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Research article

# Carbon sequestration and $CO_2$ mitigation in a burned ecosystem of *Pinus roxburghii* forest in Langtang National Park, Nepal

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**Abstract:** Carbon (C) sequestration plays a significant role in mitigation and adaptation to the impacts of the climate change. By contrast, fire is one of the factors that can alter the carbon cycles. Extensive fire destroyed the whole forest severely and affects C sequestration. However, the impact of the surface fire has been least studied. To test the impact of surface fire on C sequestration of *Pinus roxburghii* forest, we measured total carbon stock of unburned (CON) and burned sites of different intensities namely: high frequency and high intensity (HFHI), high frequency and moderate intensity (HFMI), high frequency and low intensity (HFLI), in Langtang National Park, Nepal. Total tree carbon stock (above ground + below ground) was analyzed by calculating the biomass. Coverage of ground vegetation (%) was analyzed by visual estimation. The total carbon stock between the species was highly significant *(P=0.00)* and the highest carbon stock value was recorded in *P. roxburghii* species in all sites. Similarly, total $CO_2$ mitigation in all four sites according to higher to lower values were 3346.27, 3345.16, 2484.14 and 2037.95 t.ha$^{-1}$ in HFMI, HFHI, HFLI and CON, respectively. The high amounts of $CO_2$ mitigate by HFHI and HFMI sites strongly support that forest fire limited to the surface may have a positive impact. High ground vegetation in HFMI site also suggested that the fire of medium intensity mitigate $CO_2$ and maintains the diversity of ground vegetation as well.
**Keywords:** Carbon stock - Climate change - Fire intensity - Ground vegetation - Surface fire.

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## INTRODUCTION

Human activities, especially the burning of fossil fuel, deforestation, have caused a substantial increase in the concentration of carbon dioxide ($CO_2$) in the atmosphere and leading to global warming. Green plants capture $CO_2$ from the atmosphere through the natural process of photosynthesis and store carbon for a long time called C sequestration (Watson *et al.* 2000). The $CO_2$ is naturally stored in above ground biomass (trees, shrubs, herbs, etc.), below ground parts (root, micro-organisms, etc.) and also in soil (Adam 2001). This is one of the effective techniques for mitigating the atmospheric $CO_2$ levels (Jina *et al.* 2009). Simultaneously, green plants also release $CO_2$ through the process of respiration and microorganism by decomposition to the atmosphere. These carbon gain and loss processes are continuing in nature.

Forest covers more than one-third of the world's land area and constitute the major terrestrial carbon pool (Roberntz & Sune 1999). Tree growth serves as an important means to capture and store atmospheric $CO_2$ in vegetation and biomass products; about half of its standing biomass is carbon itself (Ravindranath 1997, Petsri *et al.* 2007, Terakunpisut *et al.* 2007, Adhikari 2011). It is estimated that the world's forests store 283 Gt of carbon in their biomass alone (Anon 2005). In growing season, plants uptake large amount of $CO_2$ from the atmosphere and converted into biomass (Losi *et al.* 2003, Samalca 2007, Deo 2008, Adhikari 2011), which in turn mitigates the level of $CO_2$ in the atmosphere. Atmospheric $CO_2$, contributed from different medium including biological sources, is a primary Green House Gas (GHG) and its concentration in the atmosphere has


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been increasing steadily since 1958 (Keeling *et al.* 1989, Kumar *et al.* 2013), due to fossil fuel combustion, cement manufacture, land use, deforestation, etc. The level of $CO_2$ in today's atmosphere is 31% higher than it was at the start of the Industrial Revolution about 250 years ago (IPCC 2007). Similarly, atmospheric levels of $CO_2$ have risen from 280 ppm at the pre-industrial era (1750) to the present level of 385 ppm (WMO 2008). Because of the increase in the concentration of $CO_2$, mean earth's temperature has already increased by 0.6±0.2 °C, and is projected to increase by 2–4 °C towards the end of the 21$^{st}$ century (IPCC 2007). These increases global warming will result in climate changes like sea level rise, increased frequency and intensity of wildfires, floods, drought, unusual rain, snow, etc.

