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NET PRIMARY PRODUCTIVITY ESTIMATION IN MOUNTAINOUS AGRICULTURAL LAND AT TAKAYAMA, CENTRAL JAPAN

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Abstract

Biotic processes of carbon (C) sequestration are based on photosynthetic conversion of atmospheric carbon into the terrestrial pool comprising biomass. Limited knowledge on the dynamics of biomass or carbon in managed and unmanaged ecosystems has limited the ability to predict the contribution of biomass in other words, carbon dynamics effects on the ecosystem. Based on the above fact, monitoring the carbon distribution in cropland and abandoned cropland has been studied.This study calculated LUE values for different crop and non-crop vegetation using seasonal biomass and absorbed Photosynthetic Active Radiation (APAR) data. LUE varied with species and growing seasons. Spatial distribution NPP map was produced using the simple PEM model, PAR data and classification map of agricultural land. The NPP map shows the aerial distribution of NPP. This suggested that combined use of ground and remote sensing techniques can estimate NPP reasonably. Detailed information of carbon distribution can be obtained by producing multi-season NPP maps.

Keywords: NPP, PEM, Agriculture, PAR.

Introduction

Agriculture is one of the most important primary activities of human and it is the basis of food supply for the entire population of the world. It is practiced from tropic to temperate and from flatland to mountain region. However, mountainous agriculture is considered as marginal activities and gave less attention in the past. Hence, mountainous agriculture and its impact on environment are less studied and less discovered. Mountainous crop lands like other crop land, in addition to producing crops, have important environmental roles, such as air regulation, soil conservation (Vikram *et al.,* 2009; Xinzhang *et al.,* 2007), supplying habitat for wildlife (Best *et al.,* 2001) and fixing carbon from the atmosphere (Huang *et al.,* 2009). Agricultural lands (ALs) are

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considered as important potential sink for CO_2 absorption (Moureaux *et al.,* 2006).

In many parts of the mountain, traditional farmlands are transformed (Vikram *et al.,* 2009). One of the most common transformation of agricultural land in mountain area is crop land abandonment (Verburg and Overmars, 2009). Succession begins from annual plants, moves into perennial plants, and then to bush and trees after several years of abandonment. These different statuses make it difficult to estimate carbon circulation. Japan is a mountainous country in which managed farmland occupies only 10% of the land area (ca.3, 868,000 ha) (Odagiri 2008). In Gifu prefecture, 5.5% of the land is covered with croplands (Gifu Prefecture, 2009). In the 1970s, the Japanese Government started to limit the amount of land that could be used for rice production. Subsequently, the amount of abandoned cropland began to increase (MAFF, 2007). In Gifu prefecture, the abandoned area was 3,803 ha in 2000 and it increased to 5,528 ha in 2005 (Gifu Prefecture, 2009). In 2007, 67% of the abandoned area in Gifu prefecture was located in mountain-foot and inter-mountain areas. Such land abandonment activity is crucial for any study linked to land use. Land use is a critical factor in the carbon cycle, but land use effects on carbon fluxes are poorly understood in many ecosystems. One such ecosystem is mountainous agricultural land (AL), where land use intensity decreased or altered substantially due to politico-socio-economic reasons. It caused widespread of farmland abandonment. However, effects of farmland abandonment on carbon distributions are unclear due to unclear trend of farmland abandonment in AL. With the cease of farming activities, a large amount of carbon can be sequestered due to succession of cropland to grassland, shrubland, and forest finally. It can offset potentially a significant amount of anthropogenic carbon-di-oxide (CO_2) emissions.

Over the last decades, much attention has been given to the contribution of forest and grassland to the carbon budget, while less attention has been given to the AL where croplands are dominant. Compared to forest and grassland ecosystems, ALs are more artificially controlled through cropping systems, fertilization and irrigation in order to improve production. In recent years, the importance of AL as sink for carbon-di-oxide (CO_2) has been reported. Therefore, quantifying carbon distribution of abandoned cropland along with cropland has great importance and scientific values. In carbon dynamic study, most widely used method for carbon fixation study is to estimate biomass or Net Primary Production (NPP). Net Primary Productivity (NPP) is a quantitative measure of the carbon absorption by plants per unit time and space. NPP data are useful in many applications, one such application is terrestrial carbon cycle research (Chen *et al.*, 2000). Croplands are important land-cover types in the carbon (C) cycle. Croplands cover 12% of the total vegetated land surface in the world (Ramankutty and

Foley, 1998). In Japan, managed cropland occupies around 10% of the land area (ca.3, 868,000 ha) (Odagiri 2008). In Gifu prefecture, 5.5% of the land is croplands (Gifu Prefecture, 2009).The net amount of carbon fixed by plants, estimated that 7.8 Pg C yr^{-1} is associated with croplands, or 16% of the global total (Potter *et al.,* 1993).

