CHAPTER-5

DISCUSSION

DISCUSSION

Findings of the present investigation are discussed below:

5.1. Objective 1: To study the seasonal and annual variation of CO_2 flux and changes in atmospheric CO_2 concentration.

5.1.1. Variation of CO_2 concentration at different heights during the growing season:

CO_2 concentration of only growing period (February, 2016-April, 2016) are presented to understand the effect of canopy photosynthesis on atmospheric CO_2 concentration at different heights of canopy (fig 4.1.1-4.1.2). During the three months of observation, it has been observed that CO_2 concentration was higher at 2 meter height compared to other levels. The higher concentration recorded at 2 meter attributes to the addition of CO_2 released from the soil, ground flora primarily weeds and herbs to atmospheric CO_2. Irrespective of the heights higher CO_2 concentration was observed during night compared to day hours which is due to respiratory CO_2 release by the plants during night and CO_2 absorbed by the plants during the day time for photosynthesis [1]. Irrespective of heights high CO_2 concentration were recorded during morning hours which might be due to the flushing of stored CO_2 in the morning after development of strong atmospheric turbulence [2, 3, 4]. The nighttime CO_2 concentration was found to decrease with the increasing measurement heights. During night highest CO_2 concentration was recorded at 2 meter height and least was recorded at 37 meter as the influence of CO_2 efflux on CO_2 concentration becomes smaller with increase in height of the measurement [5].

5.1.2. Monthly variation of CO_2 concentration above the forest canopy:

Gradual decrease in CO_2 concentration above the canopy from Feb, 2016 to April, 2016 (fig 4.1.3) may be attributed to gradual increase in LAI from February to April which increased the CO_2 absorption rate of the canopy for photosynthesis. High peak of CO_2 concentration 403.62 $\mu mol\ mol^{-1}$ has been observed in June, which might be because of higher emissions of CO_2 from wet soil [6, 7] caused by high monsoonal rain. From the month of July to November, fluctuating trend in average CO_2 concentration (between 382.09 $\mu mol\ mol^{-1}$ to 394.13 $\mu mol\ mol^{-1}$) has been recorded due to impact of flood events on CO_2 efflux and photosynthetic efficiency of the plants. Average CO_2 concentration increased in December compared to November due to decrease in leaf area index in December which reduced to photosynthetic CO_2 absorption of the canopy. Average CO_2 concentration decreased again in the month of January, 2017 (394.59 µmol mol^{-1}) compared to December, 2016(401.69 µmol mol^{-1}) perhaps due to lower CO_2 emissions from dry soil. Lower CO_2 efflux during winter was also reported by Wangdi et al., [8] in a study on soil CO_2 flux over two different forest ecosystems of Bhutan.

5.1.3. Variation of CO_2 flux above the canopy:

Diurnal variations of CO_2 flux (monthly mean) for the whole period of study are depicted in fig 4.1.4. The monthly variation of CO_2 flux in fig 4.1.4 is very clear and distinct. Conventionally, net CO_2 uptake by the ecosystem is indicated by negative sign and the positive sign indicates net release of CO_2 to the atmosphere. Peak negative CO_2 flux of -9.97 µmol m^{-2} s^{-1} was observed in the month of June around noon hours with the beginning of the monsoon season. Our estimates of peak net CO_2 uptake (≈-10 µmol m^{-2} s^{-1}) is on the lower side compared to other studies on temperate deciduous forests [9, 10, 11]. The CO_2 uptake by the ecosystem gradually increased from winter season (February) to the beginning of monsoon season (June). Similar pattern of seasonal variation of CO_2 fluxes were reported by Proutsos et al., [12] over a deciduous forest in Greece. From the month of July to October irregular pattern in diurnal variation of CO_2 flux was observed and from November to January CO_2 uptake by the ecosystem decreased gradually. Similar kind of seasonal impact on CO_2 fluxes was observed by Hirano et al., [13] in a larch forest of northern Japan. Thus, the monthly and seasonal variation in CO_2 flux of KNP was due to seasonal change in phenology and climate of the semi deciduous forest.

5.2. Objective 2: Investigation and analysis of the factors regulating the seasonal and diurnal variations of CO_2 concentrations and fluxes.