Nepal's contribution to the global annual GHG emission is 0.025% (MoPE 2004). The total GHG emission from Nepal is estimated at 39,265 Gega gram (Gg) and per capita emission is 1,977 kg (GoN 2008a). Over the last twenty-five years, the temperature in Nepal has also been increasing at the rate of 0.06°C per year (GoN 2008b). In high altitudes, it increased by 0.6°C over the last thirty years (Liau & Rasul 2007). In Nepal, $CO_2$ emissions are those stemming from the burning of fossil fuels and the manufacture of cement (http://data.opennepal.net-/content/carbon-dioxide-emissions-nepal).

In Nepal, the forest is frequently under fire and considered as one of the dominant disturbances generally repeats every year during dry seasons (visual observation). Additionally, the frequency and intensity of fire in protected and non-protected areas differ significantly (local communications and visual observation). In protected areas usually controlled fire has been practiced by the authorities, however, in non-protected areas and sometimes in protected areas it happens accidentally or intentionally. It is well-known fact that forest fire causes a change in the vegetation composition (Romanya *et al.* 2001, Mackenzie & DeLuca 2006), damages flora, fauna, human livelihoods, local climate change every year and also change the carbon sequestration.

Carbon sequestration and reduction of emission are the major mitigative options to reduce the consequences of climate change (IPCC 1995). It was observed that the maximum carbon is stored in the order of conifers>deciduous>evergreen>bamboos (Negi *et al.* 2003). Among conifers *Pinus roxburghii* Sarg. forests perform maximum C sequestration (Negi *et al.* 2003, Sheikh & Kumar 2010, Panthi 2011, Afzal & Akhtar 2013). In contrast, high concentration of resin in its tree trunk and needles make the plant more sensitive to fire (Paudyal 2008, Kumar 2015), however, the quantity of destruction mainly depends on the intensity of the fire. It is also observed that *P. roxburghii* forests are still surviving after surface fire (visual observation, local communication). In this background, we hypothesized that surface fire has a low impact on forest structure and C sequestration. Therefore, the present study focused on determining the status of tree C stock of various surface fire intensities in a burned affected ecosystem to provide total $CO_2$ mitigation in burned ecosystem of *P. roxburghii* forest.

