for mixed forest of *Q. serrata*, *P. koraiensis*, and *Q. mongolica* (70-80 years) using Closed Dynamic Chamber (CDC) method. Katagiri (1988) reported 5.03 (upper slope), 4.16 (middle), 4.30 (lower slope) ton C ha^{-1}yr^{-1} according to altitude for *Q. serrata* and *C. crenata* communities in Shimane, Japan using Akali Absorption (AA) method and Katagiri et al. (1979) reported 4.09 ton C ha^{-1} yr^{-1} which showed similar value to this research result. Nakane et al. (1996) reported 9.40 ton C ha^{-1} yr^{-1} for *Q. serrata* forest (102 years) in Hiroshima, Japan, Yim et al. (2002) reported 9.52 ton C ha^{-1} yr^{-1}for *Q. serrata* forest (70 years) in the same region, and 5.68 ton C ha^{-1} yr^{-1} for *Q. serrata* dominant mixed forest in Tokyo all using AA method. Takahashi et al. (2004) reported 6.42 ton C ha^{-1} yr^{-1} for *Q. variabilis* and *Q. serrata* forest using

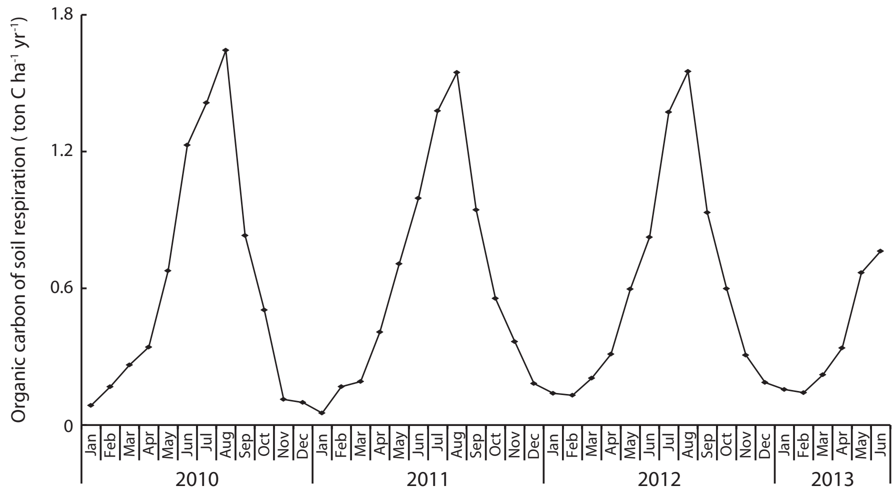

Fig. 4. Seasonal variation of organic carbon of soil respiration in the *Quercus serrata* forest from 2010 to 2013.

CO_2 gradient method, whereas Yim et al. (2002) reported 8.88 ton C ha^{-1} yr^{-1} using CDC method showing higher values than this research result. The scale of soil respiration is similar to NPP and it is influenced by soil temperature, moisture, rainfall, typhoon, and root respiration but especially the rainfall increases soil respiration (Lee et al. 2006). The seasonal change in soil respiration of *Q. serrata* forest had the same trend in many other researches (Buchmann 2000) and close correlation between soil respiration and soil temperature is already well-known to scholars (Witkamp 1969, Dulohery et al. 1996, Lee 2014b). It was reported that soil moisture greatly influences soil respiration as well (Liu et al. 2006). The sharp increase in soil respiration during early summer is related to the expansion time of leaf in crown and high metabolism during the leaf production will also affect the increase in soil respiration (Kawamura et al. 2001, Lee et al. 2003). The soil respiration is the sum of heterotrophs respiration and respiration of plant roots and therefore it is important to measure them separately. The mineralization of organic carbon in soil decomposed by microbial activity is influenced by moisture and temperature of the soil (Leirós et al. 1999). In addition, there will be difference in the biomass of microbes in soil depending on vegetation type, organic carbon in soil, and environmental factors because it is affected by the level of organic carbon in soil. Thus, it is determined that decomposition of forest floor litter, high level of organic carbon in soil, plant production, decomposition and production of roots accelerated by microbial activity in summer under high atmospheric temperature, soil temperature, and rainfall increased the soil respiration in summer season. It has been reported that microbial respiration is more reactive and therefore higher in thin roots than roots with thick diameter in *Q. serrata* forest (Matsumoto et al. 2009). It seems that respiration was higher in older forests as they have more root diversity than the forest studied in this research.

