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Estimating agro-ecosystem carbon balance of northern Japan, and comparing the change in carbon stock by soil inventory and net biome productivity

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Abstract:

Soil C sequestration in croplands is deemed to be one of the most promising greenhouse gas mitigation options for agriculture. We used the crop-level yields, heterotrophic respiration (Rh) modeling and GIS land use data to estimate and analyze the spatio-temporal changes in regional scale net primary productivity (NPP), plant C inputs, and net biome productivity (NBP) in northern Japan's arable farming area and grassland over the period of 1959–2011; and compared the change in C stocks in each individual land use from 2005 to 2011 by two methods: (i) NBP and (ii) repeated soil inventory. For the whole region (2193 ha), overall annual plant C inputs to the soil representing 37% of the whole region NPP. Plant C inputs in upland (without bush/fallow) could be predicted by climate conditions. Overall NBP for all land use increased from –1.26 Mg C ha^{-1} yr^{-1} in 1959 to 0.26 Mg C ha^{-1} yr^{-1} in 2011. Though upland and paddy showed decreased NBP over the period of 1959–2011 under the current C input scenario, in the case of increased agricultural abandonment (bush/fallow) and grassland from 1988, the regional C pools slowly start to build up. The comparison of NBP method and soil inventory indicates that nonsignificant difference in two methods, and C loss in upland, paddy and land use change from paddy to upland, and C gain in grass from 2005 to 2011. Underestimation measured by means of NBP or an overestimation by means of repeated C inventories cannot be excluded, thus either method may be suitable for tracking absolute changes in soil C unless with indication of uncertainty analysis.

Keywords: net ecosystem carbon; soil inventory; C change; agriculture; regional scale; uncertainty

1. Introduction

The carbon (C) balance in terrestrial ecosystems has large implications on the variation in atmospheric carbon dioxide (CO_2) emission. Soil have the potential to sequestrate organic matter and thus to significantly contribute to the terrestrial C sink. Agriculture profoundly affects global C, water and nutrient cycles, as well as the planetary surface energy balance (Bondeau et al., 2007). Both land-use change and agricultural management are important and controllable factors in the C balance of soils and may help to mitigate the increase in atmospheric CO_2. The greenhouse gas (GHG) emission saving potential of agriculture has been estimated as 5.5–6.0 Gt CO_2-eq.$^{-1}$, with 89% of it by means of soil C sequestration because of combined measures, such as cropland conversion, cropland management, grassland management or restoration of organic soils (Leifeld et al., 2011). It is believed that agricultural soils can be a significant sink by adopting appropriate improved management practices and therefore contribute to mitigating atmospheric CO_2 emissions (Lokupitiya et al., 2012; Smith et al., 2007).

Assessment of soil C stock changes over time is typically based on application of two methods, namely (i) repeated soil inventory and (ii) determination of the net biome productivity (NBP) by continuous measurement of CO_2 exchange in combination with quantification of other C imports and exports (Leifeld et al., 2011). Repeated soil inventory is often studied by measuring changes in total soil organic C over long periods from years to decades (Smith et al., 1997). In many sites, while soil organic matter concentration has been measured several years, calculations of total soil organic C contents has been hindered by the absence of data on soil bulk density and by discrepancies in sampling techniques (e.g. no standardization of soil depth and of soil layers) (Smith et al., 2010). Moreover, Soil inventory fails to provide an annual C budget, not necessarily taking into account dead organic matter C, and placing limitations on extrapolation due to high spatial variability (Leifeld et al., 2011). The NBP is the C remaining the ecosystem when all other fluxes have been accounted for. In croplands, due to the removal each year of the crop material, the NBP is estimated by measuring the long-term change in soil organic carbon (SOC). The C mass balance approach, as used to determine NBP, could overcome the obstacles of soil inventory as it integrates the C budget over the whole ecosystem independently of allocation in soil (Leifeld et al., 2011).

The main method for integrating NBP of croplands at the continental scale is the use of process-based models (Wattenbach et al., 2010; Ogle et al., 2010), based on soil, climate, land use and management activity data. However, the main hurdle to applying such models at the regional level is data limitation. Especially in the developing world, the datasets such as high spatial resolution of soil data and land-use data are poor or non-existent (Smith et al., 2010). In a series of papers assessing the C budget, Ciais et al. (2010a) and Smith et al. (2010) estimated the NBP of grassland. NBP is usually estimated as NBP = NPP – Rh – C_{export} + C_{import}. NPP, Rh, C_{export} and C_{import} are the net primary productivity, heterotrophic respiration, C export and C import. Recently, estimating cropland NPP through manipulation of yield statistics from governmental bodies and crop-specific allometric relationships has become the more common approach at large spatial scales (e. g. Prince et al., 2001; Bolinder et al., 2007; Kimura et al., 2011; Koga et al., 2011). The main advantages of using yield statistics in estimating cropland NPP arise from their: (i) spatial explicitness, (ii) flexibility over a range of crops, (iii) reflection of local varieties and field management practices used in the study area and (iv) allowing a simple estimation of annual plant C inputs.

Long-term trends in agricultural productivity and residue inputs to soil, driven by technological and management changes, impact the magnitude and direction of change in soil C storage (Johnson et al., 2006). Because of the high NPP of many agricultural crops, relative to non-cropland vegetation, agricultural systems can substantially increase short-term C exchanges between the land surface and the atmosphere in regions converted to agricultural land use. Interannual variability and changes in crop species distribution, as well as interannual variability in net ecosystem C storage, may have significant implications for estimating short-term changes in terrestrial C balances, for both atmospheric-based estimates of regional C cycling and ground-based soil C inventories. A large proportion of NPP (about 40–50% of above ground biomass in grain crops) is removed as yield and thus the long-term C balance in croplands is instead governed by the amount of crop residues, which is remained on the field. Thus spatial and temporal variability of C inputs present significant challenges for estimating the C balance in agricultural ecosystems.

In principal, an indication for the uncertainty in NBP should be provided and thus a direct quantitative evaluation of methods is available. Meanwhile, the NBP value for an agricultural system should be directly comparable with the C stock change measured by repeated sampling of soil, but up to now, there has been few field study that directly compared the two approaches at an agricultural system at the regional scale.

The first goal of our study was to explore trends and interannual variability of NBP at regional scale, focusing on the spatial and temporal patterns of NPP, crop residue inputs and NBP at main land use: upland, paddy, grass from 1959 to 2011. Secondly, comparing the change in ecosystem C stocks at main land use from 2005 to 2011 by two methods: (i) repeated soil inventory and (ii) full C flux budget (NBP) by continuous measurements of CO_2 exchange in combination with quantification of other C imports and exports.

2. Material and Methods

2.1 The study site

The study site is the Ikushunbetsu River watershed (43°14′N, 141°57′ E), which covers an area of 35,887 ha, located in central Hokkaido, Japan (Mu et al., 2008). The 30-year average temperature is 7.4°C, and the annual precipitation is 1,154 mm (Japan Meteorological Agency, 2014). At the regional scale, there are 4 main soil types according to a basic survey on soil fertility (Hokkaido Central Agricultural Experimental Station, 1971), included

Brown lowland, Gley lowland, Grey lowland and Pseudogley. There are 15 soil types under the 4 main soil types and 6 soil textures (Table S1 in Supplementary Data). The main agricultural land uses are paddy rice (paddy) (*Oryza sativa* L.), onion (*Allium cep* L.) and winter wheat (wheat) (*Triticum aetivum*). Vegetables such as soybean (*Glycine max* L.) are the minor crop. The soils of the area are mostly Fluvisols near the river and Cambisols at higher elevations. For detailed inventory of agricultural activities, land management and flux measurements (see Mu et al., 2008a; Kimura et al., 2007; Li et al., 2015). The cultural conditions and plant biomass components for major crops are presented in Table S2 in Supplementary Data. Ground survey were conducted in 2002, 2005, 2007 and 2011 to estimate the land use areas, then, the land use distribution was mapped digitally using ArcGIS 10.0 (Esri). Land use history was analyzed using 1:25,000 maps from the Geographical Survey Institute (1959, 1966, 1976, 1988, 1994). Fallow was defined as an area with previous artificial land use, but no cultivation or construction in following ground survey years (Kimura et al., 2007). Bush was defined as the fallow land, which was abandoned for more than two years. The growing season is defined from the beginning of May to the middle of September.