5.2.1. Meteorological parameters and radiation:

In the present investigation four seasons were studied winter (December, January and February), pre-monsoon (March, April and May), monsoon (June, July, August and September) and post monsoon (October and November) and the seasonal interpretation of the results are discussed below. Diurnal variations of monthly mean air temperature (fig 4.2.1 a) indicated summer as the warmest season and winter as the coldest season. Higher temperature in summer is caused by more incoming short wave radiation in Northern hemisphere [14]. Recorded relative humidity in the forest (fig 4.2.1 b) showed very high humidity values in the autumn season. Humidity recorded during the winter season was very low. Wind speed was very high during pre-monsoon season especially in the month of April (fig 4.2.1 c). Over the whole annual cycle of study large amount of rainfall was received by the site during the month of April before the arrival of monsoon. The Northeastern part of India gets affected by Nor'westers from the month of March to May, as a result this part receives high rainfall events during this period [15, 16]. During the monsoon season, the amount of rainfall received by the site was 55 % of total rainfall recorded over the period of observation (fig 4.2.1 d). The net radiation was observed to be negative during the night time because the outgoing longwave component of radiation is higher than the other components of radiation. The net radiation started to become positive (fig 4.2.4) at different times during different months of the year (between 0500 to 0630 hours), as a result of seasonal change in sunrise time in this part of the globe. Similar kind of variation in net radiation was also observed by Anthoni et al., [17] and Bisht et al., [18] over different surfaces. The observed photosynthetically active radiation (PAR) inside the forest varied (fig 4.2.4) in a similar way following the pattern of net radiation because PAR is a part of incident radiation with its wavelength varying between 400 nm to 700 nm and the results are in agreement with [19].

5.2.2. Leaf area index:

Leaf area index (LAI) is a parameter which quantifies the amount of leaf present in the canopy and it regulates the biological productivity of plants [20, 21]. The measured LAI of the forest canopy was very low during the winter season (table 4.2.1) due to cold and dry condition as well as due to leaf abscission. The LAI started to increase from the month of March with the arrival of rain and increase in temperature [22]. LAI of the forest canopy started to increase from the beginning of the spring and attained maximum during the summer, since this period is favorable for the physiological growth of plants. The measured LAI decreased in the autumn season due to senescence and abscission process of leafs [23]. The measured LAI values of KNP are very near to the LAI values of a temperate deciduous forest reported by Saigusa et al., [11], they reported LAI of 3 to 4 during the peak leaf growth periods of the forest. The seasonal changes in LAI of KNP forest can have the direct impact on the atmosphere –biosphere flux dynamics and thus plays a vital role in net ecosystem productivity [24].

5.2.3. Atmospheric turbulence and stability:

One of the most important criteria for generation of high quality eddy covariance data is development of full turbulence [25]. Turbulence parameters u* and σ_w has been used to picturize (fig 4.2.6 a-f) the changes in atmospheric turbulence during different seasons of the year. Considering the data from a complete one year it has been seen that occurrence of lower turbulence events ($u*$ and σ_w <0.2 m s^{-1}) is the highest ($u*$ ≈52% and σ_w ≈44%). Seasonal variation of u* and σ_w (fig 4.2.6 a, b) indicates that the atmosphere was very calm during the post monsoon and winter season. Due to the strong wind flow and phenomenon of surface heating, occurrence of high turbulence events were more during pre-monsoon season. Night time data of u* and σ_w (fig 4.2.6 d-f) indicates that the winter and post monsoon nights are the calmest as compared to other seasons. Stability parameter (z-d)/L have been used (fig 4.2.7 a-c) to study the seasonal variation of atmospheric stability in different classes. It has been found that during complete one year cycle (fig 4.2.7 a) the atmosphere was in moderately unstable conditions followed by stable state. Similar kind of temporal variation of atmospheric turbulence and stability conditions was observed by Barr et al., [26] over boreal forest ecosystems in Canada. In our study, we used the turbulence parameter friction velocity as the standard parameter to identify the lower mixing condition and to reject the data of those periods as reported by Zeri et al., [27].