Budget and distribution of organic carbon

The budget and distribution of organic carbon per carbon storage during the study period of *Q. serrata* forest in Mt. Worak is shown in Fig. 5. The total average organic carbon was 130.745 ton C ha^{-1}, aboveground part of plant was 50.041 ton C ha^{-1}, and belowground part was 12.510 ton C ha^{-1}. The organic carbon of litter on forest floor was 4.075 ton C ha^{-1} and the soil was 64.119 ton C ha^{-1} having the highest distribution. The total average of carbon fixation in plants from photosynthesis was 4.935 ton C $ha^{-1}yr^{-1}$ and amount of organic carbon released from soil respiration to microbial respiration was 3.972 ton C $ha^{-1}yr^{-1}$ during the study period.

The annual NEP estimated from annual organic carbon production of the *Q. serrata* forest and soil respiration was 0.963 ton C $ha^{-1}yr^{-1}$. As result of this research, the *Q. serrata* forest showed to be a positive factor in improving the atmospheric environment as it absorbs more carbon then it releases through respiration. There are no researches on NEP of *Q. serrata* forest in Korea at present except for the research result of 0.36 ton C $ha^{-1}yr^{-1}$ by Lee (2014b). However, NEP (0.23 ton C $ha^{-1}yr^{-1}$) estimated by using NPP of 4.3 ton C $ha^{-1}yr^{-1}$ (Lim et al. 2003) and HR of 4.07 ton C $ha^{-1}yr^{-1}$ (Min 2006) from the research results of Gwangneung deciduous forest (*Q. serrata* dominant) was lower than the result obtained in this research. The NEP of deciduous forest in cool-temperate regions of Japan, where

