Imperata grasslands: carbon source or sink?

Karabi Pathak, Arun Jyoti Nath* and Ashesh Kumar Das

Department of Ecology and Environmental Science, Assam University, Silchar 788 011, India

***Imperata* grasslands, among the oldest forms of managed village land use, provide rural people with subsistence and monitory benefits. Yet, little is known about their role in global carbon (C) budget under the scenario of changing climate. The present study was carried out in managed *Imperata* grassland in Cachar district, Assam, North East India. The study was designed to understand whether *Imperata* grasslands are C source or sink, because they are managed through annual fire practice. We studied (i) organic carbon accumulation rate in the soil, (ii) C input from aboveground biomass (CIAB), (iii) C input from below-ground biomass (CIBB) and (iv) Soil CO_2 efflux/soil respiration (R_s) on monthly intervals from October 2013 to September 2014 following standard methods. Later monthly data were merged into four distinct seasons, viz. autumn, winter, summer and rainy season to have a clear vision of seasonal influence on C source/sink status. The study showed highest (2.52 g C m^{-2} $month^{-1}$) soil organic carbon accumulation during summer season. Highest values for CIAB (14.31 g C m^{-2} $month^{-1}$), CIBB (30.98 g C m^{-2} $month^{-1}$) and R_s (31.85 g C m^{-2} $month^{-1}$) were observed during rainy, autumn and summer seasons respectively. C budget analysis with respect to seasons showed *Imperata* grasslands act as C source during winter and summer, whereas they serve as sink during autumn and rainy seasons. However, annual C budget (across all the months) showed *Imperata* grasslands as a net sink of 38.45 g C m^{-2} $year^{-1}$ (0.40 Mg C ha^{-1} $year^{-1}$). Further research is needed to develop better management systems to enhance sink capacity of *Imperata* grasslands.**

Keywords: Carbon budget, climate change mitigation, *Imperata* grasslands, soil organic carbon, soil respiration.

THE global soil organic carbon (SOC) storage is estimated at 1500 Pg (1 Pg = 10^{15} g), which is larger than the sum of the atmospheric (500 Pg) and biotic C pools (800 Pg)[1]. Therefore, SOC storage is an important global C sink[2]. The use of C sinks has been included in many national and international policy plans designed to mitigate greenhouse gas emissions, including the Kyoto Protocol[3]. From a global perspective, grasslands store approximately 34% of the global terrestrial stock of C, whereas forests store approximately 39% and agro-ecosystems approximately 17% (ref. 4). Recommended management practices minimize soil disturbance, while they optimize productivity and increase the SOC pool[5]. However, unscientific management systems alter SOC stock resulting in significant impacts on the atmospheric concentration of CO_2 (ref. 6). Therefore, management systems determine the fate of an ecosystem to act as a source/sink of CO_2.

The *Imperata* grasslands of the tropical region are a vast underutilized natural resource and occupy about 35 million ha in Asia; India is the second largest area holder of such grasslands[7]. Annual fire practice is a key tool for the management of *Imperata* grasslands[7,8]. The grassland is exploited for monetary benefits[9], other than its traditional uses in thatching material. Biomass burning represents a major mechanism by which C is transferred between the terrestrial and atmospheric C pools[10,11]. The 'fertilizing' effect of fire is known since the beginning of agriculture and forestry[12]. Low-impact burning can promote herbaceous flora, increase plant available nutrients and accumulation of organic C, all of which can favour healthy systems[13]. However, high intensity of fire can substantially alter C cycling in ecosystems[14,15] by exacerbating the rate of mineralization leading to a decrease in the SOC pool[2]. Therefore, understanding the role of fire practice in grassland C budget is an important issue of environmental research in the event of climate change. The specific objective of the present study is to describe the C source/sink status of traditionally managed *Imperata* grasslands of Barak Valley, Assam, India. Keeping in view the role of annual fire practice in grassland management, the hypothesis tested was whether *Imperata* grasslands are the source of carbon or not.

