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Net Ecosystem CO_2 Flux and Effect Factors in Peatland Ecosystem of Central China

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Abstract

Peatland ecosystems play an important role in the global carbon cycle because they act as a pool or sink for the carbon cycle. However, the relationship between seasonality effect factors and net ecosystem CO_2 exchange (NEE) remains to be clarified, particularly for the non-growing season. Here, based on the eddy covariance technique, NEE in the peatland ecosystem of Central China was examined to measure two years' (2016 and 2017) accumulation of carbon dioxide emissions with contrasting seasonal distribution of environmental factors. Our results demonstrate the cumulative net ecosystem CO_2 emissions during the study period was in the first non-growing season 2.94 ± 4.83 $\mu molCO_2\ m^{-2}\cdot s^{-1}$ with the lowest values in the same year in first growing season was $-2.79 \pm 4.92\ \mu molCO_2\ m^{-2}\cdot s^{-1}$. The results indicate the effect of seasonal variations of NEE can be directly reflected in daily and seasonal variations in growth and respiration of peatland ecosystem by environmental parameters over different growing stages.

Keywords

Dajiuhu Peatland, Ecosystem Respiration, Eddy Covariance, Gross Primary Product, Net Ecosystem CO_2 Exchange

1. Introduction

Wetlands have a high net primary production and low soil organic matter decomposition rate. Therefore, wetlands represent 15% of global organic carbon storage by acting as natural "blue carbon"—a significant role in the universal carbon sink (Niu et al. 2017; Järveoja et al., 2018; Chu et al., 2019). Wetland ecosystems are long-term CO_2 sinks; however, the sources of carbon are greatly linked with CO_2 sinks in wetlands (Chu et al., 2018). Peatlands serve as a source of greenhouse gas balance for the Earth (Lees et al., 2018). The Dajiuhu peatland of Shennongjia is in a forestry district in Central China. It is the highest subtropical peak in the Yangtze River mid-range. There are no stable carbon accumulation occurrences in the area due to CO_2 uptake through the plants and soil which release CO_2 into the atmosphere by ecosystem respiration (ER). A previous investigate by Järveoja et al. (2018) in boreal peatland of Västerbotten, northern Sweden demonstrated the long-term carbon accumulation in peatlands can occurrences principally be attributed to a persistent imbalance between carbon input through primary production and loss due to organic matter decomposition.

Peatland ecosystems play a role as a solid carbon dioxide sink (Chu et al., 2019). Environmental variables, such as soil water content (SWC), rainfall (R_n), air temperature (Ta), and photosynthetic photon flux density (PPFD), have an effect on peatland by increasing CO_2 exchange (Ward et al., 2010; Kuiper et al., 2014). Han et al. (2013) in coastal wetland of China prove that the environmental variables may accelerate the decomposition rates in some wetlands, causing them to become net source of CO_2 to the atmosphere. Thus, large-scale variability in carbon flux has been observed in peatland ecosystems. There have been numerous studies which prove that spatial variability in plant species comprising the carbon sink of peatlands is the basis for plant biomass (Zhou et al., 2009; Duman & Schäfer, 2018; Chu et al., 2019). Typical peatland plant communities are composed of peat mosses and associated vascular plants (Andersen et al., 2011). Relatedly, an increase in respiration of vegetation composition of peatland areas causes greenhouse gas flux (Alm et al., 1997). Moreover, existing research has shown seasonal and interannual variation in carbon dioxide exchange and carbon balance in wetlands (Flanagan et al., 2002). Thus, there is a higher risk that wetlands will shift from a net sink to a net carbon source (Duman & Schäfer, 2018). The major aim of the research study is to illustrate the effects of environmental factors on NEE in the peatland ecosystem, using eddy covariance to measure the activities of carbon dioxide exchange by characterizing the daily and seasonal variations of NEE.

2. Materials and Methods

2.1. Study Area Site

The study area is the Dajiuhu peatland of Shennongjia Forestry District, (31˚28'44.45"N, 110˚00'14.61"E, 1758 m), located in Hubei province, Central China. It is a flat and open area in a subtropical continental monsoon climate zone. The region belongs to the typical subalpine wetland ecosystem with peat thickness over 2 m, and the vegetation pools consist of a shrub layer with tall grass and short herbs species.