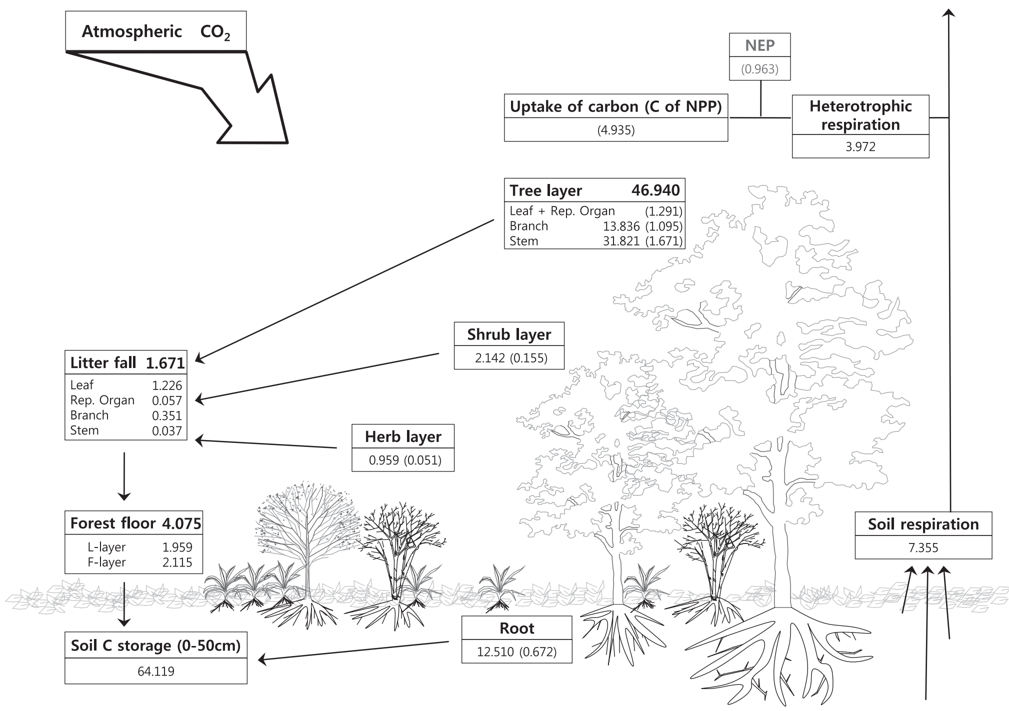

Fig. 5. Compartment model showing the distribution and flow organic carbon of *Quercus serrata* forest for four years in the study area. The box indicates standing carbon (ton C ha^{-1}) and arrow is the flux of carbon (ton C ha^{-1} yr^{-1}). The bracket gives information about uptake of carbon (ton C ha^{-1} yr^{-1}). NEP, net ecosystem production; NPP, net primary production.

secondary succession of young trees (incl. *Q. serrata*) is occurring, was 0.9 ton C $ha^{-1}yr^{-1}$ showing similar values to this research. Ohtsuka et al. (2010) stated that the NEP of young forests, together with their biomass, will rapidly increase as their NPP was greater than the forest (50 year) located 260 m higher within the same region. The young forests and mature forests have greater capability to act as carbon sinks than old forests (Bond-Lamberty et al. 2004), and the rainfall increases respiration of the ecosystem and affects annual carbon budget (Lee et al. 2006). In addition, the *Q. serrata* forest of this research with properties of tree density (1200 trees/ha), number of individual 0-20 cm trees per DBH (43 ea), forest age (18 year), and annual average temperature (12.4℃) had greater and active matter production than the forest researched by Ohtsuka et al. (2010) with tree density (1085 trees/ha), forest age (18 year), average temperature (7.3℃) and elements (850 trees/ha, 23 ea, 37 year) of *Q. serrata* forest researched by Lee (2014b) in same period and location. In addition, the *Q. serrata* forest also had greater carbon assimilation being a young forest rendering high NEP.

Therefore, the NEP was related to previously analyzed results (standing biomass, organic carbon in litter, forest floor, soil, and soil respiration etc.). The tree diameter was important as uptake of organic carbon was highest in the plant stem and the soil played a crucial role as the carbon storage. Lastly, the understanding of carbon budget will be important in the future because the amount of carbon in soil decreases together with the climate change (Kirschbaum 1995).

ACKNOWLEDGEMENTS

This research was conducted with the support of Worak National Park Monitoring Project (2010, 2011) and National Long-Term Ecological Research Project (2012, 2013).

LITERATURE CITED

Berg B, Agren G. 1984. Decomposition of needle litter and its organic chemical components: theory and field experiments. Long-term decomposition in a Scots pine forest III. Can J Bot 62: 2880-2888.

Binkley D, Stape JL, Ryan MG, Barnard HR, Fownes J. 2002. Age-related decline in forest ecosystem growth: an individual-tree, stand-structure hypothesis. Ecosystems 5: 58-67.

Black CA. 1965. Methods of Soil Analysis, Part 2. American Society of Agronomy, Madison, WI, pp 1562-1565.

Bond-Lamberty B, Wang C, Gower ST. 2004. Net primary production and net ecosystem production of a boreal black spruce wildfire chronosequence. Glob Cahnge Biol 10: 473-487.

Bray JR, Gorham E. 1964. Litter production in forests of the world. Advance in Ecological Research 2: 101-157.

Buchmann N. 2000. Biotic and abiotic factors controlling soil respiration rates in Picea abies stands. Soil Biol Biochem 32: 1625-1635.

Cannell MGR, Dewar RC, Thornley JHM. 1992. Carbon flux and storage in European forest. In:Responses of Forest Ecosystems to Environmental Changes (Teller A, Mathy P, Jeffers JNR, eds). Elsevier, New York, NY, pp 256-271.