5.2.4. Surface fluxes:

The available net radiation gets converted in to latent heat flux (LE) and sensible heat flux (H). The diurnal pattern of variation of LE and H (fig 4.2.8) followed the similar pattern as net radiation (Rn). Peaks of LE and H were seen during the midday when the net radiation was maximum. From the starting of the experiment (February) up to the month of December more energy was portioned as LE than H because of high evapotranspiration from the forest. Contrastingly, in the month of January the observed H was higher than LE. Similar kind of wet and dry season variation in energy partitioning has also been reported by Sanwangsri et al., [28] in a dipterocarp forest of western Thailand. The reason behind this reverse result was the dryness of the soil and lowest LAI of the forest canopy in the month of January. The diurnal peaks of LE were seen to increase in a continuous pattern from February to April due to continuous growth of surrounding vegetation as well as high soil moisture condition caused by higher rain fall events effected by Nor ’westers [29]. The continuous growth of the vegetation is clear from the continuous increase in LAI from February to April (table 4.2.1). In the following two months from May to June the diurnal peaks of LE were less than the month of April which might have been caused by less evaporation rates due less rainfall on the site compared to April indicated by rainfall data (fig 4.2.1 d). The observed diurnal peak was also very less in July, this might be due to less radiation received by the ecosystem and fluctuation of incoming radiation due to cloudy sky [30].

5.2.5. Energy balance closure:

Energy balance closure of the site has been estimated using the average values of net radiation (Rn), soil heat flux (G), latent heat flux (LE) and sensible heat flux (H). Using half hourly average of the above data the estimated energy balance closure of our site was found to be 78% (fig 4.2.10 a). Wilson et al., [31] carried out a comprehensive study over diverse ecosystems and climatic zone on energy balance closure of 20 FLUXNET sites. They found that energy balance closure ranged from 53 to 99% in different ecosystems. Our estimated energy balance closure of 78% is well within the range reported by Wilson et al., [31]. This indicates reliability of eddy covariance flux data generated from the tower inside KNP. The energy imbalance of 22% is expected to increase by some amount with the inclusion of storage terms [32, 33, 34]. Energy balance closure of the forest has also been estimated using daily averaged data of Rn, G, H and LE (fig 4.2.10 b). It has been observed that uses of daily average of data on the energy balance equation closure improved to 85%. Improvement of energy balance closure after using daily average of data compared to hourly data are reported from other studies and our results are well corroborated with Saigusa et al., [11]. Analysis of energy balance closure in different turbulence and stability conditions has been shown in fig (4.2.11-4.2.13). Energy balance closure was poor in low turbulent conditions ($u^*<0.2$ m s^{-1} and σ_w <0.4 m s^{-1}). Improvement of closure has been noticed with the increase in atmospheric turbulence. At very high turbulence (u^* and $\sigma_w > 0.8$ m s^{-1}), the closure crossed 90% (fig 4.2.11-4.2.12). Similar effect of turbulence on energy balance closure are reported by other researchers [31, 32, 35]. Energy balance closure has also been stratified in different classes of atmospheric stability. In moderately unstable state ($-1< (z-d)/ L<-0.05$), recorded closure was 81 % (fig 4.2.13 b). The energy balance closure was seen to increase up to 83% (fig 4.2.13 c) in neutral conditions ($-0.05< (z-d)/ L<0.05$). When the atmosphere was very unstable ($(z-d)/ L<-1$), energy balance closure reduced and attained a value of 71%. Similar variation in energy balance closure in different stability conditions was observed by Barr et al., [26] in a study over three boreal forests of Canada.

5.2.6. Effect of different factors on CO_2 flux variation:

5.2.6.1. CO_2 flux and LAI:

During the summer season, the estimated CO_2 fluxes showed its negative peak in the month of June (table 4.2.1), parallelly LAI also showed its peak (3.07) in the month of June. In figure 4.2.14, the scatter plot between monthly average LAI and maximum negative CO_2 flux of the particular month revealed a good correlation (r^2=0.74). Therefore, the estimated highest CO_2 uptake in the month of June may be attributed to the peak LAI of June. Photosynthate assimilation rate and stomatal density of the leaves can be modulated by changing LAI [10, 36, 37] and this might be the mechanism of observed relationship of LAI with CO_2 flux in the present study. The observed gradual increase in CO_2 uptake from winter to summer (fig 4.1.4) attributes gradual increase in LAI from winter to summer. Similar phenomenon of changes in photosynthetic activity of leaves during different seasons was reported by [38, 39]. The estimated lower CO_2 uptake in our study may be due to lower LAI of the KNP forest. Our results of good correlation between carbon fixation (through photosynthesis) and LAI is well corroborated with some recent findings [40, 41].