The study was conducted in managed *Imperata* grassland in Rosekandy area of Cachar district, Barak Valley, NE India (24°41′N and 92°40′E, ca. 50 m amsl). The present grassland was originally a degraded tea plantation area. The size of the grassland is 1.2 ha. For the last 20 years this grassland has been managed for selling thatching material. Topography of the study area is undulating, dominated by small hillocks and low-laying waterlogged areas. Soil of the study area is acidic (pH = 4.5.0–5.2), with mean bulk density of 1.12 g cm^{-3}, water holding capacity of 35% and soil texture being silty clay loam. Woody tree species like *Balakata baccata*, *Macaranga peltala* and bamboo species (*Melocanna baccifera*) dominate the adjacent forest areas. The climate of the area is subtropical warm and humid with average rainfall of 2226 mm and average maximum and minimum temperatures 30.5°C and 20.3°C respectively.

Imperata grasslands in Barak Valley represented by *Imperata cylindrica*, are micro-scale in size (0.25–1.5 ha), being managed traditionally at individual level. These grasslands are inevitable to the rural dwellers for thatching material in traditional houses and also for monetary benefits which make them an important rural land use. Annual harvesting and fire practice are the foremost

*For correspondence. (e-mail: arunjyotinath@gmail.com)

strategies of traditional management of *Imperata* grasslands. Small growers harvest the grass at the end of winter when the growth is retarded, followed by fire management during February–March before rainfall begins (Figure 1). The low intensified fire produces partially combusted charred materials on the grasslands. Five permanent quadrats (50 cm × 50 cm) were laid in the grassland to study aboveground dead parts on the floor as litterfall at monthly intervals from October 2013 to September 2014. For belowground dead parts, sampling was done with soil corer up to 20 cm soil depth at monthly intervals with five replicates[16]. Soil samples were brought to the laboratory and necromass was separated based on colour and texture[16]. Sub-samples were oven-dried at 65°C, to obtain biomass content of above- and belowground dead parts. C concentration in each component was determined by muffle furnace[17].

Three randomly collected soil samples from 0 to 20 cm soil depth were used to prepare composite soil sample for SOC analysis. For bulk density analysis, soil samples were collected separately. They were collected on the first day of each month at monthly intervals from October 2013 to September 2014. Later, sampling periods were categorized under four distinct seasons, viz. autumn (October–November), winter (December–February), summer (March–June) and rainy season (July–September)[18]. Soil C concentration was determined by Walkley and Black's wet oxidation method[19]. Subsequently, SOC stock was calculated by multiplying the C content (%) by the bulk density (BD; g cm^{-3}) and the thickness of the soil horizon (cm).

C accumulation rate in the soil 0–20 cm (g m^{-2} $month^{-1}$) (A)
= [(soil C stock in grasslands in *n*th month) – (soil *C* stock in grasslands in (*n*th – 1) month)].

C input from aboveground parts (g m^{-2} $month^{-1}$)[20,21] (B)
= Aboveground mortality per unit time × C content of above ground parts (%)

$$\text{CIAB} = A\,(e^{k} - 1),$$

where *A* represents the aboveground dead parts and *k* is the decomposition rate of aboveground dead parts.

To find *k*, 120 nylon bags containing known weight of dead aboveground parts were placed in the study area, and five bags were collected every two weeks to determine the rate of decomposition.

C input from roots and rhizomes (g m^{-2} $month^{-1}$) (C)
= belowground loss by death and fallout[20] × C content of belowground parts (%).

Belowground loss by death and fallout[20] was estimated by the formula[21]

$$\text{Lo} = F(e^{k} - 1),$$

where *F* is the belowground necromass and *k* is the decomposition rate of belowground dead parts.

To find *k*, 120 nylon bags containing known weight of dead rhizomes and roots were buried in the study area, and five bags were collected every two-weeks to determine the rate of decomposition.

Measurement of soil CO_2 efflux (g C m^{-2} $month^{-1}$), (D)

was made at monthly intervals from 10 permanent chambers established in the field using the alkali absorption method of CO_2 by soda lime[22].

Thus,

Soil carbon budget (source/sink status) = $(A + B + C) - D$.

When $(A + B + C) > D$, *Imperata* grassland acts as C sink and when $(A + B + C) < D$, it acts as C source.