Chae N, Kim J, Kim DG, Lee D, Kim RH, Ban J, Son Y. 2003. Measurement of soil CO_2 efflux using a closed dynamic chamber system. Korean J Agric For Meteorol 5: 94-100.

Chang NK, Kim IJ. 1983. A study of the matter production and decomposition of *Quercus serrata* and *Carpinus laxiflora* Forest at Piagol in Mt. Jiri. Korean J Ecol 6: 198-207.

Chen H, Harmon ME, Griffiths RP. 2000. Effects of temperature and moisture on carbon respired from decomposing woody roots. For Ecol Manag 138: 51-64.

Choi HJ. 2007. Organic carbon distribution and budget in *Quercus variabilis* and *Quercus mongolica* forests at Mt.Worak National Park. MS Thesis. Kongju National University, Gongju. (In Korean)

Chung TH, Lee WC. 1965. A study of the Korean woody plant zone and favorable region for the growth and proper species. Thesis Collect SungKyunKwan Univ 10: 329-435.

Ciais P, Sabine C, Bala G, Bopp L, Brovkin V, Canadell J, Chhabra A, DeFries R, Galloway J, Heimann M, Jones C, Le Quéré C, Myneni RB, Piao S, Thornton P. 2013. Carbon and other biogeochemical cycles. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (Stocker TF, Qin D, Plattner GK, Tignor M, Allen SK, Boschung J, Nauels A, Xia Y, Bex V, Midgley PM, eds). Cambridge University Press, Cambridge, pp 465-570.

Cole DW, Rapp M. 1981. Elemental cycling in forest ecosystems. In:Dynamic Properties of Forest Ecosystems (Reiche DE, ed). No. 23. Cambridge University Press, Cambridge, pp 341-409.

Dulohery CJ, Morris LA, Lowrance R. 1996. Assessing forest soil disturbance through biogenic gas fluxes. Soil Sci Soc Am J 60: 291-298.

Houghton RA, Hobbie JE, Melillo JM, Moore B, Peterson BJ, Shaver GR, Woodwell GM. 1983. Changes in the carbon content of terrestrial biota and soils between 1860 and 1980: a net release of CO_2 to the atmosphere. Ecol Monogr 53: 235-262.

Hu H, Wang GG. 2008. Changes in forest biomass carbon storage in the South Carolina Piedmont between 1936 and 2005. For Ecol Manag 255: 1400-1408.

IPCC. 2007. Climate change 2007: Mitigation Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge.

Jeong HM, Kim HR, Shin DH, Lee KM, Lee SH, Han YS, Jang RH, Lee SK, Kim TK, You YH. 2013. Litter production and soil organic carbon dynamincs of *Pinus densiflora, Quercus mongolica* and *Robinia pseudo-acacia* forests in Mt. Nam. Korean J Environ Biol 31: 87-95.

Jeong JH, Lee WK, Kim CS. 1998. Soil organic carbon content in forest soils of Korea. For Res Inst J For Sci 57: 178-183.

Johnson FL, Risser PG. 1974. Biomass, annual net primary production, and dynamics of six mineral elements in a post oak-blackjack oak forest. Ecology 55: 1246-1258.

Jones PD, Wigley TML, Wright PB. 1986. Global temperature variations between 1861 and 1984. Nature 322: 430-434.

Kang SJ, Kwak AK. 1998. Comparisons of phytomass and productivity of watershed forest by allometry in South Han River. J Kor For Energy 17: 8-22.

Katagiri S. 1988. Estimation of proportion of root respiration in total soil respiration in deciduous broadleaved stands. J Jap For Soc 70: 151-158.

Katagiri S, Ishii H, Miyake N, Fukuyoshi T. 1979. Studies on mineral cycling in a deciduous broad-leaved forest at Sanbe forest of Shimane University. VII. Rate of soil respiration and a few factors affected. Bull Fac Agric 13: 50–56.

Kawamura K, Hashimoto Y, Sakai T, Akiyama T. 2001. Effects of phenological changes of canopy leaf on the spatial and seasonal variations of understory light environment in a cool-temperate deciduous broad-leaved forest. J Jap For Soc 83: 231-237.

