B-1.3.3 Quantitative Analysis of Carbon Cycle and Budget in Agroforest

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Abstract The object of the study is to clarify quantitatively carbon cycles in agroforest ecosystems which are disturbed artificially.

The experimental plots are a managed agroforest which is cut undergrowth and raked litter, an abandoned agroforest which is dominated by draft bamboo in the forest floor, and a natural forest. The agroforests are 20 years old deciduous forest, and the natural forest is 50 years old deciduous forest. We measured plant biomass, litter fall, litter biomass, soil carbon stock, CO_2 emission, and environmental factors such as soil temperature. Carbon cycle of each forest was estimated from the measured data.

The carbon storage of the managed agroforest, the abandoned agroforest, and the natural forest was estimated 43, 45 and 108 tC/ha in plants, and 80, 88 and 224 tC/ha in soil, respectively. The carbon sink in each plot was estimated 3.7, 3.5 and 2.2 tC/ha/yr in plants, and -0.8, 1.3 and 1.5 tC/ha/yr in soil, respectively.

Carbon in soil of the managed agroforest did not accumulate. Raking litter and cutting undergrowth reduce carbon supply to soil, then reduce amount of carbon sink of forest. The carbon storage of the 50 years old forest was accumulating still. Estimation of global carbon cycle has to take account of area and age of secondary forest which had been disturbed artificially.

Key Words Carbon cycle, Agroforest, Carbon sink, Cutting undergrowth, Raking litter

1. Introduction

To estimate dynamics of carbon dioxide at the global level, mechanisms of carbon sink and source at a terrestrial ecosystem and an oceanic ecosystem are researched. At a terrestrial ecosystem, a carbon cycle in plant-soil system at various ecosystems such as a forest ecosystem, a grassland ecosystem, an agro-ecosystem, etc. are researched.

Carbon cycles of such agro-ecosystems are affected by agricultural activities, as a paddy field, an upland field, a pasture, and an agroforest. An agroforest is affected by felling, cutting undergrowth, and raking litter.

It is necessary to clarify quantitatively carbon cycles in agroforest ecosystems as one of ecosystems to estimate a global carbon cycle, and to analyze such human disturbance as cutting and raking in a carbon cycle of agroforest ecosystem.

2. Research Objectives

The object of this study is to clarify quantitatively carbon cycles in agroforest ecosystems. We constructed a carbon cycle model of an agroforest, and measured the amount of carbon storage and carbon supplies and removals. And we estimated the amount of carbon sink based on the carbon cycle model.

We evaluate human disturbance in carbon cycles of agroforests. An agroforest is kept young by felling. We compared carbon cycles at an old forest without human disturbance with young forests with felling. Agroforest is cut undergrowth and raked litter for manure making. Then we compared carbon cycles of an agroforest affected cutting and raking with an abandoned agroforest.

3. Research Methods

(1) Study areas

Study area was located in an oak (*Quercus serrata*) forest at Ibaraki Prefecture. The area is covered with Inceptisol. The forest was abandoned for about 20 years. Canopy of the forest was about 12m high. Draft bamboo (*Pleioblastus Chino*) was about 1.5m high and dominated over the forest floor. We set up study plots of an abandoned forest and a managed forest to evaluate effects of cutting undergrowth and raking litter on carbon cycles of agroforests.

Additionally, we set up a study plot in a natural forest at Tochigi Prefecture to compare old forest with young forest. The forest had never been disturbed by human activities for longer than 50 years. The forest consisted of Chestnut (*Castanea crenata*) and oak (*Quercus serrata*) and was higher than 20m. The forest floor was sparsely covered with lower trees. Soil type was Typic Melanudand.

