Plant-derived carbon and nitrogen addition due to mowing in the early stages of post-agricultural succession

Seiji Shimoda

Memuro Research Station, Hokkaido Agricultural Research Center, National Agriculture and Food Research Organization (NARO/HARC/M), Shinsei, Memuro, Kasai, Hokkaido 082-0081, Japan

ABSTRACT

Input and decomposition of plant-derived organic matter are key processes of the C and N cycling in the post-agricultural succession. This study compared three treatments in order to better understand the contribution of plant-derived organic matter to the C and N levels of the ecosystem in abandoned agrosystems. Mowing without plant residue removal can increase the addition of fresh plant residue and prevented the succession to *Solidago altissima*. In the fifth year of experimentation, the significantly higher floor litter C in the no mowing lead to a higher total C accumulation than that in the mowing treatments. Mowing reduced the floor litter C by 40% and 13%, in the third to fifth year of experimentation, respectively. Additionally, it rapidly changed the vegetation coverage, and decreased the total C in the early stages of post-agricultural succession. Therefore, mowing was less effective in retaining the C pool due to the addition of fresh plant residue and its decomposition, whereas no mowing can increase the addition of plant residue, leading to be relatively high total N. However, the N input might be insufficient to compensate for the mineral soil-N reduction in the early stages of post-agricultural succession.

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1. Introduction

Mowing has been widely practiced in Japan as a method for preparing paddy fields after a fallow period, controlling weeds in abandoned paddy fields, and conserving rural landscapes (Koyanagi et al., 2012). In Japan, a variety of native annual plants is observed in abandoned paddy fields that are under a mowing management plan (Katayama et al., 2015). Mowing can prevent the rapid succession from short annual grasses to tall perennial grasses, alter plant species composition, and maintain their richness after the agricultural abandonment due to the increased intensity of light within the canopy. Species richness has been demonstrated to be a major determinant of biomass productivity in grasslands (e.g., Loreau and Hector, 2001; Tilman et al., 2001). Additionally, mowing contributes to the rapid decomposition of plant residue (Carson and Peterson, 1990; Foster and Gross, 1998) and nitrogen (N) enrichment (Collins et al., 1998; Maron and Jefferies, 2001). It may also enhance the rapid carbon (C) sequestration after the agricultural abandonment, because plant biomass incorporates C rapidly into the soil organic matter due to the fast development of the root system (e.g. Weaver, 1958). Plant growth strategies that determine

litter decomposability are crucial for understanding vegetation-soil C and N dynamics. Mowing may convert a low-N ecosystem dominated by perennial plant species to a high-N ecosystem dominated by annual plant species (Maron and Jefferies, 2001); thus, mowing can alter plant species composition as well as C and N storage in the ecosystem.

The recycling of organic matter and nutrients is a fundamentally important process after the agricultural abandonment that significantly affects the C budget, as well as the availability of N and other nutrients vegetation growth. C balance is controlled by the C input rate through litterfall and the organic matter decomposition rate through plant litter quality (Köchy and Wilson, 1997). Previous studies have reported the decadal response of C and N pools to land management in abandoned upland fields (e.g., Condron et al., 2014; Silva et al., 2013) and grasslands (e.g., Foster and Gross, 1998; Nagler et al., 2015). Plant-derived C and N may not be associated with land use in the long-term post-agricultural succession (Foote and Grogan, 2010). However, little information is available regarding the effect of plant-derived materials on C stability after the agricultural abandonment as well as the contribution of invasive plant species and their floor organic matter to the C and N dynamics in the early stages of post-agricultural succession. The input and decomposition of plant-derived organic matter are key processes of the C and N cycling in the early stages of post-agricultural succession (Paul et al., 2002; Kramer et al., 2010). Therefore, the short-term succession could reveal the temporal changes in the

plant-derived C and N and the effects of mowing on plant species composition.

Rice (*Oryza sativa* L.) cultivation in paddy is the major agricultural land use in the temperate climate regions of East Asia (e.g., Maruyama et al., 2015). Yet very few studies have showed plant-derived materials such as labile pools in abandoned paddy field (Zhang et al., 2007). The light fraction (LF) soil C that has been used as an indicator of soil quality, since it is mainly composed of partially decomposed fragments of plant residue that are not associated with mineral particles (Wagai et al., 2009). The aim of this study was to investigate the effects of mowing and abandoning on plant-derived C and N pools after the rice paddy abandonment. The hypothesis was that mowing or abandoning would rapidly enhance the addition of plant-derived C and N into the soil, increasing the productivity of the ecosystem. Thus, the floor organic matter and LF soil were used as indicators of plant-derived organic matter due to mowing with or without the removal of plant residue compared with no mowing.