Due to time and labour-intensive nature, ground measurements of NPP are very limited in temporal and spatial coverage. It is, therefore, necessary to use models, calibrated with existing data, in combination with remote sensing and other data sets, to study the spatial distribution of NPP. Production efficiency models (PEMs) are based on the theory of light use efficiency (LUE) which states that a relatively constant relationship exists between photosynthetic carbon uptake and radiation receipt at the canopy level (Monteith, 1972)

Remotely sensed data are important in providing spatially explicit inputs for NPP estimation. These include vegetation indices as the key driving variables (Sellers *et al.,* 1997; Abdullah *et al.,* 2011a; Abdullah *et al.,* 2011b) and land cover types in recognition of substantial physiological differences among vegetation types (Bonan, 1993).

In the study, a simple method to estimate LUE based on seasonal biomass data was carried out for AL types. Using these LUE values, field measured fAPAR and tower based PAR data, NPP of different CNCVs of an AL in the study site was estimated and mapped. The main objectives of the study are to estimate and map NPP of AL to know the spatial distribution of carbon fixation by vegetations in a year to understand the difference between cultivated (crop) and semi natural (non-crop) vegetations and their contribution to ecosystem by producing NPP map in AL.

Materials and Methods

Study Area: The study site is a 60 km^2 area to the east of Takayama city in the northern part of Gifu prefecture, Japan. This site is a

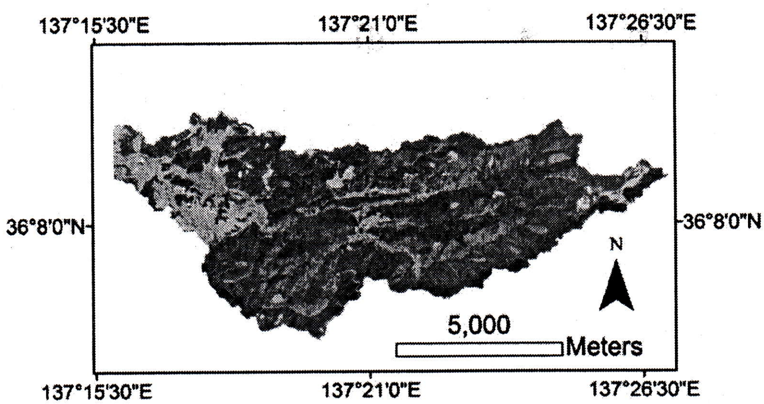


Fig. 1. Study site at Takayama.

part of a river basin with mixed land cover consisting of forests, agricultural fields, rivers, and urban areas.

The agricultural areas consist of diverse croplands with paddy fields, corn fields, upland grasslands and numerous abandoned croplands in an intermediate mountain area which makes it an ideal mountainous AL; therefore Takayama was selected as study site. Biomass samplings were carried out in croplands and abandoned croplands. Elevation of this landscape varies from 500m to 1500m above sea level (ASL). Annual mean air temperature and precipitation at 500m ASL is 10.6 °C and 1734mm, respectively. Most of the sample areas are located in the basin but four abandoned sites are also in the mountain terrace.

Table 1. Summary of parameter inputted in PEM.

Parameters	Collection site	Interval
PAR(crop growing season)	AsiaFlux site Takayama	Daily average
PAR (Incident)	Field	3 times with 30minute average
PAR(reflectance)	Field	3 times with 30minute average
PAR (transmittance)	Field	3 times with 30minute average
PAR (background)	Field	3 times with 30minute average
Biomass	Field	6 times in 2010
Field spectra	Field	6 times in 2010

Field data collection

In this study, different parameters (biomass, PAR, field-based NDVI, etc.) were measured and inputted into production efficiency model (PEM) to estimate NPP of AL. Time intervals for different parameters were different but to use those input data in one model, time interval were adjusted to same time interval (Table 1).Biomass and spectral measurement date of 2010 was listed in Table 2.

Table 2. List of biomass sampling and spectral measurement date in 2010.