Kim CS, Lim JH, Lee IK, Park BB, Chun JH. 2013. Annual variations of litterfall production in a broadleaved deciduous forest at the Mt. Keumsan LTER site. J of Korean For Soc 102: 210-215.

Kim JH. 2012. Global warming through the eyes of a biologist. Seoul National University Press, Seoul.

Kim JH, Yoon SM. 1972. Studies on the productivity and the productive structure of the forests - II. Comparison between the productivity of *Pinus densiflora* and of *Quercus mongolica* stands located near Choon-Chun City. J Plant Biol 15: 71-78.

Kim KD, Kim CM. 1988. Research trends on forest biomass production in Korea. J Korea For Energy 8: 94-107.

Kim YS, Ko SC, Oh BU. 1981. Distribution Atlas of Plants in Korea (V)-Atlas of Fagaceae in Korea. Korea University Press, Seoul.

Kimmins JP. 1987. Forest Ecology. Macmillan Publishing Company, New York, NY.

Kirschbaum MUF. 1995. The temperature dependence of soil organic matter decomposition, and the effect of global warming on soil organic C storage. Soil Biol Biochem 27: 753-760.

Kittredge J. 1944. Estimation of the amount of foliage on trees and stands. J For 42: 905-912.

Koh SD. 2002. Ecological studies on the community structure and productivity of *Quercus* Forests of Munjangdae valley in Mt. Sokni. Bull Sci Educ 18: 33-43.

Koo JW, Son YH, Kim RH, Kim J. 2005. A Study on methods of separating soil respiration by source. Korean J Agric For Meteorol 7: 28-34.

Korea Meteorological Administration. 2010. Climate past data of Korea http://www.kma.go.kr/weather/climate/past_table.jsp?stn=221&yy=2010&obs=07&x=20&y=3. Accessed 3 January 2014.

Korea Meteorological Administration. 2011. Climate past data of Korea http://www.kma.go.kr/weather/climate/past_table.jsp?stn=221&yy=2011&obs=07&x=14&y=16. Accessed 3 January 2014.

Korea Meteorological Administration. 2012. Climate past data of Korea http://www.kma.go.kr/weather/climate/past_table.jsp?stn=221&yy=2012&obs=07&x=13&y=5. Accessed 3 January 2014.

Korea Meteorological Administration. 2013. Climate past data of Korea http://www.kma.go.kr/weather/climate/past_table.jsp?stn=221&yy=2013&obs=07&x=7&y=9. Accessed 3 January 2014.

Kwak YS, Hur YK, Song JH, Hwangbo JK. 2004. Quantification of atmospheric purification capacity by affo restation impact assessment of Kwangyang Steel Works. RIST Res Pap 18: 334-340.

Kwak YS, Kim JH. 1992. Secular changes of density, litterfall, phytomass and primary productivity in Mongolian Oak (*Quercus mongolica*) Forest. J Ecol Environ 15: 19-33.

Lee EH. 2009. Analysis of soil carbon flux using the automatic long term measurement of soil respiration in the temperate deciduous forest at Gwangneung. MS Thesis. Konkuk University. Seoul, Korea.

Lee EH, Lim JH, Lee JS. 2010. A Review on soil respiration measurement and its application in Korea. Korean Soc Agric For Meteorol 12: 264-276.

Lee JY. 2014a. Carbon budget and nutrient cycling in the *Pinus densiflora* forest at Mt. Worak. PhD Dissertation. Kongju National University, Gongju, Korea.

Lee MS, Mo WH, Koizumi H. 2006. Soil respiration of forest ecosystems in Japan and global implications. Ecol Res 21: 828-839.

Lee MS, Nakane K, Nakatsubo T, Koizumi H. 2003. Seasonal changes in the contribution of root respiration to total soil respiration in a cool-temperate deciduous forest. Plant Soil 255: 311-318.