2.2 Measurements of the net biome productivity

The net ecosystem carbon balance (NECB) is the term applied to the total rate of organic C accumulation in (or loss from) ecosystems (Chapin et al., 2005). Extrapolation of NECB to larger spatial scales has been termed "net biome productivity" (NBP) (Schulze and Heimann, 1998; Buchmann and Schulze, 1999). Based on studies by Ciais et al. (2010a), Smith et al. (2010) and Jia (2012), NBP is quantified as

$$NBP = NPP - Rh - CH_4 - H - NH + I \quad (1)$$

NPP is the net primary production (NPP) using crop-level yield statistics and crop-specific allometric relationships developed by Bolinder (2007). Rh is the soil heterotrophic respiration (Rh). CH_4 is methane emission from paddy. CH_4 losses from the well aerated soils (upland) are expected to be negligible, or even a net sink (i.e. methane oxidation outweighs methane production) (Smith et al., 2010). CH_4 emission from paddy was calculated by a function of the amount of straw residues (Naser et al., 2007). H is the harvested component of NPP. NH is the non-harvested biomass removed from the field. I is the input by organic fertilizer such as manure or slurry. Manure input (2.41 Mg C ha^{-1} yr^{-1}) was only considered at grass in study area (Kimura et al., 2010). The ratio of NBP/NPP is defined as the C sequestration efficiency (CE) (Ciais et al., 2010a).

2.3 Estimation of net primary production, carbon harvest and residue carbon inputs

For each crop, crop-level NPP and plant C inputs from plant residues to the soil were calculated using crop yield (Table S3 in Supplementary Data) and crop-dependent plant parameters (Table 1), which were developed by Koga (2011). Crop yield (kg ha^{-1} yr^{-1}) in 1994, 2002, 2005, 2007, 2009 and 2012 were from the total yield (t) per year and planted area (ha) in Iwamizawa city; and crop yield (kg ha^{-1} yr^{-1}) in 1959, 1966, 1976 and 1988 were estimated by the total yield (t) per year and planted area (ha) in Hokkaido (Ministry of Agriculture, Forestry and Fisheries, Japan).

$$\mathrm{NPP} = \mathrm{TC_h} + \mathrm{TC_r} + \mathrm{TC_a} + \mathrm{TC_b} \quad (2)$$

$$\text{Plant C input} = \mathrm{TC_a} + \mathrm{TC_b} \quad (3)$$

where, $\mathrm{TC_h}$, $\mathrm{TC_r}$, $\mathrm{TC_a}$ and $\mathrm{TC_b}$ were the quantities of C (Mg C ha^{-1} yr^{-1}) found in harvest biomass C, non-harvested biomass C removed from the field (straw of wheat and paddy in this study), above-ground residue biomass C and below-ground residue biomass C, respectively. These, were calculated as follows:

$$\mathrm{TC_h} = \mathrm{Y} \times \frac{\mathrm{D_h}}{100} \times \frac{\mathrm{C_h}}{100} \quad (4)$$

$$TC_r = Y \times \frac{D_h}{100} \times R_r \times \frac{C_h}{100} \quad (5)$$

$$TC_a = Y \times \frac{D_h}{100} \times R_a \times \frac{C_a}{100} \quad (6)$$

$$TC_b = Y \times \frac{D_h}{100} \times R_b \times \frac{C_b}{100} \quad (7)$$

where, Y was the crop yield on a fresh weight basis (Mg ha^{-1}) obtained from crop yield statistics (Table S3 in Supplementary Data), D_h was the dry matter content in harvested biomass (%), R_r, R_a and R_b were the dry weight ratios of non-harvested biomass removed from the field, above-ground residue biomass and below-ground residue biomass to harvested biomass, respectively, and C_h, C_r, C_a and C_b were the dry weight-based C contents (%) of harvested biomass, non-harvested biomass removed from the field, above-ground residue biomass and below-ground residue biomass, respectively.

Crops such as fruits, melon and pumpkin which are lack of details of crop-dependent plant parameters (Table 1), their NPP and C in harvest were estimated from dry weight of total plant and dry weight of main plant using the linear regression from Osaki (1992). Dry weight of total plant, main product and crop residues were estimated from total crop production, water content of main product (%), and the ratio of by product to main product (Nagumo, 2000).

2.4 Soil heterotrophic respiration

Rh was from decomposition of soil organic matter decomposition (SOMD) in uplands, which was simulated based on soil temperature (T, 0-5-cm depth), water-filled pore space (WFPS, 0-5-cm depth) and soil texture (Li et al., 2015). Soil temperature was calculated by air temperature based on the empirical equation (Kimura et al., 2010). We converted the gravimetric soil water content to WFPS after making the assumption, based on local soil textural data, that bulk density of the clay loam (CL), light clay (LiC), silty clay (SiC) and silty clay loam (SiCL) was 1.22 (±0.15) g cm^{-3}, 1.15 (±0.12) g cm^{-3}, 1.12 (±0.11) g cm^{-3}, and 1.09 (±0.00) g cm^{-3}, respectively. Gravimetric soil water content in each soil texture was simulated by HYDRUS-1D in the 0–5 cm soil layer (Li et al., 2015). Rh in paddy was calculated on the amount of straw residues application (Naser, 2006).

2.5 Uncertainty in net biome productivity

Uncertainty classes were assigned to individual budget terms depending on the accuracy of the data source using a similar classification scheme as in Vogt et al. (2013). The overall uncertainty of the NBP ($E_{\Delta NBP/\Delta t}$) was calculated as the square root of the sum of the error (E) squares.

$$E_{\Delta NBP/\Delta t} = \text{sqrt}[(E_{NPP})^2 + (E_{Rh})^2 + (E_{CH4})^2 + (E_H)^2 + (E_{NH})^2 + (E_I)^2] \quad (8)$$

The uncertainty associated with the NPP (E_{NPP}) is estimated as the square root of the sum of the error squares of TC_h, TC_r, TC_a and TC_b. Uncertainty of TC_h, TC_r, TC_a and TC_b were calculated based on standard deviations of crop-specific plant parameters (Table 1). The uncertainty of C harvest (E_H) and non-harvested biomass removed from field (E_{NH}) was based on standard deviation of crop-specific plant parameters (Table 1). The manure C input is considered to carry a relatively low uncertainty (E_I) of ±10% (Kimura et al., 2011). The uncertainty of (E_{Rh}) is considered to be the 95% confidence interval of the simulated value (Li et al., 2015). There is a large uncertainty (±90%) associated with CH_4 emissions (E_{CH4}) due to straw application in paddy rice field (Naser et al., 2007). The temporal uncertainty of NPB was estimated as the inter-annual variation between 1959 and 2011.

2.6 Soil inventory

There are total 51 soil sampling sites across land use of upland, paddy and grass at Ikushunbetsu river watershed. There are 4 soil-sampling sites are grass, 15 are paddy, 29 are upland, and 3 are land use change from paddy to upland from 2005–2011. The first soil inventory took place on September 2005 and the second one on September 2011. For each soil inventory, in the soil depth (0–30 cm), each soil depth was divided into 2 or 3 layers, volumetric soil samples were taken by hand with steel cores (100 cm^3) in each layers with 5 replications. Soil samples were sieved over 2.0 mm mesh to remove stones and coarse roots and dried as dry soil. Total carbon (TC) (g C kg^{-1}) was analyzed by TC analyzer (NC-1000, Sumika Chemical Analysis Service, Ltd., Osaka, Japan). Bulk density (BD) (Mg m^{-3}) was measured in 2007, 2009 and 2011. There was no data record of BD in 2005, therefore, the average value from 2007–2011 was used to calculate BD in 2005.

2.7 Statistical analysis

Correlations between each weather variable with NPP, C harvest, plant C input and NBP were determined using the Pearson correlation. To determine which combination of weather variables could best predict the observed temporal pattern of NPP, C harvest, plant C input and NBP, weather data were used as independent variables in a suite of backward stepwise regression by using RStudio Version 0.98.501. The differences in the C change from 2005 to 2011 between the methods (NBP and soil inventory) and the land use were analyzed with two-way ANOVA and Tukey test.

3. Results

3.1 Land use change from 1959 to 2011

Urban area was the largest artificial land use, occupying about 28% of the landscape throughout the study year (Fig. 1). Urban area slightly increased from 24% in 1959 to 28% in 2011. The grass increased from 38 ha in 1959 to 320 ha in 2011. In cropland, paddy area declined from 1254 ha in 1959 to 430 ha in 2011, upland area keeps stable from 1959 to 1994, and then decline from 977 ha in 1042 ha to 723 ha in 2011, bush/fallow area keeps slightly increase from 1959 to 1994 and then increased from 270 ha in 1994 to 673 ha in 2011.