DOY	Date
168	16-Jun-10
176	24-Jun-10
200	18-Jul-10
230	17-Aug-10
243	30-Aug-10
259	15-Sep-10

PAR measurement in the AL in 2011

The fraction of absorbed PAR (fAPAR) is defined as the fraction of PAR absorbed by green vegetation. Photosynthetically active radiation (PAR) is the solar radiation reaching the canopy in the wavelength region of visible light (0.4 - 0.7 micrometers) (McCallum *et al.,* 2009).

Field fAPAR measurements were conducted during the crop growing season in one paddy, one corn and three abandoned croplands. fAPAR measurements were carried out three times [25 May 2011(145 DOY), 24 June 2011(175 DOY) and 21 July 2011 (202 DOY)]. LI-COR Quantum Sensors (Li-190SA; LI-COR®, NE, USA) are used to measure photosynthetic photon flux density (PPFD) of photosynthetically active radiation (PAR). Ten Li-190SA sensors were set on platform fixed in extension poles. PAR sensor (Li-190SA) measures number of quantum in visible light in $\mu mol\ s^{-1}\ m^{-2}$. Three data logger (Li-1400, LI-COR®, NE, U.S.A.) were employed in this study. Sensors were attached to the data logger to record the data at pre-defined 30 second interval. In each sample site, three simultaneous repetitions were carried out. Incident PAR (PAR_0), PAR reflectance from the vegetation canopy (PAR_{ref}), PAR transmitted through the canopy (PAR_{Trans}) and PAR reflected from the soil background (PAR_{back}) were measured in the field at each site. fAPAR was calculated by the following equations (2.1)

$$fAPAR = \frac{PAR\,0 - PAR\,ref - PAR\,Trans + PAR\,back}{PARo} = \frac{APAR}{PARo} \quad [2.1]$$

Incident PAR data from Asia flux tower through the growing season

Daily average incident PAR data for the crop growing season was collected from an Asia Flux tower situated close to the sampling plots in AL. The Asia flux tower is located on the base of Mt. Norikura in the central Japan (36° 08 'N, 137°22' E, 810 m a.s.l.). The PAR data were originally daily averaged and they were summed up for the growing season.

fAPAR and APAR estimation in 2010

Many studies revealed that there is a relationship exist between NDVI and fAPAR (Fensholt *et al.,* 2004). The current result (Fig. 2) showed the linear relationship (fAPAR= 1.4163NDVI-0.4098) existed between fAPAR and NDVI. Thus fAPAR can be estimated using NDVI for NPP estimation. The fAPAR-NDVI relation (Fig. 2.) obtained in 2011 was applied to 2010 seasonal NDVI data to obtain the seasonal fAPAR in 2010. These 2010 fAPAR data was inputted in equation 5.2 to obtain APAR data of 2010 to estimate LUE for PEM based NPP of 2010.

$$APARi = \frac{fAPAR_{starti} + fAPAR_{endi}}{2} \times PARi \quad [2.2]$$

Here, $fAPAR_{starti}$ and $fAPAR_{endi}$ were derived from the field measurements and $PARi$ is the summed up of daily averaged PAR data collected from the Asia Flux site in the ith period.

LUE calculation

Light Use Efficiency (LUE ε) is one of the key bases for the diagnosis and prediction of plant growth and carbon exchange between ecosystems and the atmosphere. It was calculated for crop and non-crop vegetation by the following equation (2.4).

$$LUEi = \frac{Bgi}{APARi} = \frac{Biomass_{endi} - Biomass_{starti}}{APARi} \quad [2.3]$$

Where, Bgi is biomass growth and $APARi$ is APAR in ith period calculated by equation 2.2. LUE value was estimated from start to end of the CNCVs growing season. Point LUE data obtained were connected by drawing straight line between two adjacent LUE values (Fig. 2). It was also categorized to paddy, corn and mid biomass abandoned (Ab_mid). It is to be noted that for NPP mapping of abandoned crop land was done by utilizing LUE of mid biomass abandoned (Ab_mid).

NPP estimation and mapping in 2010

Hand held MS720 derived seasonal NDVI data of 2010 were transformed to fAPAR according to the relationship obtained (2011) in the study (Fig. 2). Field based NPP (point) was computed using equation (2.4)

NPP= ε.fAPAR.PAR was modified as bellow

$$NPPi = \frac{\text{Biomass}_{endi} - \text{Biomass}_{starti}}{\text{APAR}i} \text{XAPAR}i \quad [2.4]$$

Here, simply NPP is the difference between end season biomass and start season biomass i.e., biomass increase in a growing season. They were summed up for the growing season.