Lee NY. 2010. Carbon cycle in terrestrial ecosystems-net ecosystem production (NEP) in a forest. J Natl Park Res 1: 163-168.

Lee NY. 2011. Estimation of carbon storage in three cool-temperate broad-leaved deciduous forests at Bukhansan National Park, Korea. J Natl Park Res 2: 53-57.

Lee SH. 2014b. Carbon distribution and budget of the dominant deciduous plant communities in Worak National Park. MS Thesis. Kongju National University, Gongju, Korea.

Lee SH, You YH. 2012. Measurement of ecological niche of *Quercus aliena* and *Q. serrata* under environmental factors treatments and its meaning to ecological distribution. J Ecol Environ 35: 227-234.

Leirós MC, Trasar-Cepeda C, Seoane S, Gil-Sotres F. 1999. Dependence of mineralization of soil organic matter on temperature and moisture. Soil Biol Biochem 31: 327-335.

Li ZA, Zu B, Xia HP, Ren H, Mo JM, Weng H. 2005. Litterfall dynamics of an evergreen broadleaf forest and a pine forest in the subtropical region of China. For Sci 51: 608-615.

Lim HJ. 1985. A study on the production structure of a *Quercus serrata* forest at a ridge in Songkwang experiment forest. Thesis of Suncheon National University 4: 51-57.

Lim JH, Shin JH, Jin GZ, Chun JH, Oh JS. 2003. Forest stand structure, site characteristics and carbon budget of the Kwangneung Natural Forest in Korea. Korean J Agric For Meteorol 5: 101-109.

Liu Q, Edwards NT, Post WM, Gu L, Ledford J, Lenhart S. 2006. Temperature-independent diel variation in soil respiration observed from a temperate deciduous forest. Glob Change Biol 12: 2136-2145.

Lousier JD, Parkinson D. 1976. Litter decomposition in a cool temperate deciduous forest. J Bot 54: 419-436.

Marks PL. 1974. The role of pin cherry (*Prunus pensylvanica* L.) in the maintenance of stability in northern hardwood ecosystems. Ecol Monogr 44:73–88

Matsumoto A, Kominami Y, Makita N, Kanazawa Y. 2009. Direct measurement of heterotrophic decomposition respiration from root litter in warm-temperate secondary deciduous forest in Japan. http://asrr.boku.ac.at/fileadmin/files/RRcd/session04/poster/102.pdf. Accessed 3 January 2014.

Meentemeyer V. 1978. Macroclimate and lignin control of decomposition rates. Ecology 59: 465-472.

Meentemeyer V, Box EO, Thompson R. 1982. World patterns and amounts of terrestrial plant litter production. BioScience 32: 125-128.

Min YK. 2006. Characteristics on the soil carbon flux in the cool-temperate deciduous forest at Gwangneung. MS Thesis. Konkuk University, Seoul, Korea.

Mun HT. 2004. Decay rate and nutrients dynamics during decomposition of Oak branches. J Ecol Environ 27: 97-98.

Nakane K, Kohno T, Horikoshi T. 1996. Root respiration rate before and just after clear-felling in a mature, deciduous, broad-leaved forest. Ecol Res 11: 111-119.

Namgung J. 2010. Production and nutrient cycling in the Quercus variabilis forest in Mt. Worak. PhD Dissertation. Kongju National University, Gongju, Korea.

Namgung J, Mun HT. 2009. Litterfall and nutrient input via litterfall in *Pinus densiflora* forest at Mt. Worak National Park. Korean Soc Environ Biol 27: 261-265.

National Institute of Environmental Research. 2013. The Third Stage Report (2010-2013) of KNLTER. National Institute of Environmental Research, Incheon.

Oh KK, Park SK, Shim HY, Kim TH. 2005. Actual vegetation and management in the Woraksan National Park. Korean J Environ Ecol 19: 119-129.

Ohtsuka T, Shizu Y, Nishiwaki A, Yashiro Y, Koizumi H. 2010. Carbon cycling and net ecosystem production at an early stage of secondary succession in an abandoned coppice forest. J Plant Res 123: 393-401.