3.2 Net primary production, carbon harvest, carbon inputs, soil heterotrophic respiration and CH_4 emission

Crop-dependent NPP, C harvest and plant C inputs in the study region are presented in Fig. 2. Of all the crops, the crop-dependent NPP was highest for greenhouse (11.84±0.74 Mg C ha^{-1} yr^{-1}) and following to vegetable (10.12±2.92 Mg C ha^{-1} yr^{-1}), paddy (5.03±0.82 Mg C ha^{-1} yr^{-1}), wheat (4.67±1.69 Mg C ha^{-1} yr^{-1}), and lowest in buckwheat (0.74±0.08 Mg C ha^{-1} yr^{-1}). Greenhouse had the highest plant C inputs (4.21±0.26 Mg C ha^{-1} yr^{-1}) per cropland hectare, followed by vegetable (3.60±1.04 Mg C ha^{-1} yr^{-1}) and wheat (2.09±0.71

Mg C ha^{-1} yr^{-1}). Onion and potato had relatively low plant C input. Ratios of plant C inputs to NPP varied significantly, depending on crop species (Fig. 2), with larger ratios being recorded for buckwheat (58%) and maize (54%) and smaller ratios for onion (10%) and potato (12%). Consequently, 38% of crop NPP was returned to the field at the regional scale.

Total annual NPP of all land use (upland+paddy+grass+bush/fallow) over the analysis period averaged 12.04±2.13 Gg C yr^{-1}, which was equivalent to 5.51±1.05 Mg C ha^{-1} yr^{-1}. At regional scale, NPP of all land use over the study period ranged from 4.19 Mg C ha^{-1} yr^{-1} in 1959 (Fig. 5b) to 6.03 Mg C ha^{-1} yr^{-1} in 2011 (Fig. 5g) (Fig. 3a), while the plant C inputs over the period ranged from 0.86 Mg C ha^{-1} yr^{-1} in 1959 (Fig. 5d) to 2.81 Mg C ha^{-1} yr^{-1} in 2011 (Fig. 5i) (Fig. 3c). NPP of upland (not included bush/fallow), paddy and grass ranged from 2.85–4.42, 3.26–5.95, and 6.41–7.76 Mg C ha^{-1} yr^{-1}, respectively, from 1959 to 2011(Fig. 3a). As a result, the annual C harvest from all the field combined increased from 1959 to 2011 in all land use, upland (not included bush/fallow), paddy and grass by 1.50, 0.58, and 0.63 Mg C ha^{-1}, respectively (Fig. 3b). Total annual plant C input from all the field combined increased from 1959 to 2011 in all land use, upland (not included bush/fallow), paddy and grass by 1.95, 0.058, 0.46 and 0.63 Mg C ha^{-1}, respectively (Fig. 3c). In bush/fallow field, the overall trend of plant C input was considered as neither increasing nor decreasing over the study period.

Rh in upland was estimated at 3.14±0.27 Mg C ha^{-1} yr^{-1} (Fig. 3d). Rh in paddy over 1959–2011 averaged 0.98±0.09 Mg C ha^{-1} yr^{-1} and Rh increased from 0.78 to 1.09 Mg C ha^{-1} yr^{-1} from 1959 to 2011 (Fig. 3d). Rh at all land use which takes a fraction of 77% (±14%) of the total NPP at the regional scale. The CH_4 emission from the paddy over the analysis period 1959–2011 averaged 0.25±0.07 Mg C ha^{-1} yr^{-1}. CH_4 emission from paddy increased from 0.10 to 0.33 Mg C ha^{-1} yr^{-1} from 1959 to 2011 (Fig. 3d).

3.3 Regional annual net biome productivity

Though the mean NBP in all land use (upland+paddy+grass+bush/fallow) was estimated to –0.32±0.72 Mg C ha^{-1} yr^{-1} through to the period from 1959 to 2011, the time series of NBP in all land use showed a slowly upward trend. The NBP in 1959 and 2011 in all land use ranged from –1.26±2.84 Mg C ha^{-1} yr^{-1} to 0.26±2.66 Mg C ha^{-1} yr^{-1} (Fig. 3e; Fig. 4; Figs. 5e, 5j). NBP of upland (not included bush/fallow) ranged from –1.99±0.53 Mg C ha^{-1} yr^{-1} in 1959 to –2.22±0.57 Mg C ha^{-1} yr^{-1} in 2011 (Fig. 3e). NBP of paddy ranged from –

0.69 to –0.92 Mg C ha^{-1} yr^{-1} from 1959 to 2011 (Fig. 3f). NBP of grass ranged from 1.36±0.84 Mg C ha^{-1} yr^{-1} in 1959 to 1.49±0.86 Mg C ha^{-1} yr^{-1} in 2011 (Fig. 3e). The carbon sequestration efficiency (CE), defined as the ratio of NBP/NPP, ranged from –0.13 to –0.03 for croplands (upland+paddy+bush/fallow), and equal to 0.22 ±0.04 for grass.

3.4 Temporal variation in net primary production and residue carbon inputs

The Pearson correlation of weather condition with NPP, C harvest, plant C input and NBP was shown in Table 2. The NPP for the all land use was positively correlated with annual mean temperature (r=0.93, P<0.01) over the study period (1959–2011). At individual land use level, such a positive correlation with annual mean temperature could be found for upland (r=0.80, P<0.01), paddy (r=0.76, P<0.01), and grass (r=0.70, P<0.05). The observed temporal variation of NPP can be described by climate relationships in upland, grass and all land use (Table 3).

The positive correlation of annual plant C input with annual mean temperature could be found for all land use (r=0.82, P<0.01), paddy (r=0.76, P<0.01) and grass (r=0.70, P<0.05) over the study period (1959–2011) (Table 2). The temporal variations in plant C input in upland could be described by a relationship with ratio of precipitation and potential evapotranspiration in growing season (Gratio) in upland (Table 3). The temporal variations in NBP in upland, grass and all land use varied with changing weather condition. NBP = –6.98 + 0.91 × Annt + 0.03 × Gppt – 0.12 × Gratio (R^2 = 0.75, P = 0.07) for all land use (Table 3).

3.5 Method comparison

C budget for grass, upland, paddy and land use change from paddy to upland (paddy-upland) from 2005 to 2011 based on NBP method was listed in Table 4 together with the results from the repeated soil inventory. For individual fields, both methods NBP and soil inventory indicate a decrease of soil C in upland, paddy and paddy-upland, and an increase of soil C in grass from 2005–2011, however, a higher C loss measured by soil inventory and a much smaller C decline estimated by NBP. There was no significant difference between the method of NBP and soil inventory (P=0.13), and no significant interaction between the methods and the land use (P=0.60), while a significant difference in the C change among the land use (P=0.01) was found.

4 Discussion

4.1 Influence of residue management on net biome productivity

Over the whole study region during 1988–2011, mean cropland NPP (±SD) was 6.09±0.4 Mg C ha^{-1} yr^{-1}, this result was close to the result in Tokachi region of Hokkaido with the cropland NPP was 6.66 Mg C ha^{-1} yr^{-1} over the period of 1971–2010 (Koga et al., 2011). The average amount of C input at regional scale in this study area over the period of 1959–2011 was 2.04±0.76 Mg C ha^{-1} yr^{-1}, and this C input represented 37% of the NPP. This result was close to the result in arable farmlands of northern Japan estimated by Koga et al. (2011), which the regional annual plant C input was 2.52±0.32 Mg C ha^{-1} yr^{-1} and the C input represented 38% of the NPP.

Crop production increased markedly between 1959 and 2011, which augmented the amount of residue and root input to the soil. Under field conditions, merely 15–50% of the C input will remain in soil as un-decomposed after one year (Sleutel et al., 2006). The average amount of C input in upland and paddy in this study over the period of 1959–2011 was 1.38±0.27 Mg C ha^{-1} yr^{-1} and 0.86±0.14 Mg C ha^{-1} yr^{-1}. Even though the increasing C input to the soil over the years, NBP in upland and paddy showed decreasing trend from 1959–2011 under the recent C input scenario. Yokozawa et al. (2010) used Rothamsted Carbon Model (RothC) to simulate soil C stocks in Japanese cropland at a national scale.