## MATERIALS AND METHODS

*Study area*

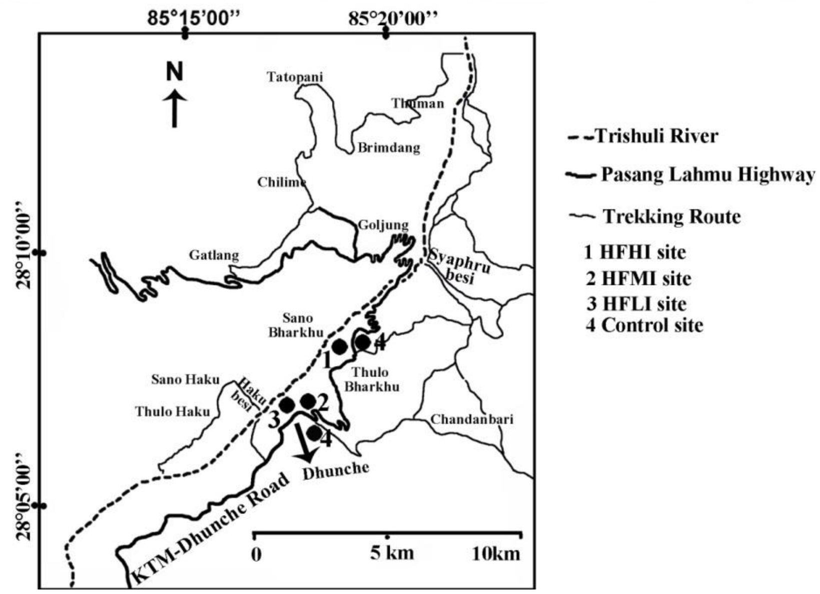


**Figure 1**. Study area in Langtang National Park showing four sites in black dots (Dhunche and Syapru VDCs of Rasuwa).

The study was carried out in Langtang National Park, Rasuwa district, Central Nepal. The district lies in between 27° 55' to 28° 25' N latitude and 85° 00' to 85° 50' E longitudes (Fig. 1). The altitude ranges from 617 m to 7,227 m within 1,512 $km^2$. It encompasses three distinct geographical zones: the Himalaya, the mid hill and basin. Mid hill and basin covers less area but the productive land lies in this region. According to the interview with park authorities, local people and also the visual observation of forest fired conditions, the *Pinus roxburghii* forest of Dhunche (headquarter of Rasuwa District) and Syapru VDCs (Village Development committee) of Rasuwa District were selected for the study. Sites 2 and 3 are located in Dhunche VDC (28°6'42" N, 85°17'52" E, 2,030 m) while sites 1 and 4 are selected from Syapru VDC (28°16'80.47" N, 85°32'90.87" E, 1,352 m) (Fig. 1).

*Vegetation*

The vegetation of the *P. roxburghii* forest in both selected VDCs was dominated by tree species like *P. roxburghii*, *Rhododendron arboreum* Sm., *Lyonia ovalifolia* (Wall.) Drude, etc. Similarly, understory was occupied by saplings of *Pinus roxburghii*, *Rhododendron arboreum*, *Lyonia ovalifolia*; shrubs like *Indigofera cassioides* DC., *Inula cappa* (Buch.-Ham. ex D.Don) DC., *Desmodium* sp., *Salix* sp., *Berberis aristata* DC. and *Rubus ellipticus* Sm., etc. Ground vegetation are dominated by *Ageratina adenophora* (Spreng.) R.M.King & H.Rob., *Anaphalis* sp., *Artemesia* sp., *Aconogonum* sp., *Anaphalis* sp., *Arisaema* sp., *Bidens bipinnata* L., *Calicarpa* sp., *Capillipedium* sp., *Carex* sp., *Cyprus* sp., *Dryopteris* sp., *Hypericum* sp., *Melastoma* sp., *Persicaria capitate* (Buch.-Ham. ex D.Don) H.Gross, *Trifolium repens* L., *Selaginella* sp., etc.

*Climatic conditions*

The climate of Nepal falls within the monsoon system of the Indian subcontinents with dry periods in the winter and wet periods in the summer. More than 80% of the rainfall occurs during the four summer months (June to September). Mean maximum temperature of the study area was 24.52°C during the June and mean minimum air temperature was 2.26°C in January. Similarly mean maximum precipitation was 593.45 mm in July, minimum in December (6.6 mm). These values are mean from 1999 to 2013 AD (Department of Hydrology and Metrology, Nepal Government).

*Site selection criterion*

Key informants who have knowledge about the issues and an idea about the sites were requested to prepare a community map including different intensity burned affected forest ecosystem. With the help of community map, forest sites were surveyed with the local people. After visiting the surface burned affected forest, three sites were classified on the basis of frequency (fire event within a time period) and intensity (fire severity) of surface fire and one site as a control. The sites were categorized as high frequency and high intensity site (HFHI), high frequency and moderate intensity site (HFMI), high frequency and low intensity site (HFLI), and a control (unburned) site, after collecting the basic data of height of ground vegetation (Armour *et al.* 1984), charcoal accumulation on ground (Turcios *et al.* 2016), needle accumulations, fired level on tree trunks of Pine and other species (Fire Science Brief 2009), presence of olive trees (James *et al.* 1985), coverage of bare land, number of burned species etc. The criterion has been summarized as below:

**a)** *High frequency and high intensity (HFHI) site*: Characterized by low canopy coverage (22%) of ground vegetation (Fig. 2), total ground coverage lower than in control, site affected by annual surface fire events during dry season (according to park authority, local communication, visual observation) and remains of burned needles and bark on the ground, burned stumps and even trunk of pine tree up to 4 meters.