Ovington JD, Heitkamp D. 1960. The accumulation of energy in forest plantation in Britain. Ecology 48: 639-646.

Park GS, Lee SW. 2002. Biomass and net primary production of *Quercus serrata* natural stands in Kwangyang, Muju and Pohang areas. J Korean For Soc 91: 714-721.

Park IH, Kim DY, Son YH, Yi MJ, Jin HO, Choi YH. 2005. Biomass and net production of a natural *Quercus Mongolica* forest in Namsan, Seoul. Korean Soc Environ Ecol 19: 299-304.

Park IH, Moon GS. 1994. Biomass, net production and biomass estimation equations in some natural *Quercus* forests. J Korean For Soc 83: 246-253.

Pyo JH, Kim SU, Mun HT. 2003. A study on the carbon budget in *Pinus koreansis* plantation. Korean J Ecol 26: 129-134.

Rochow JJ. 1974. Litter fall relations in a Missouri forest. Oikos 25: 80-85.

Rodin LE, Bazilevich NI, Fogg GE. 1967. Production and Mineral Cycling in Terrestrial Vegetation. Olover and Boyd, London.

Sabine CL, Feely RA, Gruber N, Key RM, Lee K, Bullister JL, Wanninkhof R, Wong CS, Wallace DWR, Tilbrook B, Millero FJ, Peng TH, Kozyr A, Ono T, Rios AF. 2004. The oceanic sink for anthropogenic CO_2. Science 305: 367-371.

Shidei T. 1960. Studies on the productivity of the forest. Ⅰ. Essential needle-leaved forest on Hokkaido. Kokusaku Pulp Industry Co., Tokyo.

Shin CH. 2012. Carbon budget and nutrient cycling in the *Quercus mongolica* forest at Mt.Worak National Park. PhD Dissertation. Kongju National University, Gongju, Korea.

Shutou K, Nakane K. 2004. Change in soil carbon cycling for stand development of Japanese cedar (*Cryptomeria japonica*) plantations following clear-cutting. Ecol Res 19: 223-244.

Singh JS, Gupta SR. 1977. Plant decomposition and soil respiration in terrestrial ecosystems. Bot Rev 43: 449-528.

Smith FW, Long JN. 2001. Age-related decline in forest growth: an emergent property. For Ecol Manag 144: 175-181.

Takahashi A, Hiyama T, Takahashi HA, Fukushima Y. 2004. Analytical estimation of the vertical distribution of CO_2 production within soil: application to a Japanese temperate forest. Agric For Meteorol 126: 223-235.

Tans PP, Fung IY, Takahashi T. 1990. Observational constrains on the global atmospheric CO_2 budget. Science 247: 1431-1438.

Triska FJ, Cromack Jr K. 1980. The role of wood debris in forests and streams. In: Forest : Fresh Perspectives from Ecosystem Analysis (Waring RH, ed). Oregon State University Press, Corvallis, OR, pp 171-190.

Vitousek PM. 1991. Can planted forest counteract increasing atmospheric carbon dioxide?. J Environ Qual 20: 348-354.

Wang G, Qian J, Cheng G, Lai Y. 2002. Soil organic carbon pool of d soils on the Qinghai-Tibetan plateau and its global implication. Sci Total Environ 29: 207-217.

Waring RH, Schlesinger WH. 1987. Forest Ecosystems: Concepts and Management. Academic Press, London.

Whittaker RH, Marks PL. 1975. Methods of assessing terrestrial productivity. In:Primary Productivity of the Biosphere (Lieth H, Whittaker RL, eds). Springer, Berlin, pp 55-118.

Witkamp M. 1969. Cycles of temperature and carbon dioxide evolution from litter and soil. Ecology 50: 922-924.

Yim MH, Joo SJ, Nakane K. 2002. Comparison of field methods for measuring soil respiration: a static alkali absorption method and two dynamic closed chamber methods. For Ecol Manag 170: 189-197.