The results showed that the required C input to Japanese upland and paddy are 5.06–5.66 Mg C ha^{-1} yr^{-1} and 2.76 Mg C ha^{-1} yr^{-1}, respectively, to maintain the soil C level in 1990. This illustrates that crop residues play a crucial role in maintaining soil C stocks in croplands and that the removal of residues or smaller return of C to the soil has adverse effects on soil C storage and the mitigation of greenhouse gas emissions from agricultural lands (Zhang et al., 2006; Koga et al., 2011). Addition, paddy at Ikushunbetsu watershed was continuous flooding and drained for harvest at the end of the growing season. Decreasing NBP in paddy from 1959 to 2011 might also be explained by the C loss in leaching under irrigation managements. As Xu et al. (2013) indicated that C leaching loss in flooding irrigation paddy increased by 46.4% than in nonflooding controlled irrigation paddy.

The CE of croplands (upland+paddy+bush/fallow), defined as the ratio of NBP/NPP, ranged from –0.13 to –0.03. This CE value is low compared to the values of European cropland, ranged from –0.03 to 0.01 (Ciais et al., 2010a). The grass CE equals to 0.22±0.04, which is higher than the grass CE in European (0.13) (Ciais et al., 2010a). The smaller CE values in croplands reflect a smaller return of C to the soil, coupled with an accelerated decomposition of soil organic matter due to plowing and tillage (e.g. destruction of soil micro aggregates and oxygenation). Another reason is that manure application in Ikushunbetsu watershed was the rare case. At face value, improved cropland management can greatly increase cropland soil C sequestration (Smith et al., 2008). The major contribution of croplands to longer term sequestration of C, and hence mitigation of the greenhouse effect, is likely to be in soil C accumulation, especially in "no-till" agriculture where the land is not ploughed (Prince et al., 2001).

4.2 Influence of climate condition on net biome productivity

In long trends, the interannual variability of crop production, largely driven by weather variability and climate cycles, and also vary spatially across the regional scale related to differences in soil quality, moisture and nutrient availability that may be directly or indirectly related to climatic differences (Lokupitiya et al., 2012). To simulate both spatial and temporal changes in ecosystem C balance at a regional scale, detailed information regarding C inputs from crop residues, green manure and composted manure is necessary. However, accurate measurements or simulations of annual plant C inputs (part of crop NPP) to croplands are difficult due to the unpredictability of a number of regional-specific factors such as crop species, cultivars and field management practices, as well as variable micrometeorological and soil conditions. The temporal variability of cropland NPP and pant C input is determined by fluctuating climate conditions (Ciais et al., 2005; Trenberth et al., 1988; Lokupitiya et al., 2012). According to our study, yields and plant C inputs showed an increase trend for most crops over the 1959–2005. Our study revealed that plant C inputs could be predicted by climate condition. Plant C inputs in this study tended to be positively proportional to the annual mean temperature (Annt) (Table 3). Increasing temperature may increase NPP where it can increase the length of the seasonal and daily growing cycles, but it may decrease NPP in water-stressed ecosystems as it increases water loss (IPCC, 2007). Lokupitiya et al. (2012) found a negative relation over the 16-year period in US croplands, due to the higher temperature and drought occurred in North Central region, US in 1993.

In this study, we estimated trends in C budget by NBP at regional scale based on residue inputs and climate impacts on Rh (Material and Method 2.4). Our study revealed that NBP could be well predicted by the relationship based on climate condition in upland, grass and all land use (Table 3), however, this relationship cannot be found in paddy, because straw application and irrigation impacts on Rh in paddy, smaller return of C to the soil might have the major impact on C budget.

4.3 Influence of land use change on net biome productivity

The land area of upland and paddy was found to decrease from 1956 to 2011, however, the yield and plant C input in all croplands showed an overall increase. The upland and paddy are the main land use contributing the increase of plant C input at the regional scale. The long-term trend of increasing yields for most major crops such as soybean, vegetable, wheat and paddy are largely attributed to an array of technology and management developments (i.e., crop genetics, fertilization, plant breeding and pesticide use, etc.). The declined in paddy area has been encouraged by the set aside policy of the Japanese government (Ministry of Agriculture, Forestry and Fisher, 2006). The decline in onion area might be due to the low market price of onion from 2002. The fallow land area increased from 1989 due to the closure of mine activity in 1989 (Mikasa City, 1994) and agricultural activity in this area (Kimura et al., 2004).

The upland in this study showed decreased NBP over the period of 1959–2011. In Japanese upland cropland, Koizumi (2001) reported that the amount of C loss from the soil was within 1.58–3.14 Mg C ha^{-1} yr^{-1} in fields under upland crop cultivation. Another field experiments in upland under wheat, onion and soybean cultivation in the northern part of Japan showed significant loss of 1.47–4.10 Mg C ha^{-1} yr^{-1} from the soil (Hu et al., 2004; Mu et al., 2006). However, there is large uncertainty in this estimate because the historical land use changes are poorly quantified in terms of both spatial and temporal before 1994 in our study. Generally, the range of estimated NBP shown in this study is similar to those literatures in cropland (Kutsch et al., 2010; Koizumi, 2001; Nishimura et al., 2008). Other previous studies showed quite different results, with NBP near zero or with significant C accumulation into the upland soils, however, these results were only found in no-tillage cultivation (Hollinger et al., 2005; Nouchi and Yonemura, 2005).

The paddy in this study showed decreased NBP over the period of 1959–2011. C input in paddy increased over the study period along with increasing paddy rice yield, which lead to the increasing CH_4 emission loss from paddy field. Though C input in paddy increased over years, it is still far from the amount to maintain the soil C level. Paddy was not a C source in fallow season, due to non harvest, retention of crop residues, and the fact that biomass incorporated into the soil was not completely decomposed during the season (Ono et al., 2013). Though, our estimation was based the over one year including fallow season, the paddy in study region showed a C source during study period. The land area of paddy declined from 1959 to 2011. Our study presents that land use change from paddy to upland causes 5.18(1.18) Mg C ha^{-1} yr^{-1} C loss from 2005–2011. Though land use change from paddy cultivation to upland cultivation might cause significant loss of C from cropland soil (Nishimura et al., 2008), in the case of increased agricultural abandonment (bush/fallow) from 1988, C pools slowly start to build up.

In our study, we find a tendency for a C sink in grass (Fig. 3e). Our study indicated that cropland to grass conversion sequester C from 2002. The NBP in all land use across the whole region showed a slowly increase. Though upland and paddy showed decreased NBP over the period of 1959–2011, the increased land use of grass and bush/fallow contributed to less C loss from field, which led to the increased NBP at regional scale.

4.4 Comparison of repeated soil inventory and net biome productivity method

Independent of method, we observed a significant difference between land uses. Both methods indicate that C loss in upland, paddy and land use change from paddy to upland, and C gain in grass. This is in line with previous studies showing that, C loss in fields under upland, paddy cultivation (Koizumi, 2001; Hu et al., 2004; Mu et al., 2006). Hardly any direct comparisons of the NBP approach and repeated soil inventories are reported in cropland in the literature. NBP and soil inventory results in Table 4 reveal the nonsignificant difference in the two methods. NBP values indicate a less negative (more positive) C budget for each land use. Thus, the significant management effect observed by both methods is interpreted differently. One study comparing NBP and soil C inventories over a 3 year period for maize-soybean rotations found similar C budgets between methods with non significant changes in soil inventories and no or small changes in NBP (Verma et al., 2005). However, no indication for the uncertainty in NBP was provided and thus a direct quantitative evaluation of methods proved difficult. Studies on grassland C budgets used either the NBP or the soil inventory approach. Ciais et al. (2010b) and Soussana et al. (2007, 2010) reported that on average temperate grasslands act as C sinks but showed that attributed sink was smaller for studies where C stock inventories were used. Hopkin et al. (2009) indicates that the long-term grass use does not go along with a change in soil C by means of soil inventory. Leifeld et al. (2011) made a comparison of soil inventory and NBP to detect soil C stock after conversion from cropland to grass, and showed that the soil inventory method showed a tendency towards higher C loss / smaller C gain than NBP method. Together, these data tentatively indicate that an underestimation measured by means of NBP or an overestimation by means of repeated C inventories in this study cannot be excluded. The possible reason for the difference between the two methods is NBP disregards potential C losses by dissolved inorganic C (DIC) and dissolved organic C (DOC) leaching owing to the lack of site-specific information, whereas it is covered in the soil inventory approach. C leaching as DOC or DIC has not been systematically investigated at our field site. We consider C leaching to be of minor importance for the NBP determination. Losses of dissolved C at the site were significant in relation to estimates of net ecosystem exchange (NEE) (~10% of NEE) support that dissolved C should be considered a major component of the C budget of many terrestrial ecosystems, including croplands (Siemans, 2003). We acknowledge that a loss of dissolved C of soil would decrease the estimated NBP compared to the results of the inventory method.