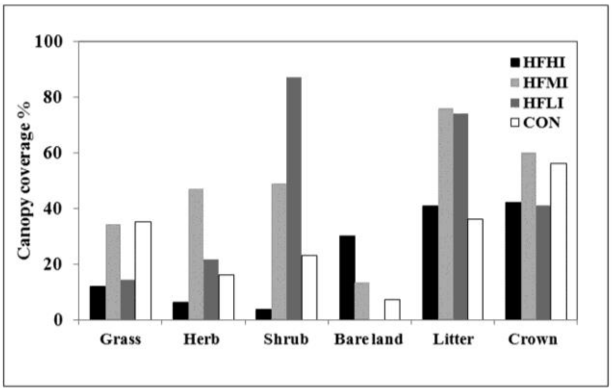


**Figure 2**. Canopy coverage (%) of ground vegetation, litter, bare land and crown coverage of all sites.

**b)** *High frequency and moderate intensity (HFMI) site*: The site was occupied by higher canopy of understory (131%) than high-intensity site. Although, the impact of fire has been observed on the stem of ground vegetation as well as on the trunk of *P. roxburghii*, regenerating young leaves on ground vegetation suggested the low severity of fire (Fig. 2).

**c)** *High frequency and low intensity (HFLI) site*: Characterized by the vigorous growth of understory species and burned have been observed at the base of mature trees. The site has almost similar features with HFMI site except for the height of the understory, which was up to 2m and the value of shrub coverage (87%) and litter accumulation (74%) was higher with negligible damage (Fig. 2).

**d)** *Control (CON) site*: The control (unburned) site has been supported by high coverage of species, the absence of bare land (Fig. 2), almost no charcoal accumulation, and luxuriant growth of epiphytes (data not shown).

*Sampling*

Random sampling method was used for sampling the above ground (AG) vegetation. Five replicates of the sampling plots were surveyed in three burned sites and four replicates in control site. The sampling was done in August to September 2015 with the help of 3 nested circular plots of radii 10 m, 5 m and 2.5 m for trees, saplings, shrubs, respectively (FRA 2011). Similarly, for the ground vegetation 1m × 1m plots were laid down within the main plots (Fig. 3). For carbon (C) analysis, plant species having DBH >10cm and height >1m was considered as a tree. To calculate the coverage (%) of understory vegetation, plant species having height of <1m was considered as shrubs (Shrestha & Singh 2008) and DBH <10cm was considered as sapling.

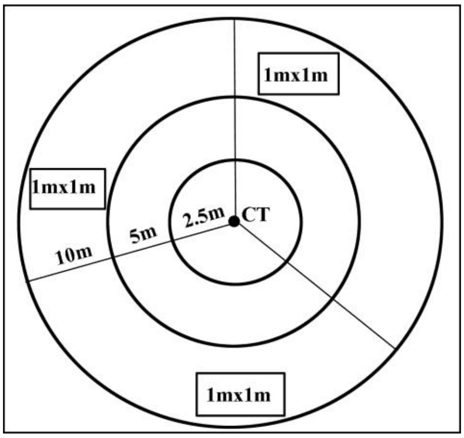


**Figure 3**. Showing plot design - CT - Central tree, 10 m, 5 m and 2.5 m circular plot for trees, sapling and shrub respectively and 1 m × 1 m for grass and herb (FRA 2011).

*Tree diameter at breast height and tree height*

Diameter at breast height (DBH) of each tree within each plot was measured using DBH tape, and height of each tree was calculated using Sunto Clinometer. Plants were identified by consulting literature and photographs.

*Above ground biomass (AGB) estimation*

The AGB of the tree includes the wood, branches, leaves, barks, etc., were measured by following methods:

**a.** *Volume*: Volume of the trees were calculated by $\pi r^2 h$.

**b.** *Biomass of wood*: The biomass of wood was calculated following the method given by Chaturvedi & Khanna (1982). Biomass of branch and foliage were calculated by MPFSN (1988).