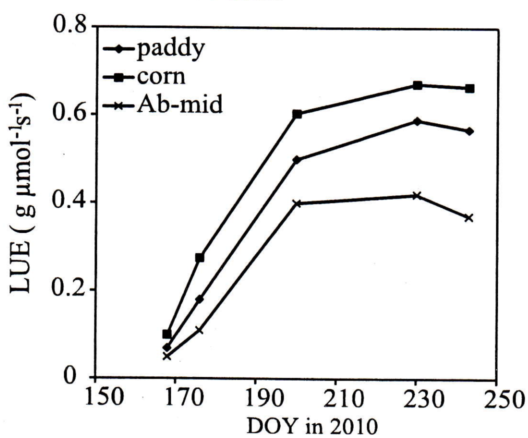
In the study, poly house NPP was estimated by calculating harvested yield (28 t/ha) information from farmers and percent moisture (90 %) content information of spinach at the time of harvest from the literature. Two spinach farmers at Takayama were interviewed to get the spinach yield information. Conversion of biomass to carbon was done by multiplying biomass with 0.5 according to Muraoka *et al.* (2008).

Validation of NPP estimation

Aerial NPP distribution map (Fig. 5) was produced by applying point based NPP value on the classified AL map (Fig. 2) produced in chapter 2. NDVI based biomass estimation model discussed in chapter 3 was applied to 18 August 2010 WV image. A comparison of NPP was done by a regression analysis between the NPP estimated by the PEM model (equation 2.4) and the biomass estimated by biomass estimation model (NDVI based equation in Table 3). It is necessary to mention that NPP described in this chapter is biomass in a strict sense since vegetation achieved the maximum growth in the mid-August. Therefore, biomass was described as NPP in this study in a broad sense.

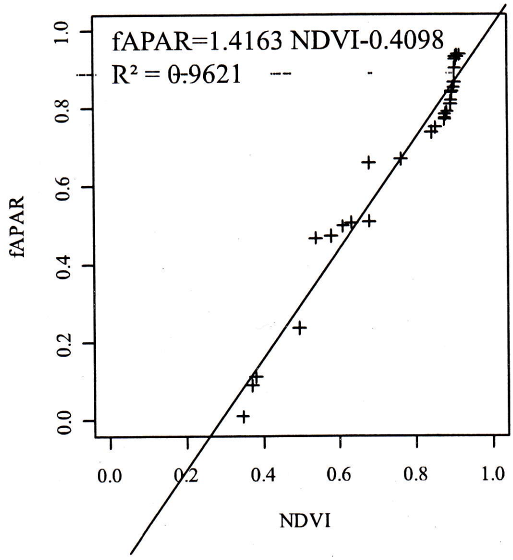
Results and Discussion

Monteith (1972) illustrated the positive relationship between NPP and absorbed photosynthetically active radiation; this proportionality has become known as the LUE model since then.



Trend of LUE value in the agricultural land

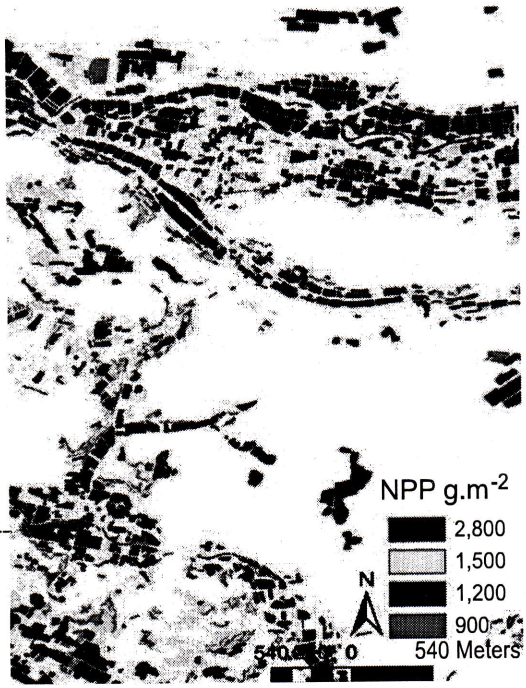
Shibles and Weber (1966) also defined LUE as the ratio of dry matter production to APAR for season-long periods may be assumed to be a constant under non-stressed condition, but it is affected by stresses, phenological stages and the physical environment (Choudhury, 2000). Hence, it may be inappropriate to assume that it is stable for whole growth period under different phenological stages and weather condition. Therefore, the seasonal trend is also observed for LUE in this study. LUE was low at the beginning of the growing season then it gradually increased and attained the pick before showing decreasing trend when leaf starts to senescence. Corn showed higher LUE. This is due to the physiology of C4 plants (Gallo *et al.,* 1993).