The herbaceous layer is mainly peat moss *Sphagnum palustre*, *Carex fulvorubescens*, *Festuca rubra*, *Euphorbia esula*, *Sanguisorba Officinalis*, *Polytrichum commune*, *Drosera rotundifolia*, and *Geranium rosthornii*. The area experiences low temperatures: the average annual air temperature are 11.08˚C ± 8.18˚C, 11.3˚C ±

7.6˚C and rainfall 0.0019 ± 0.0031 mm, 41 ± 80 mm, respectively. The source material contains alluvial and lacustrophic soils and the root zone soil composition is a standard grass layer, the same as marshes and the meadow.

2.2. Meteorological Measures and Eddy Covariance

A covariance mechanism is a simple and reliable means of studying the distribution of CO_2. The open-path eddy covariance systems in the middle of the field is placed 3 m over the ground surface. The densities of CO_2/H_2O were a three-Dimensional VOCAL (WindMaster Pro, Gill Instruments) measuring wind speed system was used as an open-way infrarot gas (IRGA, LI-7500, LI-Cor, USA) measurement system. The researchers used the thermocouples before reaching and after leaving the sample volume to measure the ambient temperature and air pressure. In comparison, wind measurement was performed with a differential pressure sensor at varying speed and precision. Increment and depression of the facial quantum sensors (LI-190SL-50, LI-COR Inc., Nebraska, US) were used to test PPFD.

A graduated rain pail was used to measure the overall ground event of rainfall (TR-525USW, Texas Electronics, Texas, USA).

Certain variables of the atmosphere were calculated using eddy covariance (LI-Cor 7500). Soil water content (Delta-TML2x, Delta-T Devices, UK) including soil temperature (Ts) was measured at the depth of 5 cm, 10 cm, 20 cm. A data logger (CR3000-XT, Campbell Scientific, Utah, USA) has reported all channels on weather and ground sensors every 15 s and 30 minutes and the data have been recovered from a portable USB unit.

2.3. Flux Data Processing

The NEE potential was determined by the eddy covariance of atmosphere and plants, variations in carbon dioxide concentration being below the carbon dioxides measurement ground (Bonneville et al., 2008). EddyPro 5.2.1 software was used to calculate carbon dioxide flux every 30 min. For input of modified fluxes in CO_2 and H_2O, 10 Hz raw eddy covariative data have been used, and filtered data have been used to measure carbon dioxide flux over 30 minutes.

The Webb-Pearman-Leuning terms correction was not used to measure CO_2 and H_2O fluxes because the enclosed analyser instantaneously illustrated mixing output ratios of CO_2 and H_2O, which were corrected for air extension (Webb et al., 1980). Then, quality tests on carbon dioxide flux data were performed using the software, allocating quality signals to every data point (Chu et al., 2019).

Results from half-hour of carbon dioxide flow is collected according to a series of criteria until they were used for further research (Chu et al., 2019). Half-hour flux results is omitted due to sensory deficiencies prior to and after precipitation observation (Falge et al., 2001). Use of appropriate environment parameters depended on nonlinear empirical equations, line interpolation, and the Michaelis-Menten equation (Ruimy et al., 1995) to make up for missing data.

2.4. Data Analysis

NEE response and ER to light availability and the carbon absorb capacity over two years of seasonal variations were calculated based on the following equation (Wang et al., 2018):

$$\mathrm{GPP} = \frac{\alpha^{\times}\mathrm{A}_{\max}{}^{\times}\mathrm{PPFD}}{\alpha^{\times}\mathrm{PPFD} + \mathrm{A}_{\max}} \tag{1}$$

where GPP is gross primary production (μmolCO$_2$ m^{-2}·s^{-1}), and PPFD is the photosynthetic photon flux density (μmol quanta m^{-2} s $^{-1}$). Alpha (α) is the apparent quantum yield, μmol CO$_2$ (μmol quanta)$^{-1}$, and Amax is the photosynthetic capacity at light saturation, μmol CO$_2$ m^{-2}·s $^{-1}$. PPFD refers to the apparent quantum efficiency and maximum photosynthetic rate of the system. The net photosynthetic rate and ER of an ecosystem tend to be maximal in daytime, which demonstrates the dark respiration rate of the system. ER was calculated based on air temperature and a, b empirical coefficients, using the following the equation (Wu et al., 2020):

$$\mathrm{ER} = \mathrm{a}^{\times}\mathrm{e}\beta\mathrm{T} \tag{2}$$

Net ecosystem CO$_2$ exchange (NEE) was calculated as follows (Tramontana et al., 2020):

$$\mathrm{NEE} = \mathrm{ER} + \mathrm{GPP} \tag{3}$$

During the study duration, modelled parameters were derived using the curve-fitting tool in Microsoft Excel, SPSS and completed using Origin 2019b.