4.5 Uncertainty

The capability of the two methods to detect changes in soil C stocks is limited by their total uncertainty resulting from various error sources. The temporal uncertainty of NBP in all land use at regional scale was estimated to be 0.72 Mg C ha^{-1} yr^{-1} described by standard deviation value as the inter-annual variation between 1959 and 2011. Another uncertainty result from systematic errors in individual land use was described in Table 1. The NBP approach uncertainty resulting from temporally random-like errors is generally not very problematic, because of the large number of measurements during a multiyear experiment. Instead, the NBP method encounters a number of sources for systematic errors, including limited field size, field heterogeneity, and measurement limitations, such as imperfect quantification/correction of high-frequency damping and of (correlated) density fluctuations. Thus, it is important that they are accounted for in the NBP uncertainty estimation (Leifeld et al., 2011). Random-like uncertainty that strongly depend on the number of distributed samples and the heterogeneity of the investigated field dominate the uncertainty of the soil inventory approach.

Estimates of NBP in cropland remain uncertain and vary strongly in the literature (Bondeau et al., 2007). Béziat et al. (2009) indicated that the larger uncertainties for NBP than for net ecosystem productivity (NEP = NPP – RH), which were mostly related to uncertainties in C removal by harvest and in C inputs or organic fertilization. The highest uncertainties are associated with the estimates o NBP. This is presumably due to the fact that many of the components that contribute to the cropland C balance are site-specific, reflecting the impact of geographic factors, such as soil type, climate, or the types of crops/cropping practice on the total C budget. This is important as differences among sites in the contribution of the different components to the overall budget result in a high level of variation in NBP at regional scale (Osborne et al., 2010). Our uncertainty ranges calculated for annual NBP are larger than those published in other grassland studies (e.g., Rogiers et al., 2008) and cropland studies (e.g., Ciais et al., 2010a). The large uncertainty in this estimate might due to the historical land use changes are poorly quantified in terms of both spatial and temporal resolution (Jain and Yang, 2005; Houghton, 2007). Yet, many authors even presented and interpreted their C budget results without indicating any uncertainty (e.g., Lloyd, 2006; Allard et al., 2007; Skinner, 2008).

5 Conclusion

Cropland NPP and residue C input rate over the study period showed significant interannual variability, depending on the changes in crop production and weather variability. Variation in plant C input and NBP can be predicted by climate conditions. For the whole region, overall NBP for all land use was slightly increased 1959 to 2011. NBP decreased in upland and paddy under the recent C input scenario. Though upland and paddy showed decreased NBP over the period of 1959–2011, in the case of increased agricultural abandonment (bush/fallow) and grass from 1988, the regional C pools slowly start to build up. The combination of allometric relationship-based estimation of plant C inputs and Rh simulation modeling used in the present study allows us to simulate C balance in an agro-ecosystem where various crops are grown under different environmental (climate and soil) conditions across large scale.

None of the agro-ecosystem studies published used NBP and soil inventories combination. Our study provides this comparison at 51 sampling sites across the study region indicates that C loss occurs in upland, paddy and land use change from paddy to upland; and C gain in grass from 2005–2011. Nonsignificant difference in the two methods in estimating C change, however, differences and large uncertainties in both methods stress the need for more direct comparisons to evaluate whether the observed difference in the outcome of the two approaches reflects a general methodological bias, and the uncertainty analysis would have important implications for regional C budgets.

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Fig. 1. The main land use change from 1959 to 2011.

Fig. 2. Crop NPP, C harvest and Plant C input through the study period. The error bar indicates standard deviation.

Fig. 3. Temporal trends of NPP (a), C harvest (b), Plant C input (c), CH_4 emission and heterotrophic respiration (Rh) (d), NBP (e,f) during the study period for main land use at the regional scale. The error bar for all filed indicates the range of standard deviation.

Fig. 4. Carbon balance presented by NBP for all land use at the regional scale at 1959 and 2011. Inputs and outputs are shown as positive and negative C exchanges (kg C ha^{-1} yr^{-1})

with the overall C balance shown at the bottom. Error bars represent the estimated uncertainty.

Fig. 5. Land use (a,f), NPP (b,g) , C harvest (c,h), C input (d,i), NBP (e,j) at study site in 1959 and 2011.

Table 1 Crop-specific allometric relationships and C contents used to estimate crop NPP, C harvest and plant C inputs.

	Dry biomass content in harvested biomass (%)	Ratio of plant biomass to harvested biomass in dary weight			C content (%)				main product water content[d]	by prod/main prod[d]
		Non-harveted biomass (removed from the field)	Above-ground residue biomass (returned to the soil)	Below-ground residue biomass (returned to the soil)	Harvested biomass (C_h)	Non-harvested biomass (removed from the field)	Above-ground residue biomass (resturned to the soil)	Below-ground residue biomass (returned to the soil)		
	D_h	R_r	R_a	R_b	C_h	C_r	C_a	C_b	%	% (DW base)
Soybean	85[a]	-	1.14(27)[a]	0.298(27)[a]	56(2.1)[a]	-	43.5(3.7)[a]	37.9(10)[a]	-	-
Potato	22.1(4.5)[a]	-	0.0845(33)[a]	0.0827(23)[a]	43.4(1.4)[a]	-	33.3(12)[a]	37(11)[a]	-	-
Buckwheat	86.5[d]	-	1.2[b]	0.17[b]	45[c]	-	45.8[b]	45.8[b]	-	-
Vegetable	28[d]	-	0.7[b]	0.04[b]	45[c]	-	33.2[b]	39.4[b]	-	-
Onion	16[d]	-	0.12[b]	0.005[b]	45[c]	-	39.3[b]	40.4[b]	-	-
Maize	19.1(14)[a]	-	1.47(13)[a]	0.422(67)[a]	47.5(1.3)[a]	-	45.2(2.4)[a]	26.4(23)[a]	-	-
Greenhouse	28[d]	-	0.7[b]	0.04[b]	45[c]	-	33.2[b]	39.4[b]	-	-
Fruits[a]	-	-	-	-	-	-	-	-	89.70	0.44
Melon[a]	-	-	-	-	-	-	-	-	74.70	1.50
Pumpkin[a]	-	-	-	-	-	-	-	-	94.70	0.53
Wheat	86.5[a]	0.986(16)[a]	0.831(18)[a]	1.1(37)[a]	44[a]	43.5(2.1)[a]	45.2(2.4)[a]	25.3(26)[a]	-	-
Grass	28[d]	-	0.1[b]	0.55[b]	45[c]	-	43.4[b]	43.8[b]	-	-
Paddy	95[d]	1.2[e]	1.42[b]	0.27[b]	45[c]	38.13[e]	38[b]	38[b]	-	-
Bush / Fallow [a]	-	-	-	-	-	-	-	-	-	-

[a] Data from Koga et al. (2011); b Data from Ogawa et al. (1988); c The C content of crop dry matter was assumed to be 45% from Matsumoto (2000) when there is no detailed data of C content in harvested biomass, above-ground reisude biomass and below-ground residue biomass; d Data from Nagumo (2000); e Data from Naser (2006).

Table 2 Pearson correlations of weather condition with net primary productivity (NPP), C harvest, plant C input, net biome productivity (NBP) from 1959–2011.

		Annppt	Annt	Gppt	Gtmean	Annratio	Gratio
upland	NPP	–0.83**	0.8**	–0.84**	0.09	–0.73**	–0.68*
	Charvest	–0.76**	0.95**	–0.66*	0.26	–0.63*	–0.35
	Cinput	–0.78**	0.53	–0.89**	–0.09	–0.69*	–0.87**
	NBP	0.48	–0.86**	0.28	–0.48	0.20	–0.29
paddy	NPP/Charvest/Cinput	–0.65*	0.76**	–0.7	0.39	–0.34	–0.69**
	NBP	0.61*	–0.74**	0.67	–0.42	0.31	0.68
grass	NPP/Charvest/Cinput	–0.87**	0.7*	–0.96**	–0.06	–0.75**	–0.88**
	NBP	–0.91**	0.56	–0.97**	-0.13	–0.67*	–0.87**
all land use	NPP	–0.91**	0.93**	–0.96**	0.13	–0.74*	–0.66
	Charvest	–0.9**	0.94**	–0.95**	0.14	–0.76*	–0.69
	Cinput	–0.84**	0.82**	–0.89**	–0.05	–0.81**	–0.87**
	NBP	–0.78**	0.71**	–0.75**	–0.33	–0.89**	–0.96**

ppt: precipitation, t: temperature, ratio: ratio of precipitation and potential evapotranspiration. "Ann" stands for annual mean value, "G" stands for growing season. ** represents P<0.01 and * reprensets P<0.05.