5.2.6.2. CO_2 flux and PAR:

Irrespective of the months of the year higher carbon uptake was recorded during the noon hours. This can be clearly elucidated due to higher availability of photosynthetically active radiation (PAR) for photosynthesis during the noon hours (fig 4.2.4). Similar impact of PAR on diurnal variation of CO_2 flux has been observed by Brummer et al., [42] over a shrub savanna ecosystem in west Africa and by Watham et al., [43] over a mixed forest plantation in India. In the month of July, 2016 the negative peak of CO_2 flux (diurnal average) was -7.42 $\mu mol\ m^{-2}\ s^{-1}$ which was lower than June (fig 4.1.4), this sudden decrease in net CO_2 uptake of the forest in July was caused by lower incoming PAR due to cloudy sky (fig 4.2.4) which reduced the photosynthetic CO_2 uptake of the canopy. Similar kind of reduction of net CO_2 uptake of a forest was reported by Zeri et al., [27] in a study over a tropical forest of southwestern Amazonia where lower values of PAR due to cloudy sky reduced the CO_2 uptake of the forest and is in good agreement with the findings of the present study.

5.2.6.3. CO_2 flux and vapour pressure deficit:

The stomatal openings of the leaves are generally modulated by the parameter VPD, which in turn controls the gas and energy exchanges between biosphere and atmosphere. Figure 4.2.5 shows comparison between diurnal variation of CO_2 flux (monthly mean) and diurnal variation of VPD (monthly mean). During the monsoon months, VPD attained diurnal peak at late afternoon hours which correspond to less negative CO_2 flux above the canopy possibly due to partial stomatal closure with increase in vapour pressure deficit after a threshold value. Our results are well corroborated with the findings of Jha et al., [44], where they reported more CO_2 assimilation up to VPD threshold < 0.7 KPa and gradual decrease in CO_2

assimilation thereafter. The negative peak of CO_2 flux recorded was -6.10 µmol m^{-2} s^{-1} in the month of August (fig 4.1.4). This decrease may be attributed to partial stomatal closure caused by high VPD in August (fig 4.2.5). Similar results of stomatal closure due to elevated VPD has been documented by Wolf et al., [45], in a study of carbon dynamics over 22 terrestrial ecosystems across the United States.

5.3. Objective 3: To study the effect of PAR on ecosystem gross primary productivity and net ecosystem exchange.

5.3.1. Partitioning of fluxes:

The estimated net CO_2 flux with the help of eddy covariance technique is the result of two fluxes (GPP and Re). It is very much essential to partition the net CO_2 flux in to its components, in order to understand the internal ecosystem process which regulates net CO_2 flux in the atmosphere.

5.3.1.1. Variation of daily averaged GPP:

Daily average values of GPP showed a peak of 15.86 g C m^{-2} day^{-1} in the last part of April, whereas minimum GPP of 1.58 g C m^{-2} day^{-1} was recorded in the month of January(fig 4.3.1 a). Most of the high values of GPP were observed during May, 2016 to June, 2016 which attributes to occurrence of favorable conditions for photosynthesis in the forest with high values of PAR coupled with LAI, these results are well corroborated with the findings of Carara et al., [46]; who observed a relationship of GPP with PAR and LAI. Reduction in daily average GPP up to 1.58 g C m^{-2} day^{-1} in the month of January signifies leafless condition of the forest canopy which is caused by leaf senescence and abscission along with dry soil conditions. Significant decrease in daily GPP was observed in July and August. In July lower GPP was caused by low incoming PAR due to heavy cloud cover and is in agreement with Thomas et al., [47]. In August, high VPD values caused stomatal closure of forest canopy which reduced the carbon uptake capacity of the forest, similar kind of relationship between VPD and stomatal closure was also reported by Pita et al., [48] in their study over four different forest sites of Belgium and France. Decrease in GPP during the mid monsoon period also attributes to the limitation of photosynthetic activity of under story vegetation due to water logged condition of the site.