3. Results and Discussion

3.1. Seasonally Variation of NEE, GPP, and ER

The eddy covariance method was used to analyse the NEE of the peatland ecosystem in Central China for two years from January 2016 until December 2017. The results show that the cumulative CO$_2$ emissions during the study period was in the first non-growing season, 2.94 ± 4.83 μmolCO$_2$ m^{-2}·s^{-1} with the lowest values in the same year in first growing season was −2.79 ± 4.92 μmolCO$_2$ m^{-2}·s^{-1} (**Figure 1(a)**, **Figure 1(b)**, **Table 1**). The variation in photosynthesis and respiration uptake in the growing seasons during the study period was smaller than the ratio of estimations in the non-growing season due to the variation of parameters among different growth periods, which is caused by changes in plant growth and environmental conditions. Previous studies by Zhou et al. (2009) proved that in the Panjin wetland ecosystem the CO$_2$ emissions outside the growing season comprised about 83% of the CO$_2$ uptake during the growing season and showed significant effect on annual net CO$_2$ balances. However, the results suggest that the relationship between NEE and GPP have an adverse effect on the photosynthetis of the peatland (Mamolos et al., 2001; Aires et al., 2008). When NEE increases, it leads to an increase in GPP and vice versa throughout the growing and non-growing durations. Growing season GPP