(2) A carbon cycle model

A carbon cycle model of an agroforest consists of four compartments, plant biomass [plant], litter layer biomass [litter], soil carbon storage [soil], and fine root biomass [root], and flows among them. The amount of output flows from litter, soil, roots to atmosphere are assumed to be 25%, 25% and 50% of CO_2 emission from a forest floor[1]. The amount of flow from roots to soil [root turnover] is estimated by fine root turnover ratio, namely 20% of fine root biomass[1]. The amount of flow from plant to root is sum of output flows from root. The amount of carbon input to plant is sum of output flows from plant and increment of plant. The amount of flow from litter to soil [litter turnover] means litter fall minus raked litter and CO_2 emission from litter. Accumulation of soil carbon means sum of litter turnover and root turnover minus CO_2 emission from soil.

(3) Measurement methods

Plant biomass consists of tree biomass and undergrowth biomass. The tree biomass was estimated from tree height and dbh [diameter of breast height] using estimation equations[2]. Height and dbh of individual tree were measured in 20m x 20m quadrate every 2 years. The undergrowth biomass was measured by cutting and weighing of undergrowth at 5 plots of 1m x 1m quadrate.

Litter falls of leaves and twigs were collected monthly by four 1 m^2 traps. Fallen branches were collected on 10m x 10m quadrate. Fallen tree biomass was estimated using estimation equations[2] from height and dbh of tree which had fallen at 2 years later.

Litter layer was collected every two months, and biomass and water content of them were measured.

Soil carbon storage was estimated from carbon %, weight per volume, and thickness of each soil layer. Soil profiles in the managed agroforest and in the abandoned agroforest were investigated, but soil profile data in the natural forest was referred from a report of a soil survey[3] on the site.

Fine roots were collected from soil samples of 30cm x 30cm area and 20cm depth.

CO_2 emission from a forest floor was measured twice a month using closed chamber method[4]. The 20 column chambers, 21cm diameter and 14cm height, were set in each forest. Air of 5ml in the chamber was sampled at 1, 2, 3 and 4 minute after the set of chamber. CO_2

concentration of the air sample was measured using IRGA. CO_2 emission was estimated from increasing ratio of the CO_2 concentration. In winter, from December to February, CO_2 emission was measured once a month. And, air was sampled at 2, 4, 6 and 8 minute after the set of chamber.

Such environmental factors as soil temperature, soil water content, etc. were measured.

4. Results

Tree biomass in the managed agroforest, the abandoned agroforest and the natural forest were 40, 39 and 108 tC/ha, and increased annually 3.7, 3.5 and 2.2 tC/ha/yr, respectively. Biomass of the natural forest was stored considerably larger than the agroforest, but annual increment was not so much. Biomass of undergrowth in the managed agroforest and the abandoned agroforest was 3.0 and 5.9 tC/ha, respectively. Amount of cutting undergrowth in the managed agroforest was 0.38 tC/ha/yr.

The amounts of fallen trees in the managed agroforest, the abandoned agroforest and the natural forest was 0.76, 0.33 and 0.19 tC/ha/yr, respectively. The amounts of fallen branches in each forest were 0.16, 0.24 and 0.50 tC/ha/yr, respectively. Fallen twigs were 0.37, 0.56 and 0.82 tC/ha/yr, respectively. The amounts of fallen branches and twigs varied in all the forest. Fallen leaves which dominated over a large part of litter fall were 2.1, 2.4 and 2.1 tC/ha/yr, respectively, and did not vary in the study period. Fallen leaves supplied stably a large amount of carbon to a litter layer stably.

Litter layers in the managed agroforest, the abandoned agroforest and the natural forest accumulated 0.1, 6.1 and 5.0 tC/ha, respectively. In the managed agroforest, accumulation of litter increased to 2.0 tC/ha after a leave falling period, and decreased to 0.1 tC/ha after litter raking. The amount of raked litter was 1.9 tC/ha/yr. Accumulation of litter in the abandoned agroforest and the natural forest varied 5.0-8.0 and 3.5-7.0 tC/ha, respectively. Water contents of litter in the managed agroforest, the abandoned agroforest and the natural forest varied 40-90, 120-200 and 50-240%, respectively.