*Below ground biomass (BGB) estimation*

The BGB includes all biomass of live roots. The below ground biomass has been calculated following Oli & Shrestha (2009).

*Carbon analysis*

Above ground carbon (AGC) like wood, branch and foliage carbon were analyzed according to Negi *et al.* (2003). The below ground carbon (BGC) has been calculated by Oli & Shrestha (2009).

*$CO_2$ mitigation ($t.ha^{-1}$)*

$CO_2$ mitigation was calculated by the method adopted by Bhattarai *et al.* (2012).

*Statistical data Analysis*

The significance of differences in AGC and BGC stock between sites was evaluated by one way ANOVA and Duncan's multiple range tests by using SPSS software (SPSS Inc., Chicago, IL, USA).

## RESULTS

*Ground Coverage*

Highest canopy coverage (%) of ground vegetation (grass, herb, shrub, etc) was observed in HFMI site while lowest in HFHI site. HFLI site was characterized by the vigorous growth of shrub coverage (87%) was highest than other sites. Similarly, highest coverage (35%) of grass species was recorded in CON site as well as HFMI (34.5%). Lowest grass coverage (12%) was recorded in HFHI site (Fig. 2).

*Above ground carbon (AGC) stock*

Among the 4 sites, the maximum mean value of AGC for *P. roxburghii* is observed in HFMI (704.78±160.13 t.ha$^{-1}$) and the minimum mean value was for CON (445.72±198.83 t.ha$^{-1}$). The minimum mean value of AGC was observed in the associated species like *R. arboreum* (2.97±1.76 t.ha$^{-1}$) in HFMI, *L. ovalifolia* (6.38±2.66 t.ha$^{-1}$) in HFHI. The AGC stock between the species was highly significant *(P=0.00)* while within the species was insignificant at all sites (Fig. 4).

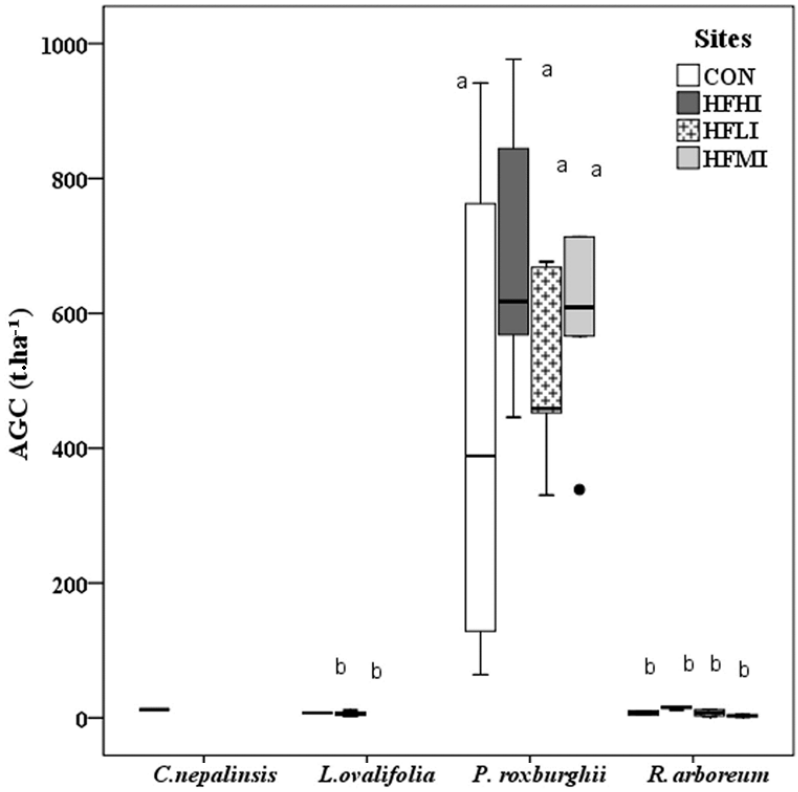


**Figure 4.** Above ground carbon stock (t.ha$^{-1}$) of all investigated species in all sites. The box plots show the median, and 25 to 75 percentile. Whiskers indicate maximum and minimum values. Different letter denotes the highly significant difference between the species tested by Duncan multiple range tests at (*P<0.05*).