Table 3 The relationship of NPP, C harvest, C input and NBP with climate data in different land use from 1959–2011.

Land use	Equation	R^2	P
upland crop	$NPP = -3.03 + 0.88 \times Annt$	0.39	<0.05
	$Charvest = -7.39 - 0.001 \times Annppt + 1.29 \times Annt + 0.0004 \times Gppt^2 - 0.383 \times Gratio$	0.82	<0.05
	$Cinput = 1.80 - 0.32 \times Gratio$	0.31	0.09
	$NBP = -6.98 + 0.91 \times Annt + 0.03 \times Gppt - 1.20 \times Gratio$	0.65	<0.05
grass	$NPP = -2.32 + 0.47 \times Gppt - 0.005 \times Gppt^2$	0.50	0.09
	$NBP = 3.01 - 0.28 \times Annt - 0.0004 \times Gppt^2 + 0.006 \times Gtmean^2$	0.72	0.04
all land use	$NPP = -6.42 + 1.56 \times Annt$	0.54	0.02
	$Charvest = -7.72 + 1.31 \times Annt$	0.60	<0.01
	$NBP = -6.98 + 0.91 \times Annt + 0.03 \times Gppt - 1.20 \times Gratio$	0.75	0.07

ppt: precipitation, t: temperature, ratio: ratio of precipitation and potential evapotranspiration. "Ann" stands for annual mean value, "G" stands for growing season.

Table 4 Six year (2005–2011) carbon budget of different land use based on a full carbon flux budget (NBP) and repeated soil carbon in ventories.

Land use	Method (Mg C ha^{-1} yr^{-1})	
	NBP	Soil inventory (30cm)
Grass	1.40(0.44)	0.92(3.48)
Upland	–1.41(2.65)	–1.43(3.57)
Paddy	–0.53(0.00)	–1.95(1.68)
Paddy-Upland	–2.45(0.90)	–5.18(1.18)

ANOVA	*d.f*	*F* value	*P* value
Method	1	2.30	0.13
Land use	3	3.94	0.01
Method × Land use	3	0.62	0.60
Residuals	79		

Positive numbers are sinks. Number in brackets are total uncertianty. "Paddy-Upland" represented landuse change from paddy to upland. *d.f.* is the degree of freedom, and F value at 5% significant level with two-sided alternative.

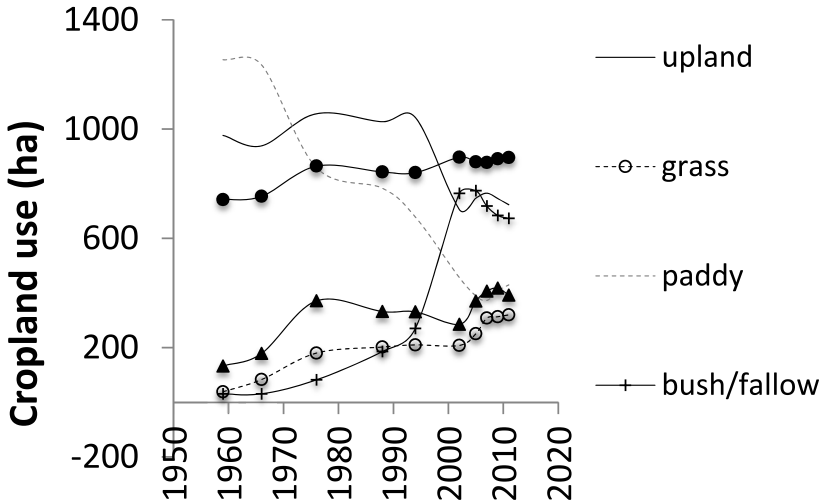


Fig. 1. The main land use change from 1959 to 2011.

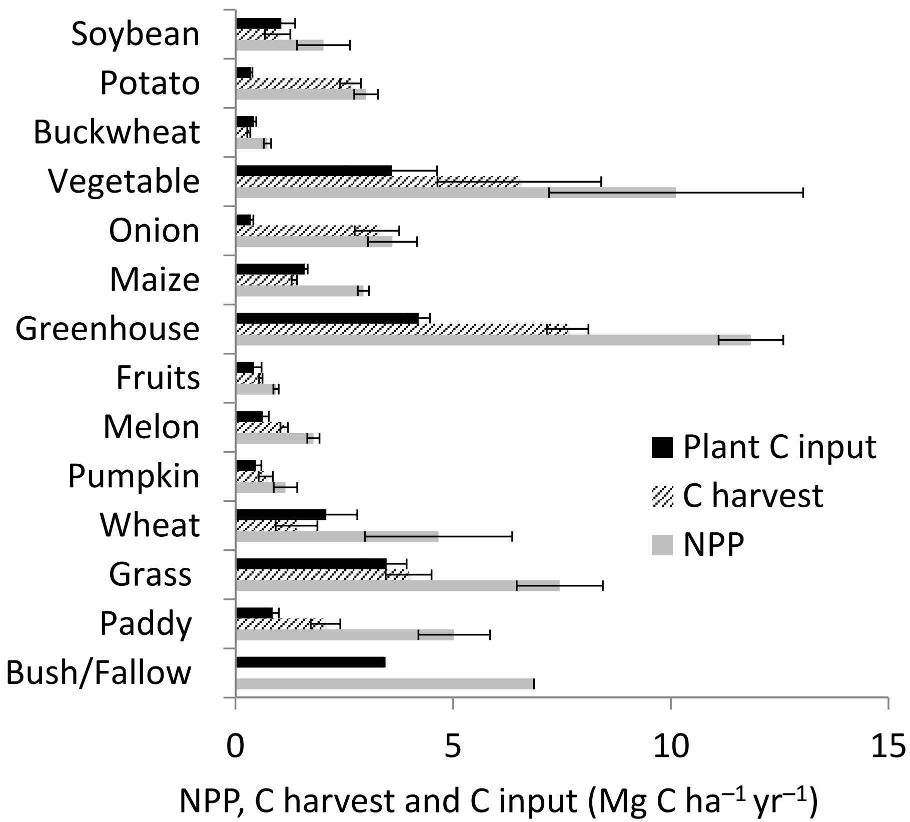
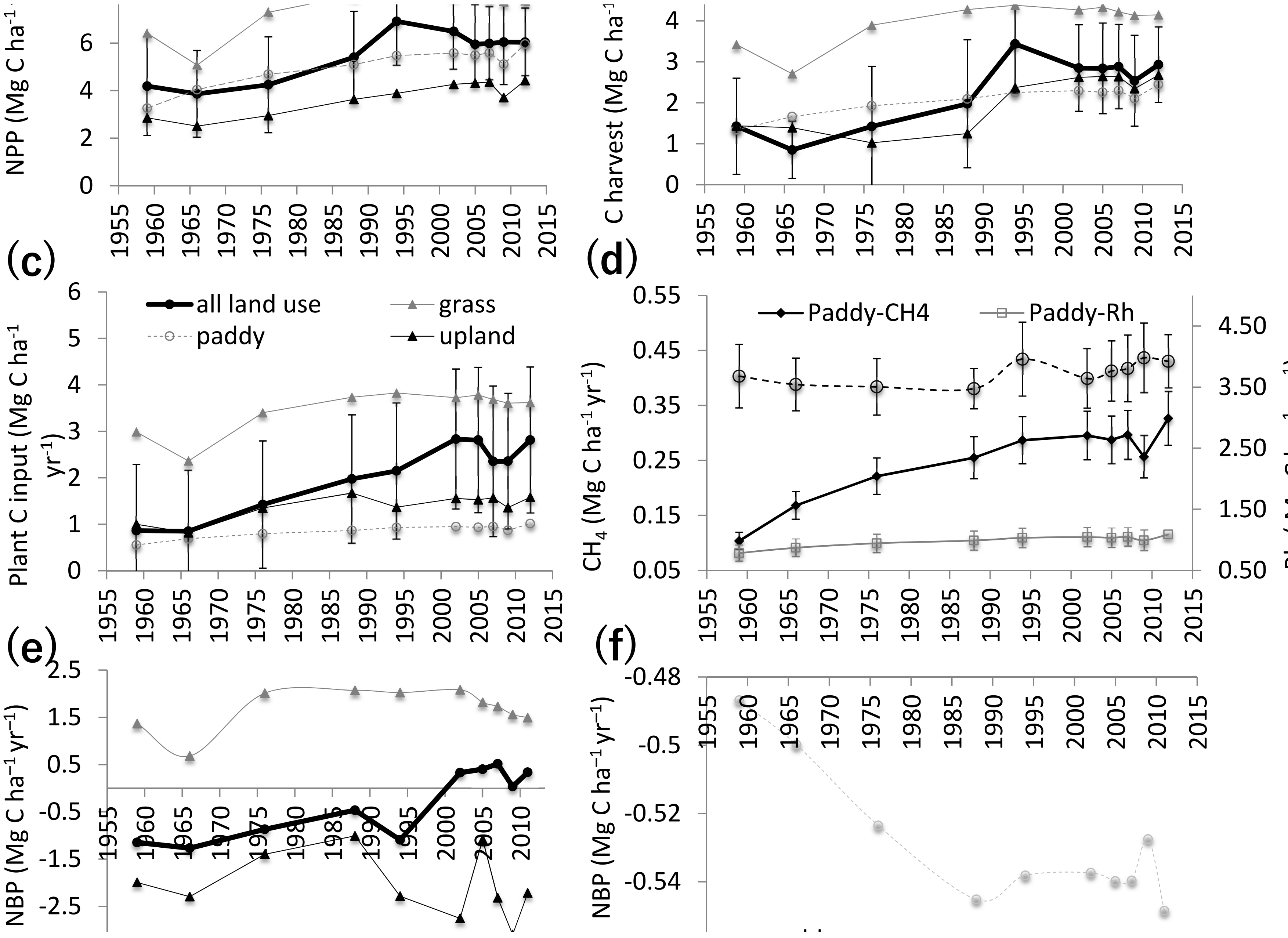