One-way ANOVA was performed to study the significant effect of seasons on variables (SOC, CIAB, CIBB and R_s) followed by Tukey's HSD analysis. Correlation was developed between SOC versus carbon input from aboveground biomass; SOC versus carbon input from belowground biomass and SOC versus soil respiration to assess the strength of the variations. Statistical analyses were performed using MS-Excel 10 and SPSS 15.

The seasonal SOC stock ranges from 23.02 to 25.54 g m^{-2} to 20 cm soil depth (Table 1). However, autumn and winter stocks were the same (23.02 g m^{-2}). This is because, after the rainy season SOC reaches an optimum level and remains there in the absence of external disturbances. SOC stock increases after winter fire and is highest in summer (25.54 g m^{-2}); it declines marginally during the rainy season (24.7 g m^{-2}). The seasonal variations in SOC content imply the influence of changing fire regimes on the grassland. The present measurements

Figure 1. Pictorial view of fire practices.

Table 1. Carbon budget data in relation to seasons in *Imperata* grasslands

Season	SOC ($g\ m^{-2}$)	SOC accumulation ($g\ C\ m^{-2}\ month^{-1}$)	CIAB ($g\ C\ m^{-2}\ month^{-1}$)	CIBB ($g\ C\ m^{-2}\ month^{-1}$)	R_s ($g\ C\ m^{-2}\ month^{-1}$)
Autumn 2013	23.02 ± 1.15^a	0	6.78 ± 0.54^a	30.98 ± 2.54^a	16.93 ± 0.68^a
Winter 2013	23.02 ± 1.29^a	0	0.436 ± 0.03^b	11.82 ± 0.89^b	13.93 ± 0.63^b
Summer 2014	25.54 ± 1.33^b	2.52	2.04 ± 0.14^c	22.34 ± 1.45^c	31.85 ± 1.59^c
Rainy 2014	24.7 ± 1.48^b	−0.84	14.31 ± 1.00^d	24.79 ± 1.74^c	29.06 ± 1.80^c

Values are mean ± SE. Different letters as superscripts refer to significant differences between the seasons at 5% level of significance. SOC, Soil organic carbon; CIAB, C input from aboveground biomass; CIBB, C input from belowground biomass.

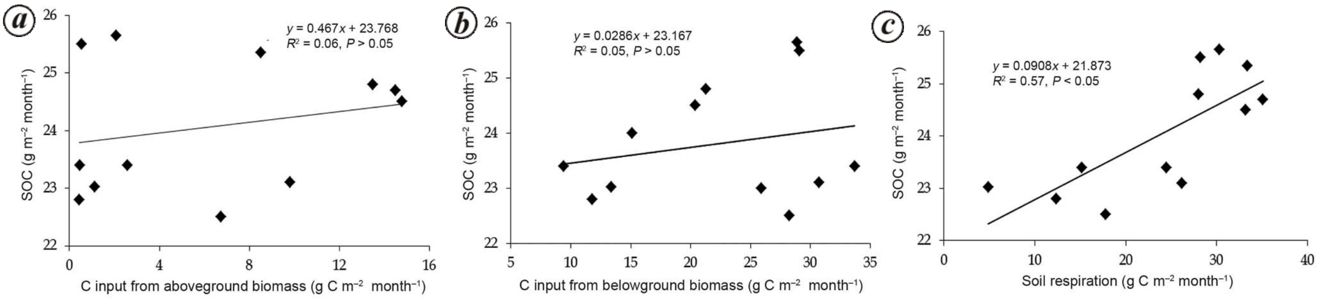

Figure 2. Correlation of soil organic carbon (SOC) versus carbon input from (***a***) aboveground biomass; (***b***) belowground biomass and (***c***) SOC versus soil respiration.

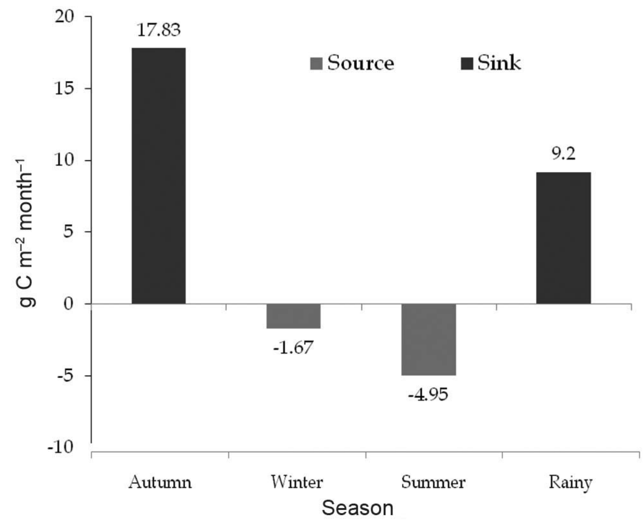

Figure 3. Source/sink status of *Imperata* grasslands with respect to seasons.