The mean value of total AGC stock of *P. roxburghii* forest was maximum in HFMI (705.96±160.43 t.ha$^{-1}$), followed by HFHI (703.37±97.80 t.ha$^{-1}$) and HFLI (523.17±67.11 t.ha$^{-1}$). The lowest value was recorded in CON (454.35±198.59 t.ha$^{-1}$) (Fig. 5). There was the insignificant difference *(P=0.472)* between the total above ground carbon stock and fired sites tested by one way ANOVA.

*Below ground carbon (BGC) stock*

The mean value of BGC for *P. roxburghii* was maximum in HFMI (206.30±46.44 t.ha$^{-1}$) and minimum in CON (131.70±56.98 t.ha$^{-1}$). The minimum mean value was also observed in other associated species like *L. ovalifolia* (1.66±0.84 t.ha$^{-1}$) in HFHI, and *R. arboreum* (2.21±0.81 t.ha$^{-1}$) in HFLI. Likewise, the AGC stock and BGC stock also showed the highly significant difference in mean values between the *P. roxburghii* and associated species (Fig. 4 & 6).

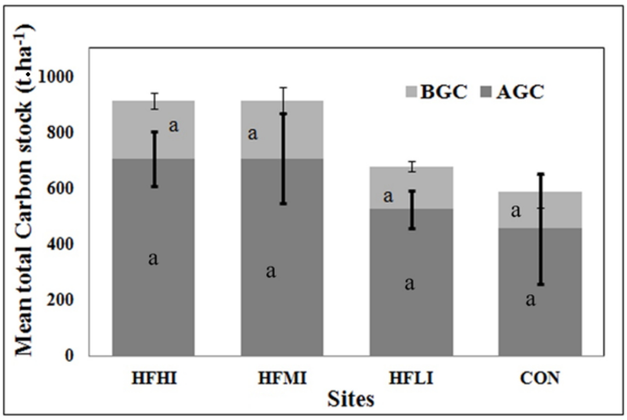


**Figure 5**. Total Carbon stock of AGC and BGC from different sites. The Same letter indicates insignificant difference tested by Duncan multiple range tests. Error bar showed ±SE (N=7-11).

The mean maximum value of total BGC stock of *P. roxburghii* forest was recorded in HFHI (208.94±27.55 $t.ha^{-1}$) followed by HFMI (206.65±46.53 $t.ha^{-1}$) and HFLI (154.31±19.47 $t.ha^{-1}$). The lowest value was recorded in CON (133.81±57.10 $t.ha^{-1}$) (Fig. 5). One way ANOVA analysis showed there was the insignificant difference (*P=0.450*) of total BGC stock between the sites.