Fig. 2. Crop NPP, C harvest and Plant C input through the study period. The error bar indicates standard deviation.


NPP (Mg C ha-1
C harvest (Mg C ha-1
(c)
(d)
all land use
grass
paddy
upland
Plant C input (Mg C ha-1 yr-1)
Paddy-CH4
Paddy-Rh
CH4 (Mg C ha-1 yr-1)
Rh (Mg C ha-1 yr-1)
(e)
(f)
NBP (Mg C ha-1 yr-1)
NBP (Mg C ha-1 yr-1)

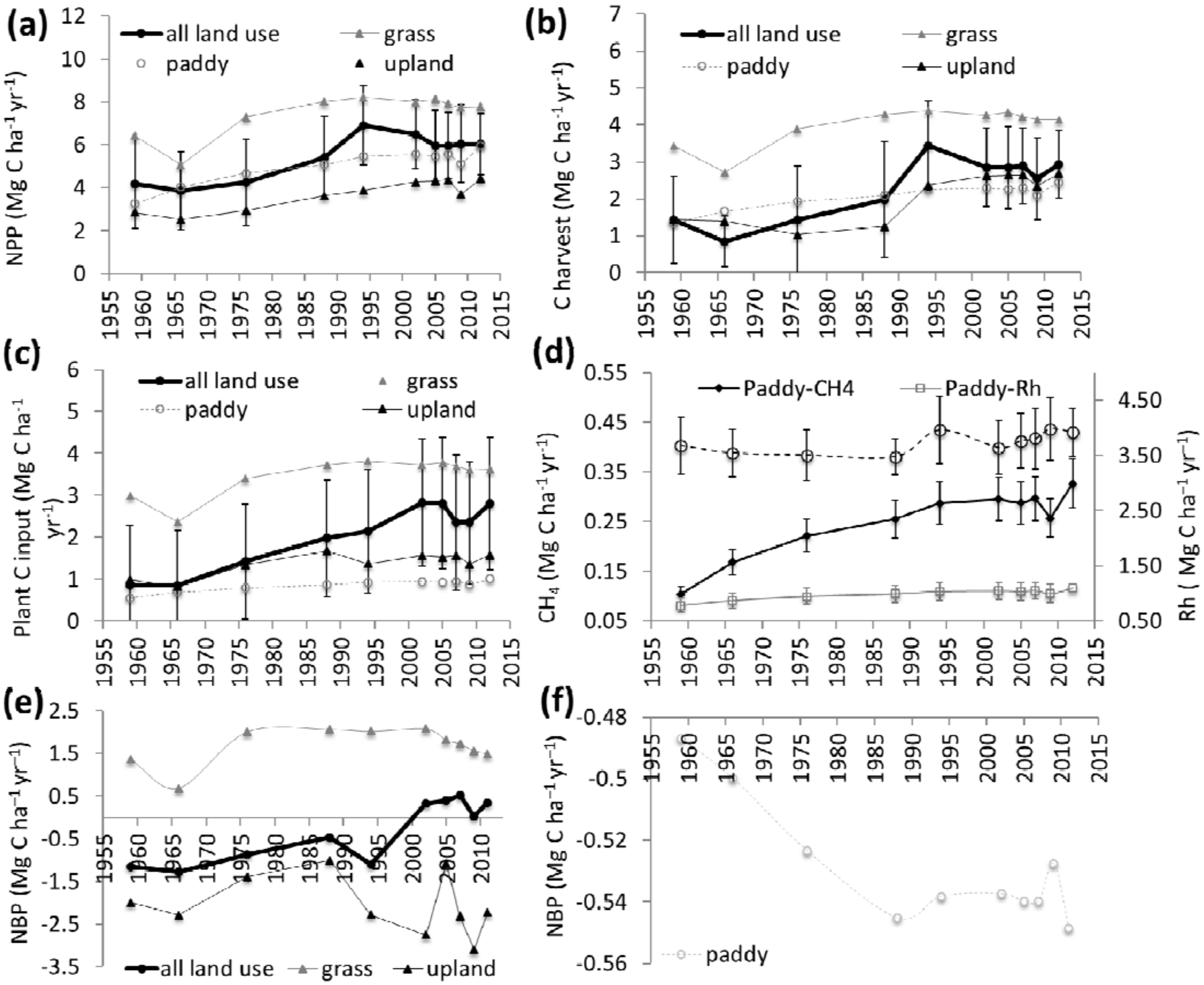


Fig. 3. Temporal trends of NPP (a), C harvest (b), Plant C input (c), CH4 emission and heterotrophic respiration (Rh) (d), NBP (e,f) during the study

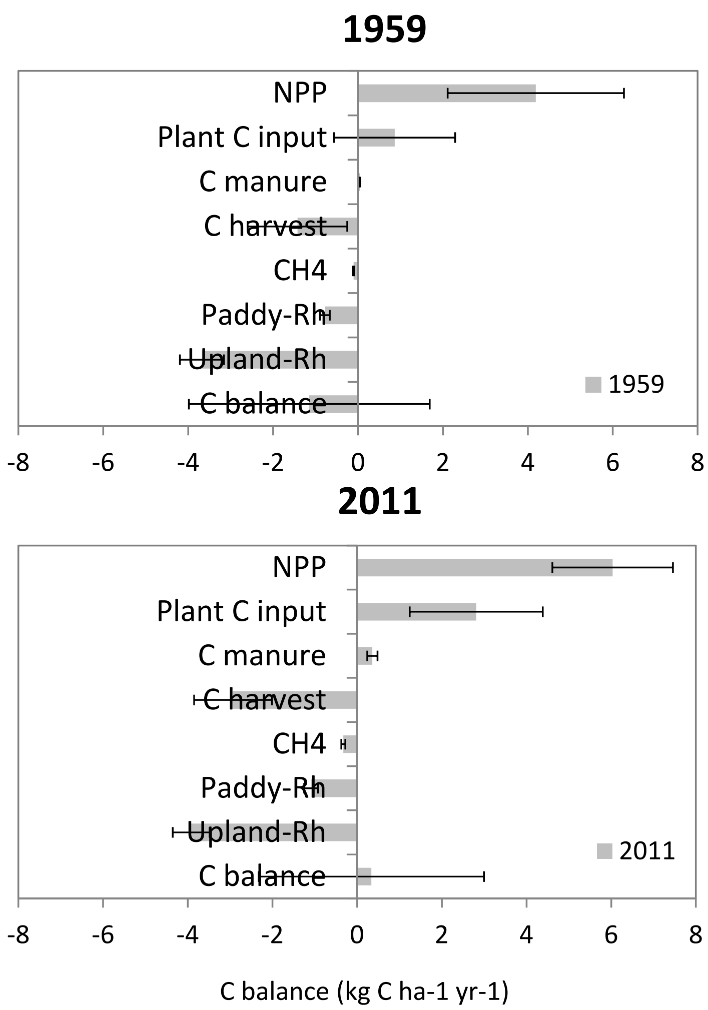


Fig. 4. Carbon balance presented by NBP for all land use at the regional scale at 1959 and 2011. Inputs and outputs are shown as positive and negative C exchanges (kg C ha–1 yr–1) with the overall C balance shown at the bottom. Error bars represent the estimated uncertainty.