Relationship between fAPAR and field-based NDVI

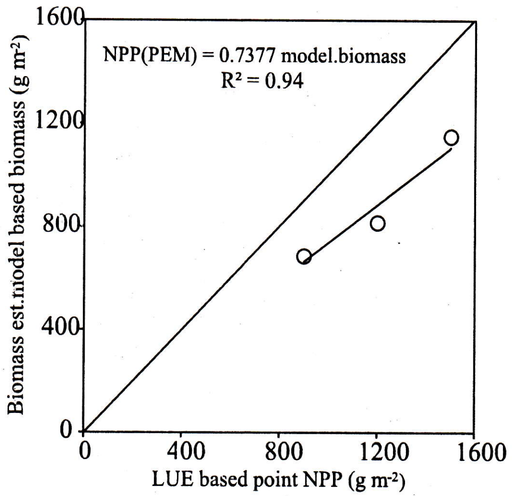
On the other hand, mid biomass abandoned (abandoned_mid) had sparse vegetation contributing lower LUE.

A study (Fensholt *et al.,* 2004) suggested that fAPAR has a linear relationship with NDVI. The current result also well agrees with the linearity between fAPAR and NDVI.



NPP distribution map of AL

In this study, NPP map is based on the AL type map. Thus it shows only the biomass of point data. Current NPP represents the overall status of the carbon distribution. It can work as general (base) NPP map providing average NPP information of the study site rather than providing more precise NPP information at pixel level.



NPP comparisons by comparing PEM based estimated NPP and 2007 field model based August 2010 biomass.

(18 August 2010). NDVI has a limitation in biomass estimation due saturation in high biomass (Huete and Jackson, 1987). NDVI saturate under high biomass or high leaf area index (Asrar *et al.,* 1984, Huete and Jackson, 1987). Although accuracy of NPP estimation by PEM model must be validated using field samples.

Total NPP by each category and total NPP of the agricultural land in the study site is presented in (Table 3.3 and Fig. 3.3). Carbon distribution in each category is also documented. It is to be noted that around 4.85 t/ha carbon is fixed in the study site. Highest carbon fixation is 7.5 t/ha happened in the corn field. On the other hand, carbon fixation by paddy is approximately 6 t/ha and abandoned cropland is 5 t/ha. Corn has potentiality to yield more but farmers harvest it before full growth to use it as fodder for cattle.

Table 3. Total NPP in agricultural land.

Category	Area (ha)	Total NPP(ton)	Total Carbon (ton)	Carbon (ton ha^{-1})
Paddy	350	4200	2100	6
Corn	54	810	405	7.5
Abandoned	110	990	495	4.5
Poly-house	210	588	294	1.4
Total	724	11070	5535	4.85

Comparisons of two NPP estimates indicate that the slopes of the regression lines were not going through the origin. It is evident from the figure that biomass model (8 July field model) is under estimating the August biomass comparing to NPP estimated by PEM model. It is perceived that early season, small biomass (8 July 2007) model might not be applicable to the late season

Conclusion

This study showed that it is possible to develop a NPP map of AL from field based

NDVI (NDVI~fAPAR), solar radiation (PAR), and LUE data. NPP map showed the carbon sequestration potentiality by each land use types. It also showed that corn fixed the greatest amount of carbon per unit area followed by paddy and abandoned. This NPP map shows just the NPP value in the sample plots, but it cannot explain the spatial pattern of NPP at pixel levels.

Japan Government is planning to avoid cropland abandonment. From the environmental point of view, the study suggested that cropland is more productive than abandoned cropland in general. Mountainous AL is facing critical problems related to farm land abandonment leading to land cover change in Japan. It causes the change in the original landscape and their effect on ecosystem is not studied in details. Especially carbon distribution is not well monitored. Thus, this NPP map can be helpful in understanding the carbon distribution of a mountainous agricultural land at Daihachiga river basin in Takayama, central Japan. This study concludes with spatial distribution of NPP using average point NPP data. However, a further study with combination of multi-scene or even using one scene is needed.

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