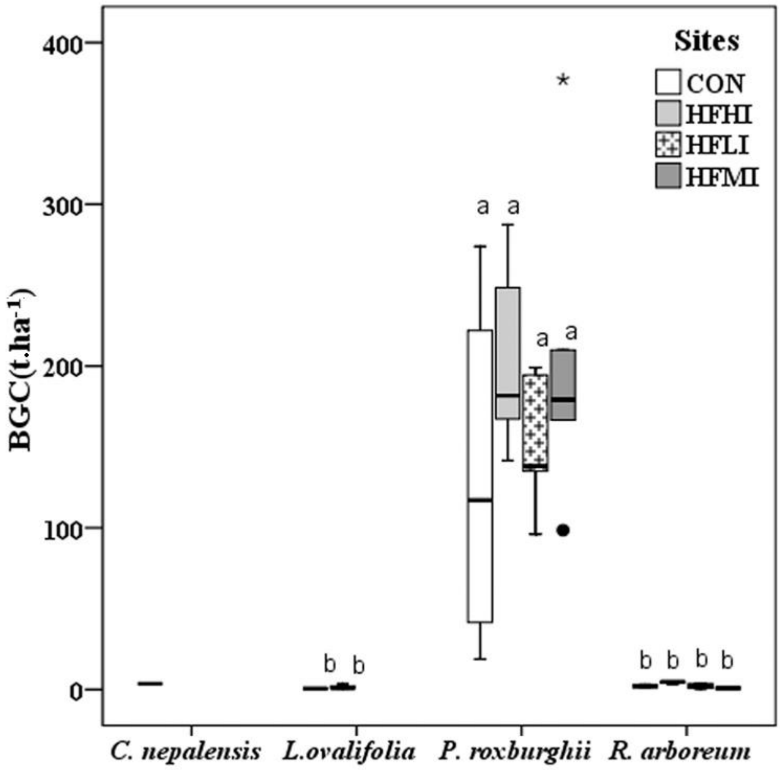


**Figure 6.** BGC stock ($t.ha^{-1}$) of all investigated species in all sites. The box plots show the median, and 25 to 75 percentile. Whiskers indicate maximum and minimum values. Different letter denotes the highly significant difference between the species tested by Duncan multiple range tests (*P<0.05*).

*$CO_2$ mitigation ($t.ha^{-1}$)*

Our measurement showed that the $CO_2$ mitigation value by vegetation (above ground + below ground) in *P. roxburghii* forest followed similar trend with mean total carbon stock. It was higher in both HFMI (3346.27 $t.ha^{-1}$) and HFHI (3345.16 $t.ha^{-1}$). The minimum in CON (2037.95 $t.ha^{-1}$), the intermediate value was in HFLI (2484.14 $t.ha^{-1}$) (Fig. 7).

## DISCUSSION

Fire is one of the factors that have negative impacts on C sequestration, although, it depends on the intensity of the fire. We have selected two VDCs of Langtang National park, where 90% of the pure *Pinus roxburghii* forest set on fire during dry season (visual observation). Although, local climatic conditions affect the annual fire behavior in *P. roxburghii* forest of Langtang National Park, various climatic agents like temperature, relative humidity, and precipitation affect fuel moisture on the forest surface. The long, hot and dry summers that last from February until May convert the Pine understory into a continuous sheet of dry and highly inflammable fuel load (IFFN 2005). The rainfall during the dry season is very low and range between 44.48 to 103.69 mm. During the dry season, the maximum temperature fluctuates from 15.25°C to 23.69°C (Data not shown) increasing the risk of ignition to high levels. Similarly, sometimes wind and its direction are also dominant factors for fire intensity.