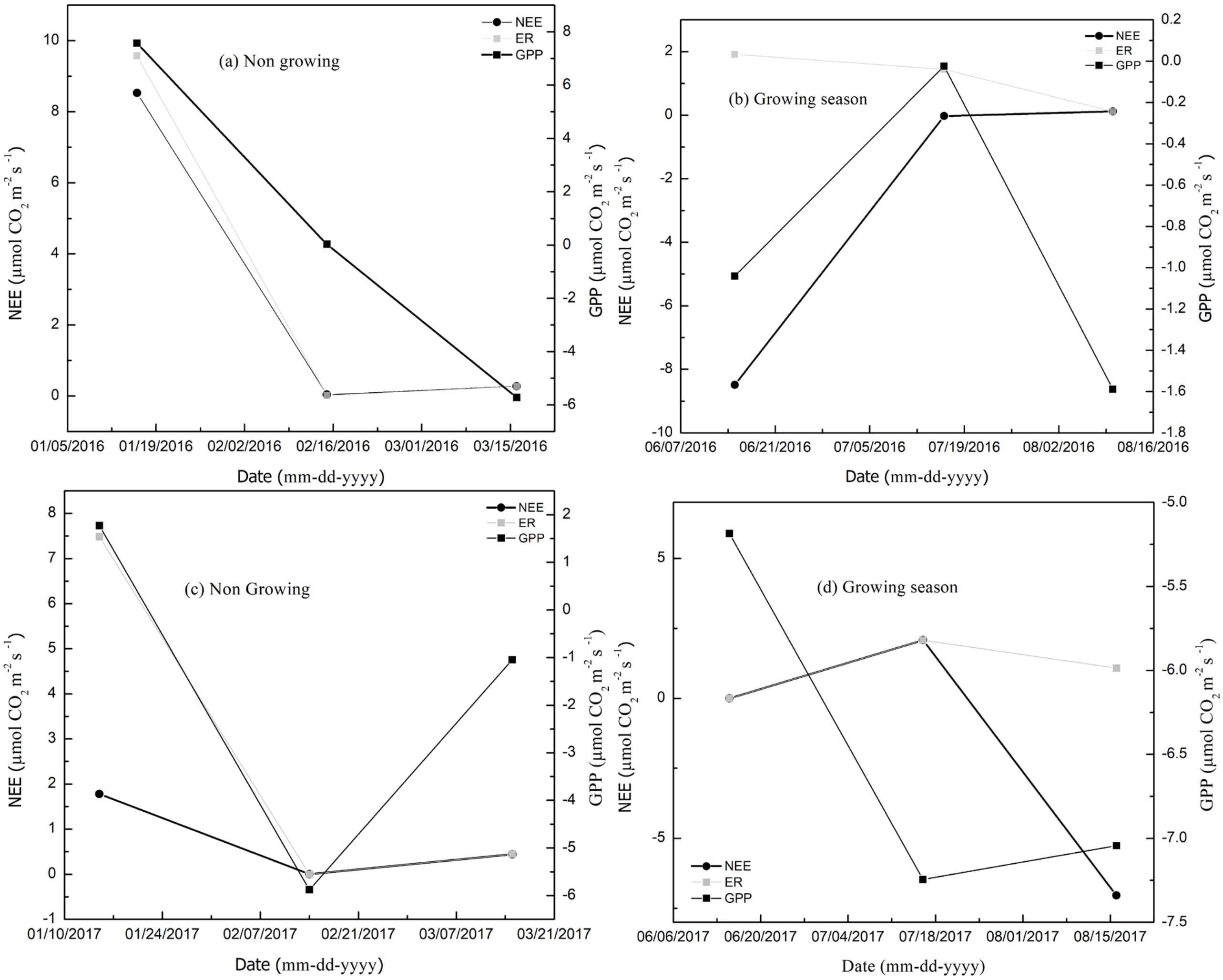

Figure 1. The seasonally variation of Net Ecosystem CO_2 Exchange, Gross Primary Product and Ecosystem Respiration depends on the growing and non-growing season through two years from January 2016 to December 2017.

Table 1. The total accumulated Net Ecosystem CO_2 Exchange, Gross Primary Product and Ecosystem Respiration for the growing season and non-growing season and the annual variation by (mean and standard deviation) in the two years from January 2016 to December 2017.

	2016			2017		
	Growing season	Non-growing season	Whole year	Growing season	Non-growing season	Whole year
NEE	−2.798 ± 4.928	2.947 ± 4.833	0.430 ± 4.251	−1.653 ± 4.782	0.740 ± 0.924	0.181 ± 2.276
GPP	0.884 ± 0.793	0.622 ± 6.667	0.443 ± 3.922	−6.491 ± 1.135	−1.718 ± 3.867	−2.511 ± 4.418
ER	1.159 ± 0.932	3.288 ± 5.445	2.198 ± 3.046	1.055 ± 1.041	2.642 ± 4.196	0.981 ± 2.137

variations in the first year increased more rapidly than in the second; the highest value was 0.88 ±0.79 µmolCO_2 m^{-2}·s^{-1} in the first growing season, and the lowest was −6.49 ± 1.13 µmolCO_2 m^{-2}·s^{-1} in the second growing season (**Figure 1**, **Table 1**).

In January 2016, the values of ER in the non-growing season decreased to 9.57 μmolCO_2 $m^{-2}\cdot s^{-1}$. This was as a result of the difference in occurrences between ecosystems and species structures.

The variations in growth and respiration also changed due to location and climatic factor emissions which are common in the area (Suyker et al., 2003; Novick et al., 2004; Nagy et al., 2007). For each measurement, a strong relationships between ER and GPP could be observed, depending on the season (**Figures 1(a)-(d)**) (Chu et al., 2019).

3.2. Effect of Environmental Variables on the NEE

The peatland ecosystem of Central China increased vegetation for photosynthesis. The ecosystem's photosynthesis rate is greater than the rate of breathing. In other words, plant absorption potential is gradually improved in the morning between 10 a.m. and 15 a.m. The absorption rate reached a peak at 12:30 in the afternoon (Alfadhel et al., 2019). Overall, the annual mean (±SE) of Soil water content was stable during the study research 0.715 ± 0.106; 0.832 ± 5.886 $m^{+3}m^{-3}$ but soil temperature was high first year then second year 12.420˚C ± 7.520˚C; 2.477˚C ± 3.747˚C (**Table 2**). Relatedly, a decrease in the intensity of the lighting and photosynthesis led to a gradual decrease in the absorption rate of CO_2. NEE increased during the non-growing season more than in the whole growing season of the study period (**Figure 4(a)**) because the vegetation is dry in winters with a very low temperature (Nilsson et al., 2008). The annual mean (±SE) of air temperature during the study period was 11.089˚C ± 8.187˚C, 11.368˚C ± 7.635˚C (**Table 2**). A report by Schedlbauer et al. (2010) determined that light and air temperature exerted the primary controls on NEE in the dry season, and inundation weakened these relationships. The ecosystem shifted from a CO_2 sink in the dry season to a CO_2 source in the wet season. **Figure 2** shows that the annual mean (±SE) of PPFD in 2016 and 2017 was 0.28 ± 0.09 μmol quanta $m^{-2}\cdot s^{-1}$ and 0.25 ± 0.09 μmol quanta $m^{-2}\cdot s^{-1}$, respectively (**Table 2**).