During the whole period of study annual GPP of the forest was estimated to be 2660.07 g C m^{-2} yr^{-1}. Our estimate of annual GPP is almost near to the model estimated value of 2.11 Kg

C m^{-2} yr^{-1} in the same ecosystem during July, 2015 to June, 2016 reported by Deb Burman et al., [49]. Estimated GPP over a broadleaf deciduous forest of Japan was reported to be 1118 g C m^{-2} yr^{-1} by Nakai et al., [50]. GPP in the range of 1012-1139 g C m^{-2} yr^{-1} over a needle – leaf deciduous forest of Japan was also reported by Hirano et al., [51]. The estimated annual GPP of KNP site is higher than the forests of Japan, which might have been caused by the differences in incoming radiation and LAI due to canopy architecture of KNP and the results are well supported by the findings of Sprintsin et al., [52].

5.3.1.2. Variation of daily averaged ecosystem respiration (g C m^{-2} day^{-1}):

Respiration values of this semi evergreen forest ranged between 0.06 g C m^{-2} day^{-1} to 15.06 g C m^{-2} day^{-1}(fig 4.3.1 b) . From February 2016 to May 2016 continuous increase in ecosystem respiration (0.94 g C m^{-2} day^{-1} to15.06 g C m^{-2} day^{-1}) was observed possibly due to increase in both soil and air temperature [53] as well as due to increase in moisture content in the soil caused by pre-monsoon rainfall events and is in agreement with the findings reported by Heinemeyer et al., [6]. Similar kind of relationship between soil moisture and total ecosystem respiration are reported by Chunlin et al., [54] over a broad-leaved mixed forest in China and also by Noormets et al., [55] in five different forest ecosystems of USA. During the pre-monsoon season, large change in soil matric potential is possible which in turn can cause favorable conditions for heterotrophic microbiota to be more active [4]. Thus, along with the beginning of pre-monsoon rain in KNP, respiration from soil became high which in turn gradually increased the ecosystem respiration from February to May. Remarkable decrement in ecosystem respiration occurred from the beginning of the monsoon season from June, 2016 to August, 2016, which perhaps is caused by the water stagnation in the site resulting in decreased respiration rates from the soil (autotrophic and heterotrophic) and other herbaceous plants. Ecosystem respiration increased in the month of September as a result of withdrawal of stagnated water and due to decomposition of fallen leaf litter in the soil [47], litter fall during the end of monsoon season is evident from the decrease in LAI in the month of September [56]. With the progress of the dry season (from October, 2016 to January, 2017), respiration of the ecosystem decreased slowly due to decrease in temperature and became almost negligible in January as a result of low temperature and dry soil conditions. Our estimated annual Re of 2567.13 g C m^{-2} yr^{-1} was higher compared to the reports from other sites [57, 58, 59] may be because of unique soil characteristics, diverse vegetation pattern of North eastern forests and its special climate [60].

5.3.1.3. Variation of daily averaged NEP:

Although high fluctuation in daily average NEP was observed (fig 4.3.2 a), but the weekly mean followed a distinct pattern. Daily average NEP showed a peak of 5.03 g C m^{-2} day^{-1} in the beginning of May. In figure (4.3.2 a) positive values of NEP represents carbon intake from the atmosphere by the forest whereas negative values represent carbon released back to the atmosphere. Estimated annual NEP of 92.93± 1.7 g C m^{-2} yr^{-1} indicates that this semi evergreen forest is a minor sink of carbon. Under Asia flux network Saigusa et al., [61] used 9 years of EC data from a cool temperate deciduous forest of Japan and reported the mean annual NEP of 237± 92 g C m^{-2} yr^{-1}. Our estimated annual NEP is lower compared to other similar ecosystems which might be caused by higher ecosystem respiration and due to lower LAI of the canopy. In a study on European forest ecosystems Valentini et al., [57] reported that ecosystem respiration is the principal factor which regulates the net ecosystem exchange of CO_2.