2. Materials and methods

2.1. Site description

The study site was located at the Tenjin experimental field (34°31′N, 133°23′E) of the National Agriculture and Food Research Organization, Western Region Agricultural Research Center (NARO/WARC) in Fukuyama, Hiroshima, Japan and used for conventional paddy rice cultivation (elevation, 17 m) before the agricultural abandonment. The fields were composed of gray lowland soil classified as Gleysol based on the World Reference Base (WRB) for soil resources (International Union of Soil Sciences Working Group WRB, 2006) with medium texture and a mean pH of 5.3 (Shimoda and Koga, 2013). The experiment was randomly assigned in two × five continuous plots. Ten experimental plots (8 m × 8 m) were established in January 2007, and three treatments (mowing with plant residue removal [MR; $n = 3$], mowing without plant residue removal [ML; $n = 3$], and no mowing [NM; $n = 4$]). Mowing was applied in May, August, and December over a period of five years (2007–2011). Mowing was applied by high skill level operators using brush cutters (25 or 36 cm^3 displacement engine). A metal cutting blade was used for heavy grasses. Meteorological data were collected in a lowland experimental field of NARO/WARC (34°30′N, 133°23′E; elevation, 2 m) near the Tenjin experimental field. Over the five-year experimental period, the mean annual temperature during the experimental period was 15.7 °C, the monthly mean air temperature reached 27.9 °C in August, and the precipitation was higher than 100 mm during the rainy season from May to July, and September (Appendix A).

2.2. Estimation of plant richness, species composition and dry mass

The vegetative coverage percentage and plant height were measured by establishing 40 quadrats (1 m × 1 m; four quadrats per plots) every month (Shimoda and Koga, 2013) from April 2007 to October 2011. To eliminate plant disturbance during mowing, the aboveground biomass (g m^{-2}) was estimated based on the multiplied dominance ratio (MDR: m^3 m^{-2}) by multiplying the coverage (m^2 m^{-2}) by the mean height (m) of each plant species (Kobayashi et al., 2004). The annual MDR values of each plant species were estimated as the maximum monthly MDR of each plant species in ML and NM within each year of experimentation and before mowing in MR. MR plots were mown at the approximately 0.05 m above ground level, plants were sorted by species, and oven-dried at 80 °C for at least 48 h. The annual aboveground

biomass of each plant species was estimated from the relationship between the dry mass and MDR (Shimoda et al., 2009). These measurements were then related to the aboveground biomass, and the best-fitted relationships were determined (Shiyomi et al., 1998). The aboveground biomass of harvested species was determined at four points (0.5 × 0.5 m) within the three quadrats in MR. To evaluate the significance of MDR effects on biomass, we used a model selection procedure based on the Akaike's information criterion (AIC); the model with the smallest AIC was considered as the best model. Then, we selected exponential models (aboveground biomass = $a \times$ MDR^b) for each plant family. Coefficients were $a = 26.3$ and $b = 0.66$ ($n = 29$, R$^2 = 0.69$) for the Gramineae; $a = 12.9$ and $b = 0.70$ ($n = 49$, R$^2 = 0.72$) for the Compositae; and $a = 37.5$, $b = 0.41$ ($n = 25$, R$^2 = 0.64$) for the Leguminosae. All other plant species were divided into three groups based on their aboveground architecture type. Belowground dry mass samples were collected from three sampling points in ML and MR and four sampling points in NM plots at 0.05-m intervals from a depth of 0–0.10 m and 0.10-m intervals from a depth of 0.10–0.30 m using a 55-mm diameter liner soil sampler. Dried soil core samples were passed through a 1.18-mm sieve and weighted to estimate the belowground biomass.

2.3. Estimation of C and N

Floor organic matter was collected from the soil surface at the center of each quadrat (1.0 m × 1.0 m) in the third and fifth year of experimentation. Floor mass in the first year of experimentation was collected from each sampling point using a 55-mm diameter soil sampler. Floor organic matter that includes the litter (L), fermented (F), and humus (H) layers of the mineral soil in the forest sector of Japan (Takahashi et al., 2010) were collected from each sampling point using a 55-mm diameter soil sampler. The samples were oven-dried at 80 °C for at least 48 h, and ground into a fine powder using a multi-bead shaker (Yasui Kikai, Osaka, Japan). Approximately 20 mg of soil and plant samples was weighed in a tin cup, and C and N concentrations were measured by an elemental analyzer (Flash EA 1112, ThermoFinnigan Co., Bremen, Germany). The C and N concentrations of floor organic matter were not analyzed in the first year of experimentation.

Dried soil core samples were passed through a 1.18-mm sieve and weighted to estimate the belowground biomass. The soil bulk density was calculated by dividing the oven-dry mass of the <2-mm fraction by the volume of the core segment. The belowground biomass was removed manually, oven-dried, and the attached soil was removed by shaking. The C and N contents were estimated as described previously. The C and N concentrations (g C kg^{-1} and g N kg^{-1}) measured by the elemental analyzer were multiplied by the corresponding equivalent soil mass to obtain C and N pools (g C m^{-2} and g N m^{-2}). The mass-based approach using the equivalent soil mass prevents errors associated with the compaction or expansion of the soil. To identify any changes in bulk density after the agricultural abandonment, the C and N contents of each soil layer were calculated using the minimum equivalent soil mass method (Ellert and Bettany, 1995). We employed the linear interpolation to calculate the soil C in any reference soil mass for each reference soil depth.

The low-density fraction liberated by sonication in a heavy liquid was considered soil mineral particles and aggregates and named LF material (Wagai et al., 2009). Approximately 10 g of sieved and air-dried samples was placed in a centrifuge tube with 25 ml of 1.60 g cm^{-3} sodium polytungstate solution, mixed on a shaker table at 150 rpm for 120 min, and centrifuged at 3500 rpm for 30 min. The floating LF in the sodium polytungstate solution was aspirated using a 0.2-μm Millipore filter unit attached to a glass sieve under a vacuum. The filtered sodium polytungstate solution