PPFD performed the main function in determining the distinction in NEE throughout the seasons. On each measurement, a high distinction in NEE was demonstrated by the changes in PPFD (**Figure 4(c)**), which is consistent with results for Monte do Tojal, Évora, in Southern Portugal, by Aires et al. (2008); this shows that more than half of the variation in NEE can be explained by the changes in PPFD. Photosynthesis increased more with limited level respiration because NEE is the equilibrium of photosynthesis and respiration. Moreover, the photosynthetic possibility of plant domains exceedingly depends on the plant species and has different temperature optima (Knapp, 1985).

Meanwhile, the seasonal variation of NEE shows that there is no clear significant relationships with rainfall (**Figure 4(a)**). However, the Dajiuhu peatland ecosystem basically maintains carbon emissions, indicating that the values of carbon emissions are high within the rainfall, and the annual mean (±SE) of rainfall in 2016-2017 was 0.0019 ± 0.0031; 41 ± 80 mm (**Table 2**). This result agree with

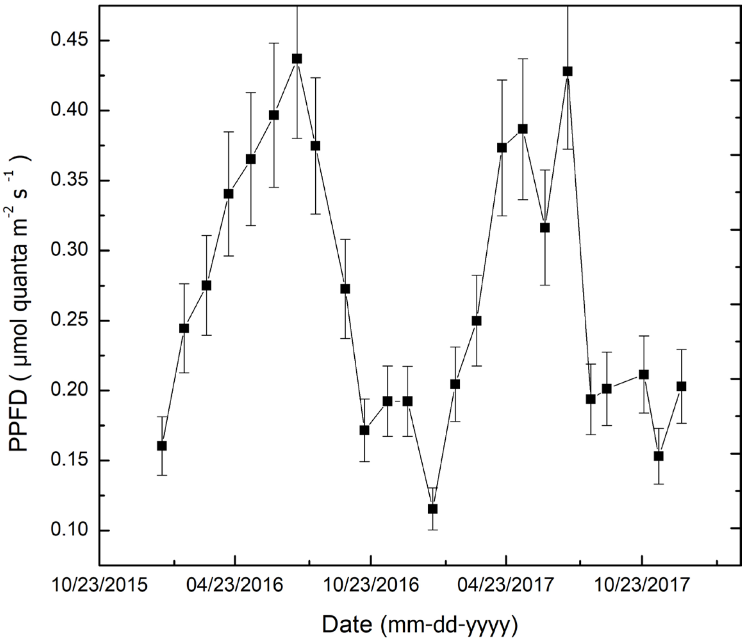

Figure 2. The seasonal variation of the photosynthetic Photon Flux density in peatland ecosystem of Central China through two years from January 2016 to December 2017.

Table 2. The Mean and Standard Deviation of Photosynthetic Photon Flux Density, Soil Water Content, Rainfall, Air temperature and soil temperature from January 2016 till December 2017.

Parameter	2016	2017
PPFD μmol quanta $m^{-2}·s^{-1}$	0.285 ± 0.095	0.253 ± 0.099
SWC ($m^{+3}·m^{-3}$)	0.715 ± 0.106	0.832 ± 5.886
R_n (mm)	0.0019 ± 0.0031	41 ± 80
Ta (˚C)	11.089 ± 8.187	11.368 ± 7.635
Ts (˚C)	12.420 ± 7.520	2.477 ± 3.747

Hunt et al. (2004) and has explained that NEE in a year with high rainfall had limited potential to capture a significant amount of carbon in the ecosystem of Twizel, Mackenzie Basin, South Island, New Zealand, between September 1998 and October 2000.

3.3. Annual Variation of Ecosystem CO_2 Exchange

The annual variation of carbon dioxide flux can be directly reflected by environmental parameters over different growing stages. In all observation years, the maximum NEE in 2016 was 8.52 μmolCO_2 $m^{-2}·s^{-1}$ and the minimum was −8.48 μmolCO_2 $m^{-2}·s^{-1}$ (**Figure 3**, **Table 3**). The maximum for 2017 was 2.08 μmolCO_2 $m^{-2}·s^{-1}$ and the minimum was −7.04 μmolCO_2 $m^{-2}·s^{-1}$ (**Figure 3**, **Table 3**), which is symmetrical with the result for a semiarid grassland of Mongolia; the annual cumulative NEE ranged from −2.09 to 8.1 μmolCO_2 $m^{-2}·s^{-1}$ (Nakano & Shinoda, 2018).