5.3.1.4. Monthly sums of GPP, Re and NEP:

Highest monthly total of GPP and Re was observed in the month of May, 2016(fig 4.3.2 b) just before arrival of Indian summer monsoon in the region. In the month of February and March the forest acted as net source of carbon to the atmosphere. Monthly total GPP dominated the respiration from April to June resulting the ecosystem to a carbon sink. From the middle of the monsoon (July) to the end of monsoon (September) the ecosystem released carbon (source) to the atmosphere as a result of dominance of Re over GPP, similar role of Re in controlling the variation in NEP was reported from other European forests [57]. From October to January, monthly annual sums indicated that the ecosystem of KNP acted as carbon sink. Similar kind of monthly variation of net carbon uptake by a temperate forest of Belgian was reported by Cararra et al., [46], where they reported higher net carbon uptake by the forest in the month of June and July.

5.3.1.6. PAR vs net CO_2 flux:

In figure 4.3.3(a-d), scatter plot between day time average of PAR and CO_2 flux are depicted in different times of the study cycle. During the period from March to April, the correlation coefficient obtained from the least square fit between PAR and CO_2 flux was $r^2=0.60$. The correlation became stronger ($r^2=0.75$) in the next two months (May-June). During the mid monsoon period (July-August) high scatter was observed in the plot between PAR and CO_2

flux (fig 4.3.3.c). In the month of July, incoming PAR was low and fluctuated a lot due frequent occurrence of heavy cloud events (fig 4.2.4), which contributed to the insignificant relationship between the parameters. In the month of August, CO_2 flux above the canopy was modulated by VPD rather than PAR. In figure (4.3.3 d), the relationship became again significant (r^2=0.62) in the following three months (September-November). Our least square fit results between PAR and CO_2 flux are in good agreement with some other studies [43, 62, 63]. In a study over a mixed forest ecosystem of Belgium, Carrara et al., [46] reported similar results of least square fits between net ecosystem exchange and incoming radiation and gives conceptual support to our findings.

5.3.1.7. PAR vs GPP:

Relationship between PAR and GPP was worked out (fig 4.3.4 a-e) and a correlation of r^2=0.55 was observed in the month of February (fig 4.3.4 a). Highest correlation (r^2=0.81) was recorded in the month of March (fig 4.3.4 b). The estimated correlation coefficients were 0.72, 0.75 and 0.71 during months of April, May and June respectively (fig 4.3.4 c-e). From July, 2016 to January, 2017 correlation between PAR and GPP remained insignificant. Similar type of relationship between PAR and GPP from a deciduous forest of Japan are reported by Saigusa et al., [11] and are in agreement with our observed relationship of PAR and GPP on month wise basis. Our month wise results of the least square fitting between PAR and GPP are very similar to the results obtained by Rodda et al., [63] in a study over tropical mangrove forest of India where they also observed nonlinear and positive relationship between daily averaged GPP and PAR.

5.3.1.8. Air temperature vs ecosystem respiration (Re):

We have made an attempt to work out a relationship between daily average air temperature and ecosystem respiration (fig 4.3.5). The regression analysis showed an exponential relationship between air temperature and ecosystem respiration (r^2=0.54). Similar kind of exponential relationship between air temperature and ecosystem respiration has also been observed by Chunlin et al., [54] in a study over a broad leaved mixed forest ecosystem of China.

5.4. Objective 4: To study the relationship of annual and seasonal variation of CO_2 flux with soil carbon dynamics.

5.4.1. Variations in SOC: We determined SOC in four seasons from four different sites around the flux tower to investigate the seasonal as well as location wise variation of soil organic carbon in the forest. Our focus was to correlate the seasonal variation of CO_2 flux (ecosystem respiration component) with soil carbon dynamics.