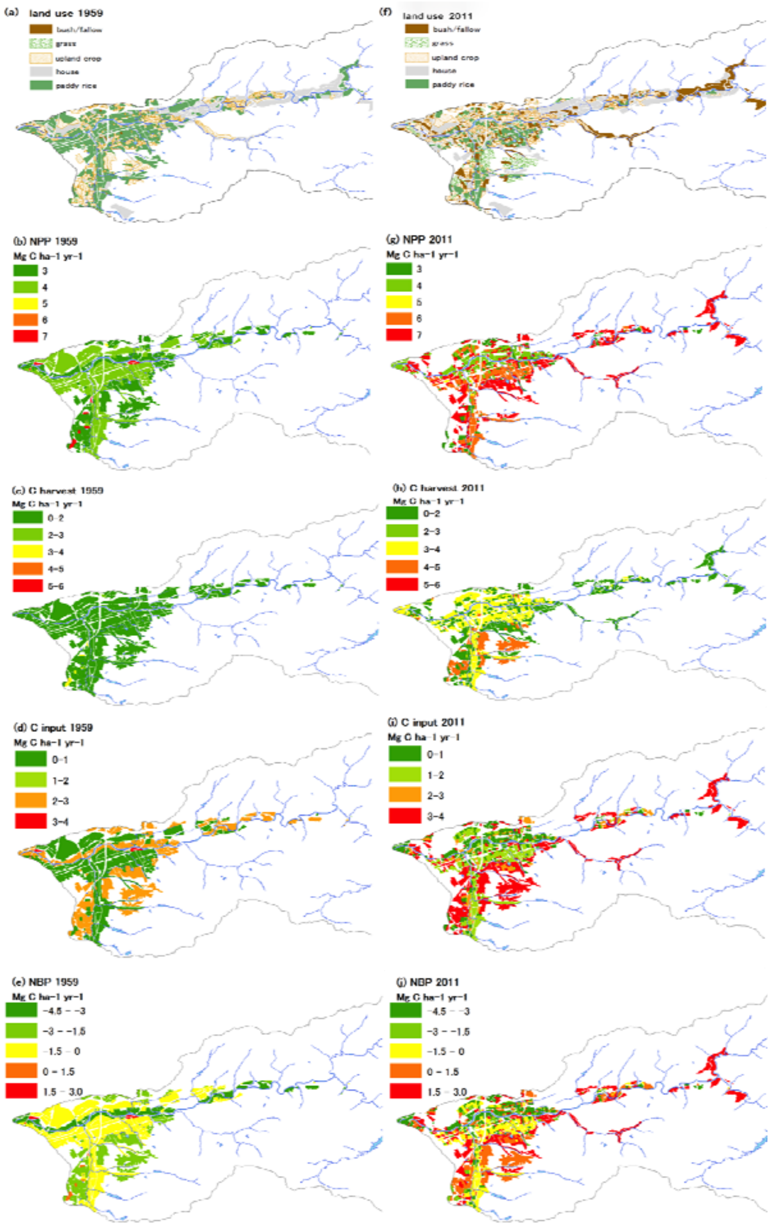


Fig. 5. Land use (a,f), NPP (b,g), C harvest (c,h), C input (d,i), NBP (e,j) at study site in 1959 and 2011.

Table S1 The general information of soil type at the regional scale.

Soil type	sand %	silt %	clay %	texture	pH	soil type
BL-1	31.8	37.9	30.2	SiC~CL	6.8	Brown lowland
BL-2	34.5	30.6	34.9	LiC	5.4	Brown lowland
BL-3	42.7	28.2	29.0	SL~SiCL	5.8	Brown lowland
BL-4	46.6	28.7	24.7	CL	6.5	Brown lowland
BL-5	36.7	30.3	33.0	LiC	5.2	Brown lowland
GleyL-1	25.7	35.2	39.1	LiC	5.5	Gley lowland
GleyL-2	31.1	34.3	34.6	LiC	5.4	Gley lowland
GleyL-3	18.6	43.8	37.6	CL~LiC	5.8	Gley lowland
GreyL-1	22.9	38.5	38.6	LiC~SiC	6.0	Grey lowland
GreyL-2	21.2	36.3	42.4	LiC	5.7	Grey lowland
GreyL-3	31.8	29.6	38.6	LiC	4.9	Grey lowland
GreyL-4	24.9	39.6	35.6	HC~LiC	5.2	Grey lowland
GreyL-5	34.9	33.5	31.6	CL	-	Grey lowland
P-1	15.5	43.3	41.2	LiC	5.5	Pseudogley
P-2	16.6	46.1	37.3	LiC	5.5	Pseudogley

HC: Heavy Clay; LiC: Light Clay; SiC: Silty Clay; CL: Clay Loam; SL: Sandy Loam; SiCL: Silty Clay Loam.

Table S2 Cultural conditions and plant biomass components for majors crops in the Ikushunbetsu watershed of central Hokkaido, Japan.

			Plant biomass component			
Crop	Sowing	Harvesting	Harvested biomass	Non-harvest biomass (removed from the field)	Above-ground resiude biomass (returned to the soil)	Below-ground residue biomass (returned to the soil)
Soybean	Mid May to late May	Late September	Grain		Leaves, stalks, pods	Stubble and roots
Potato	Mid May to late May	Late September	Tubers		Leaves and stems	Roots
Buckwheat	Mid June to late Augest	Late September	Grain		Stems	Stubble and roots
Vegetable	Mid May to late May	Late September	Heada heart		Leaves	Roots
Onion	Late April to early May	Late September	Bulb		Leaves	Roots
Maize	Mid May to late May	Late September	Ears		Leaves and stalks	Stubble and roots
Greenhouse	Mid May to late May	Late September	Heada heart		Leaves	Roots
Wheat	Mid September to late September	Late July to early August	Grain	Straw	Stubble and busks	Stubble and roots
Grass	Early May	Late September	Grass		Stubble	Stubble and roots
Paddy	Early May	Late September	Rice	Straw	Leaves and rice hulls	Stubble and roots

Table S3 Crop yield (Mg C ha^{-1} yr^{-1}) data in the Ikushunbetsu watershed

Year	1959[a]	1966[a]	1976[a]	1988[a]	1994[b]	2002[b]	2005[b]	2007[b]	2009[b]	2012[b]
Soybean	1.5	0.7	1.8	1.9	2.4	2.1	2.3	2.7	2.2	2.7
Potato					24.2	28.6	28.6	31.4	26.9	25.8
Buckwheat					0.7	0.9	0.8	0.7	0.7	0.9
Vegetable	22.6	27.0	51.2	53.5	55.2	61.5	62.2	64.5	56.6	63.4
Onion	65.5	46.9	56.2	50.2	42.2	53.1	51.0	37.4	37.4	50.0
Maize					10.2	11.3	10.8	10.4	10.4	11.2
Greenhouse					55.2	61.5	62.2	64.5	56.6	63.4
Fruits					8.9	7.3	8.5	8.5	8.5	8.5
Melon					18.4	18.4	20.2	21.1	21.1	22.3
Pumpkin					19.8	15.3	14.6	10.8	11.2	12.8
Wheat	2.0	1.2	3.1	4.1	3.9	4.5	4.7	5.0	3.4	4.9
Grass	21.3	21.5	30.9	42.2	34.8	33.9	34.4	33.5	32.8	32.9
Paddy	3.1	3.9	4.5	4.9	5.3	5.4	6.0	5.4	4.9	5.7
Bush/Fallow	38.4	38.4	38.4	38.4	38.4	38.4	38.4	38.4	38.4	38.4

[a] Crop yield were estimated from the total yield production (t) per year and planted area (ha) in Hokkaido (Ministry of Agriculture, Forestry and Fisheries, Japan).

[b] Crop yield were estimated from the total yield production (t) per year and planted area (ha) in Iwamizawa city (Ministry of Agriculture, Forestry and Fisheries, Japan)