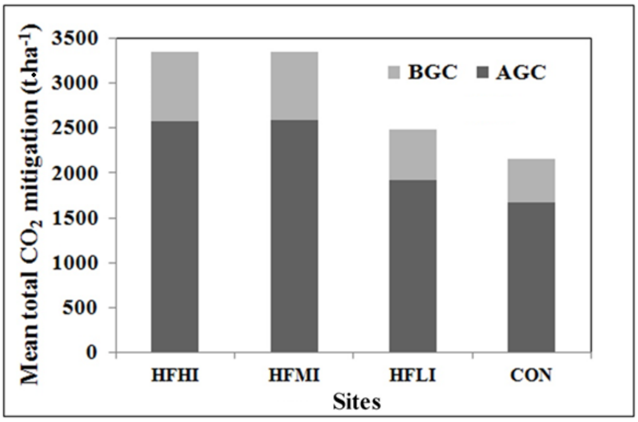


**Figure 7.** Mean total $CO_2$ mitigation (AGC+BGC) from different sites.

In fired *P. roxburghii* forest of the present study, the highly significant difference between the species in terms of C sequestration has been observed. The maximum mean value was observed in *P. roxburghii* among all three fired sites. Minimum mean value observed in associated species like *Rhododendron arboreum* and *Lyonia ovalifolia*. The study carried out by previous authors (Panthi 2011, Afzal & Akhtar 2013) in unfired mixed *Pinus roxburghii* forest reported maximum value for *P. roxburghii* similar to present study; however, there is a significant difference between the values of other associated species. In our study, the numbers of associated species were less compared to unburned forests. Therefore, the differences may be due to frequent annual fire on forest surface in the study area which allows only the growth of fire prone species like *P. roxburghii* but affects associated species. The study carried out by James *et al.* (1985) suggested that low intensity fires on lodgepole pine stands have no serious damage. Similarly, *P. roxburghii* has several fire-adaptive traits that enable mature trees to survive on low-intensity surface fires (Tiwari 1994, Semwal & Mehta 1996, Sangye 2005). The survival of *P. roxburghii* after burned of outer bark up to 1–4 m height in low-high intensity burned sites observed in the present study further justified its fire resistant nature. Among the three burned sites the total C Stock showed no significant difference. However, the highest values were observed in HFMI and HFHI sites and lowest in CON site. Highest value in HFMI, HFHI could be because of the highest number and age (girth) of *P. roxburghii* in these sites than CON *i.e.* with maximum young trees.

The intensity of fire determines the growth of ground vegetation. In high-intensity sites, there is maximum loss of ground vegetation (Armour *et al.* 1984), however luxuriant growth of shrubs occurs in medium and low-intensity sites (Fire Science brief 2009). Among the three burned sites of the present study similar results has been observed. It is possible because herbaceous plants propagate through seeds are highly affected by forest surface fire than the plants propagate through rootstocks or rhizome (underground). However, the situation is different for shrubs and saplings; only fire prone species can grow in such conditions. The reason of the luxuriant growth of shrubs (*Indigofera cassioides*, *Inula cappa*) in medium and low intensity burned sites may be due to its capacity to grow even after burning. The overall results of ground vegetation suggested that burned of any intensity can change the diversity of the species.

The increased amount of $CO_2$ in the atmosphere is a global concern and considered as one of the reasons for changed climatic conditions due to an increase of temperature. Mitigation of $CO_2$ by green plants using the machinery of photosynthesis is the easiest and inexpensive natural pathway. However, the rate of photosynthesis *i.e.* capacity to mitigate $CO_2$ may vary among the different species (Devi *et al.* 2013). Of them, conifers are regarded as one of the efficient plants to mitigate $CO_2$ (Negi *et al.* 2003). However, disturbances such as deforestation as well as fire are recognized as a driver of climate change. In our study, total $CO_2$ mitigation was found highest in HFMI, HFHI and lowest in CON site. Highest $CO_2$ mitigation in HFMI and then HFHI suggested that in the case of *P. roxburghii* forest the fire of high to medium intensity limited to the forest surface has a positive impact on $CO_2$ mitigation.

### CONCLUSIONS

Forest surface fire only encourages burned up to a certain height of the tree trunk without damaging *Pinus roxburghii* trees, sequestrate more C and sink as a long term C pool which increased the rate of $CO_2$ mitigation ultimately reduces $CO_2$ from the environment. Therefore, we concluded that the controlled forest surface fire is beneficial to the global carbon mitigation in case of *P. roxburghii* forest. The study conducted on three different fire frequency and intensity sites suggested that in terms of $CO_2$ mitigation, both HFHI and HFMI fire condition are best. However, HFHI site with low ground vegetation with few species suggested that high-intensity surface fire reduces the overall diversity because only fire prone species can grow in such areas. Therefore, the intensity of the fire in *P. roxburghii* forest can minimize either by removing the fuel load (litter) from the forest surface or by increasing frequency of induced forest surface fire in control manner.

Finally, the fire of high to medium intensity showed positive impacts on $CO_2$ mitigation by maintaining *P. roxburghii* forest and ultimately essential for conservation and management of these forests. Therefore, regular monitoring of this forest is necessary to induce control fire in manage form to increase $CO_2$ mitigation by increasing sequestration and maintaining the diversity of the area as well.

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