The depth wise variation in SOC (table 4.4.1-4.4.4) indicated decrease in SOC with the increase in depth irrespective of seasons which might have been caused by the higher liter decomposition on the top soil layer. There was no noticeable difference in SOC among four sites. Our results of higher SOC in top soil is well corroborated with some other findings [64, 65].The decrease in SOC content with depth attributes higher biological activity in the top soil layer of the forest [66]. The SOC values were low in the soil in pre-monsoon season compared to other seasons (fig 4.4.1) which attributes release of CO_2 from the soil due to occurrence of wet soil condition caused by pre-monsoonal rain. Higher SOC content during the winter indicates influence of the litter decomposition on soil after leaf abscission which is evident from decrease in leaf area index of the forest canopy in winter months. Our finding of higher organic carbon in winter season is well supported by the other results of Indian natural forest ecosystems [67]. The percentage of organic carbon present in soil ascertains the soil carbon dynamics by controlling the multiplicity mechanism of microorganisms [67].

5.4.2. Bulk density (Mg m^{-3}) and SOC (%): Bulk density of the top soil (0-15 cm) was found to be slightly lower(table 4.4.5-4.4.8) compared to soils of lower depths (15-30 cm), similar kind of results has also reported by other researchers from forest as well as different types of ecosystems [68].The relationship between SOC and bulk density (BD) of top soil (0-15 cm depth) in figure 4.4.3 revealed a negative correlation with marginal significance level (adjusted $r^2=0.73$, $p=0.09$, $r^2=0.82$) between the parameters. Similar kind of negative correlation ship has been documented by Perie et al., [69] in their study in boreal forest soils.

5.4.3. Soil temperature and SOC: SOC content decreased with increase in soil temperature as depicted in figure 4.4.5 (adj $r^2=0.06$, $p=0.39$, $r^2=0.38$), however this relationship is not significant on seasonal scale during our period of study may be because of heavy flood on the site during monsoon season. In a study of soil carbon dynamics Davidson and Janssens [70] reported similar kind of uncertainty in temperature sensitivity of soil carbon decomposition.

5.4.4. SOC and ecosystem respiration:

An attempt has been made to find out a relationship between seasonal averages of ecosystem respiration (g C m^{-2} $month^{-1}$) with seasonal average of SOC content (%) in the present study (fig 4.4.7). Computed results depicted negative correlation between percentages of SOC present in the soil to the ecosystem respiration (adj r^2=0.92, p=0.03, r^2=0.94). In our study although SOC content was high in winter but heterotrophic respiration was perhaps less on the same time due to low microbial activity caused by low temperature and moisture conditions. In the other seasons SOC content became low due to higher soil CO_2 emission. Hence, the correlation between SOC and ecosystem respiration was found to be negative. Similar kind of negative correlation between SOC and soil CO_2 emission has been reported by Dutta et al., [71] from a paddy filed of Northeast India.

5.4.5. Bulk density (BD) and ecosystem respiration:

Regression analysis between bulk density vs ecosystem respiration (fig 4.4.8) indicated positive correlation with marginal significance (adj r^2=0.82, p=0.06, r^2=0.88) indicating that BD is not a major contributor in controlling seasonal variation of ecosystem respiration , may be because of variability in natural conditions of the forest. In a study over an undisturbed forest of Slovakia, Allman et al., [72] also found a weak relationship between soil bulk density and CO_2 emission.

5.4.6. Soil temperature and ecosystem respiration:

The regression analysis between seasonal average of soil temperature at 5 cm depth and the seasonal average of ecosystem respiration showed insignificant relationship between the two parameters (fig 4.4.9) (adj r^2=0.42, p=0.22, r^2=0.61). In KNP forest heavy flood during monsoon has a greater impact on the soil CO_2 efflux during the monsoon period. This might be the possible explanation for the observed seasonal insignificant relationship between soil temperature and CO_2 efflux.

5.4.7. C/N ratio and ecosystem respiration:

Irrespective of seasons the C/N ratio of the KNP soil was higher in upper depth compared to lower depth. Higher Carbon to Nitrogen ratio (C/N) exhibited a distinct seasonal and depth wise variation during our study period (fig 4.4.10). Our finding of decrease in C/N ratio with depth is in accordance with other findings [73]. The regression analysis between seasonal average C/N ratio (upper depth) and seasonal average of ecosystem respiration (fig 4.4.11) showed a negative correlation (adj r^2=0.97, p=0.01).

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