Carbon storage in soil in the managed agroforest, the abandoned agroforest and the natural forest was 80, 88 and 224 tC/ha, respectively.

Root biomass in the managed agroforest, the abandoned agroforest and the natural forest was 2.6, 3.4, 1.3 tC/ha, respectively. Root biomass in the natural forest was less than that in the agroforest due to a lack of draft bamboo. Undergrowth cutting reduced the amount of it to 1/6 of the aboveground biomass of undergrowth in the agroforest, but to 3/4 of underground biomass.

CO_2 emissions from a forest floor in the managed agroforest, the abandoned agroforest and the natural forest were 5.0, 5.7 and 5.4 tC/ha/yr, respectively. CO_2 emission rates were 650, 900 and 800 $mgCO_2/m^2/hr$, respectively in summer and about 50 $mgCO_2/m^2/hr$ in all forests in winter. The soil water contents varied 20-35, 20-80 and 120-170%, respectively. The CO_2 emission increases exponentially with the soil temperature, but does not have clear relation to the soil water contents.

5. Discussion

The amount of carbon sink into the managed agroforest, the abandoned agroforest and the natural forest was 2.9, 4.9 and 3.7 tC/ha/yr, respectively (Fig. 1). In the managed agroforest, cut undergrowth and raked litter was 2.8 tC/ha/yr. Carbon was mostly stored in plant, but slightly in soil. In the managed agroforest, soil carbon was not stored. Storage of soil carbon was twice of plant. Soil can store a large amount of carbon, but the sinking rate of carbon in soil is slow. In estimation of global carbon cycle, sinking rate and capacity of carbon storage in soil should be considered. Temperate deciduous forests can store 80-300 tC/ha in plant and 60-240 tC/ha in soil[5]. It is expected carbon storage in plant and soil in the natural forest can increase still more. There were no difference in carbon flows and differences in carbon storage between the abandoned agroforest and the natural forest. These are differences between 20 years old forest and 50 years old forest. If ages of all the forest can be known, the global carbon cycle will estimate more correctly in the terrestrial ecosystem.

Raking removes most of litter, then reduces carbon supply to soil. As already pointed out, the effect of raking is very hard about carbon and nutrients supply to soil[6, 7]. In this study, storage of soil carbon did not increase in the managed agroforest. The amount of removals of carbon by cutting undergrowth was only 0.4 tC/ha/yr. Cutting undergrowth considerably reduced aboveground biomass of undergrowth, but slightly underground biomass. Raking litter and cutting undergrowth remove cover from a forest floor. Then, the forest floor is easily exposed to outside environment of the forest. When a forest floor is exposed to external environment by felling tree, decomposition rate of soil organic matter is accelerated[7, 8]. In spite of luck of litter layer as a source of CO_2 emission and less root biomass than the abandoned agroforest, CO_2 emission in the managed agroforest kept 90% of the abandoned agroforest. Dynamics of a forest floor (cover), especially litter layer, should be considered in prediction of carbon cycle in forest ecosystems.