show 11% increase in SOC content in summer. This increase in C content after winter fire indicates the impacts of charred material produced during fire practices and its external input to the soil. In particular, the partially combusted charred material returns to the soil as particles smaller than 2 mm in the form of ash, which gets mixed in the top horizon[23], and causes a net increase in SOC content. Black C, the so-called charred material, is a fairly stable form of C that can accumulate in the soil[24]. However, the SOC content diminished by 6.8% during the rainy season. Run-off and wind erosion are the factors to erode C from the surface soil in post-fire regime[25]. Both the factors of enriching and diminishing SOC resulted in accumulation of $2.52\ g\ C\ m^{-2}\ month^{-1}$ in summer, whereas the other seasons showed no soil C accumulation. Correlation analysis of SOC with CIAB, CIBB and R_s (Figure 2) reveals that variation in SOC is significantly related with R_s. However, variation in SOC positively related with CIAB and CIBB is not statistically significant.

Rainy season showed the largest C input from aboveground biomass in *Imperata* grasslands. This input started declining from 14.31 to $0.44\ g\ m^{-2}$ in winter, although it increased a little in summer ($2.04\ g\ m^{-2}$). Litterfall and decomposition rate are the regulatory factors to induce seasonal variations in CIAB. As temperature increases, soil moisture assumes an increasingly important role for maintaining high rates of microbial activity[26,27]. Rate of fresh litter decomposition increases with both increasing temperature and precipitation[28], signifying a progressive inflation of CIAB from winter to rainy season and a drop in autumn as both temperature and rainfall decrease.

The C input from belowground biomass was the lowest in winter season ($11.82\ g\ m^{-2}$). Less CIBB in winter implies less humification of dead belowground biomass in the season, whereas it increased by 89% in summer. High necromass production in summer as an immediate post effect of fire and its rapid incorporation by humification in the soil with increasing temperature collectively favoured high rate of CIBB in summer. A considerable number of roots and rhizomes in the 5–20 cm soil depth indicates that dead root and rhizome decomposed *in situ*[25] and were the primary source of humic substances that gradually increased till autumn.

Mean soil CO_2 efflux was 22.94 g C m^{-2} $month^{-1}$ with highest value of 31.85 g C m^{-2} $month^{-1}$ in summer (Table 1). High root and rhizome density during the growing period coupled with fire effect on root production influence C efflux in summer and rainy season[29]. Lower respiration owing to less microbial growth caused slower microbial decomposition during the dormant periods of the year that minimized the winter soil CO_2 efflux by 56.3% from the peak value during the growing season. C budget with respect to climatic seasons (Figure 3) show *Imperata* grasslands as atmospheric C source of 1.67 g C m^{-2} $month^{-1}$ in winter, followed by 4.95 g C m^{-2} $month^{-1}$ in summer. Nevertheless, they serve as sink up to 17.83 and 9.2 g C m^{-2} $month^{-1}$ in autumn and rainy season respectively. Overall the *Imperata* grasslands act as a sink of 38.45 g C m^{-2} $year^{-1}$.

Although fire practice is integral to the *Imperata* grassland management system, on an annual scale, it serves as a sink of atmospheric CO_2. Therefore, *Imperata* grasslands have a negative feedback with respect to the global climate change. Annual soil C budget showed that *Imperata* grasslands can store 38.45 g C m^{-2} $year^{-1}$, which is equivalent to removal of 1.36 Mg CO_2 ha^{-1} $year^{-1}$ from the atmosphere. Traditionally managed *Imperata* grassland in Barak Valley can provide an opportunity towards low C development approaches and a climate change mitigation strategy at the community level. Further research with improved management systems can enhance sink capacity of *Imperata* grasslands.

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