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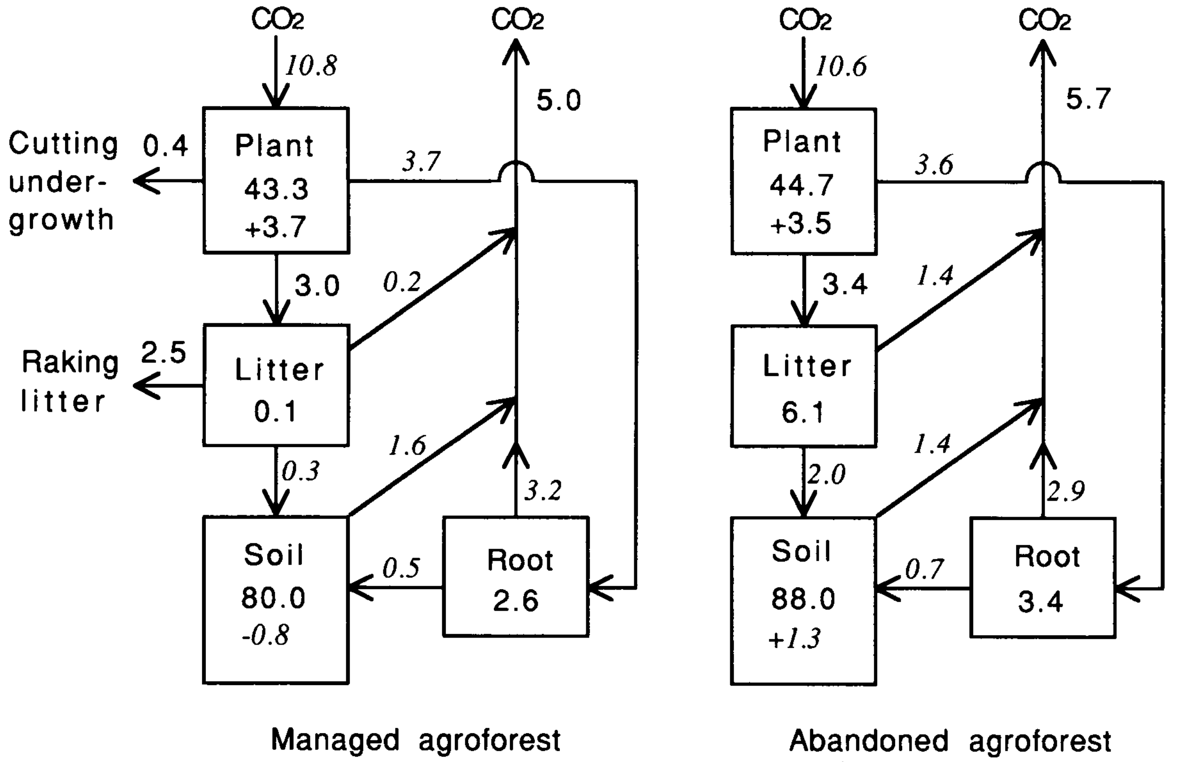

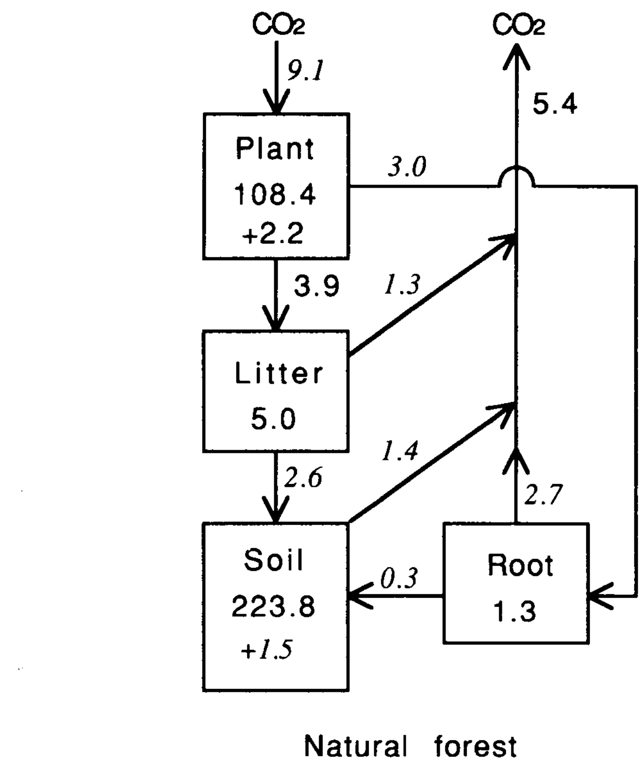

Fig.1 Carbon cycle in a managed agroforest, an abandoned agroforest and a natural forest
□: carbon storage
↓ : carbon flow
Gothic: measured data
Italic: estimation from measured data and related studies