Table 4 shows the A_{max} and the annual mean (±SE) during two years was 658.56 ± 356.83; 491.786 ± 292.25 (μmol CO_2 $m^{-2}\cdot s^{-1}$). The α is the apparent quantum yield used in Equation (1) to find GPP and the annual mean (±SE) of (2016-2017) was 0.026 ± 0.139; 0.01 ± 0.0786 (μmol CO_2 (μmol quanta)$^{-1}$). The a, b empirical coefficients of Equation (2) were used to find the ER in the same period of 2016-2017.

3.4. Effect of Temperature/PPFD and SWC on the NEE

This empirical study over a two-year monitoring period shows that there are no significant strong relationships between NEE and SWC, and PPFD and air temperature (Figure 4), because the biomass keeps changing over time and

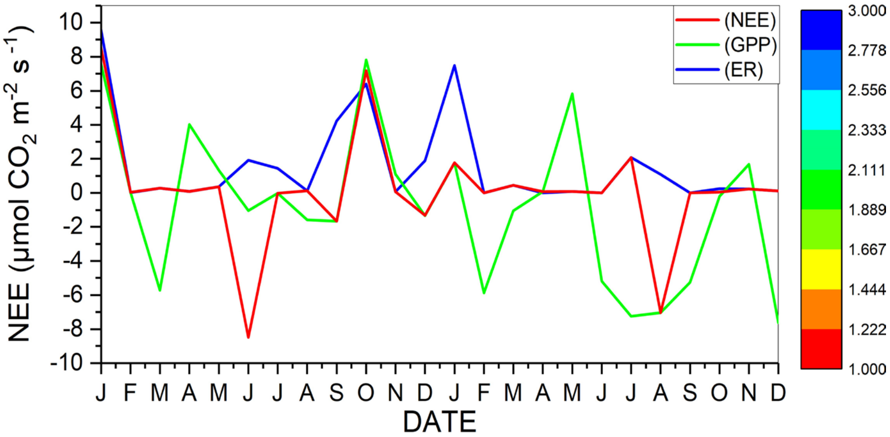

Figure 3. The annual variation of Net Ecosystem CO_2 Exchange, Gross Primary Product and Ecosystem Respiration during two years from January 2016 to December 2017.

Table 3. The Maximum and Minimum of NEE and GPP and ER in peatland ecosystem of Central China through two study years from January 2016 till December 2017.

Parameter	Maximum and Minimum 2016	Maximum and Minimum 2017
NEE μmol CO_2 $m^{-2}\cdot s^{-1}$	8.526 ~ −8.488	2.082 ~ −7.043
GPP μmol CO_2 $m^{-2}\cdot s^{-1}$	7.811 ~ −5.725	5.828 ~ −7.627
ER μmol CO_2 $m^{-2}\cdot s^{-1}$	9.575 ~ 0.015	7.481 ~ 0.00019

Table 4. The Coefficients A_{max} and α using in Equation (1) over the period 2016-2017 to find GPP in peatland and a, b empirical coefficients of the Equation (2) using to find the ER in same period. A_{max} is the photosynthetic capacity at light saturation; α is the apparent quantum yield. value of coefficients represents the Mean ± SE.

Parameter	2016	2017
A_{max} (μmol CO_2 $m^{-2}\cdot s^{-1}$)	658.56 ± 356.83	491.786 ± 292.25
α (μmol CO_2 (μmol quanta)$^{-1}$)	0.026 ± 0.139	0.01 ± 0.0786
B	0.418 ± 1.372	0.255 ± 1.327
A	0.271 ± 0.122	0.257 ± 0.1003

snow plays a crucial role in such occurrences in the study area. The correlation analysis related to the annual scale for SWC and PPFD shows that only in the early and middle growing seasons (<22.8, **Figure 4(b)**), (<0.4, **Figure 4(c)**), indicating that SWC and PPFD play an important role in the seasonal variation of NEE.

Zhao et al. (2006), examined the increase in SWC and PPFD and determined that an increased NEE shows a significant positive correlation with observed NEE between SWC and PPFD in the growing season and non-growing season.

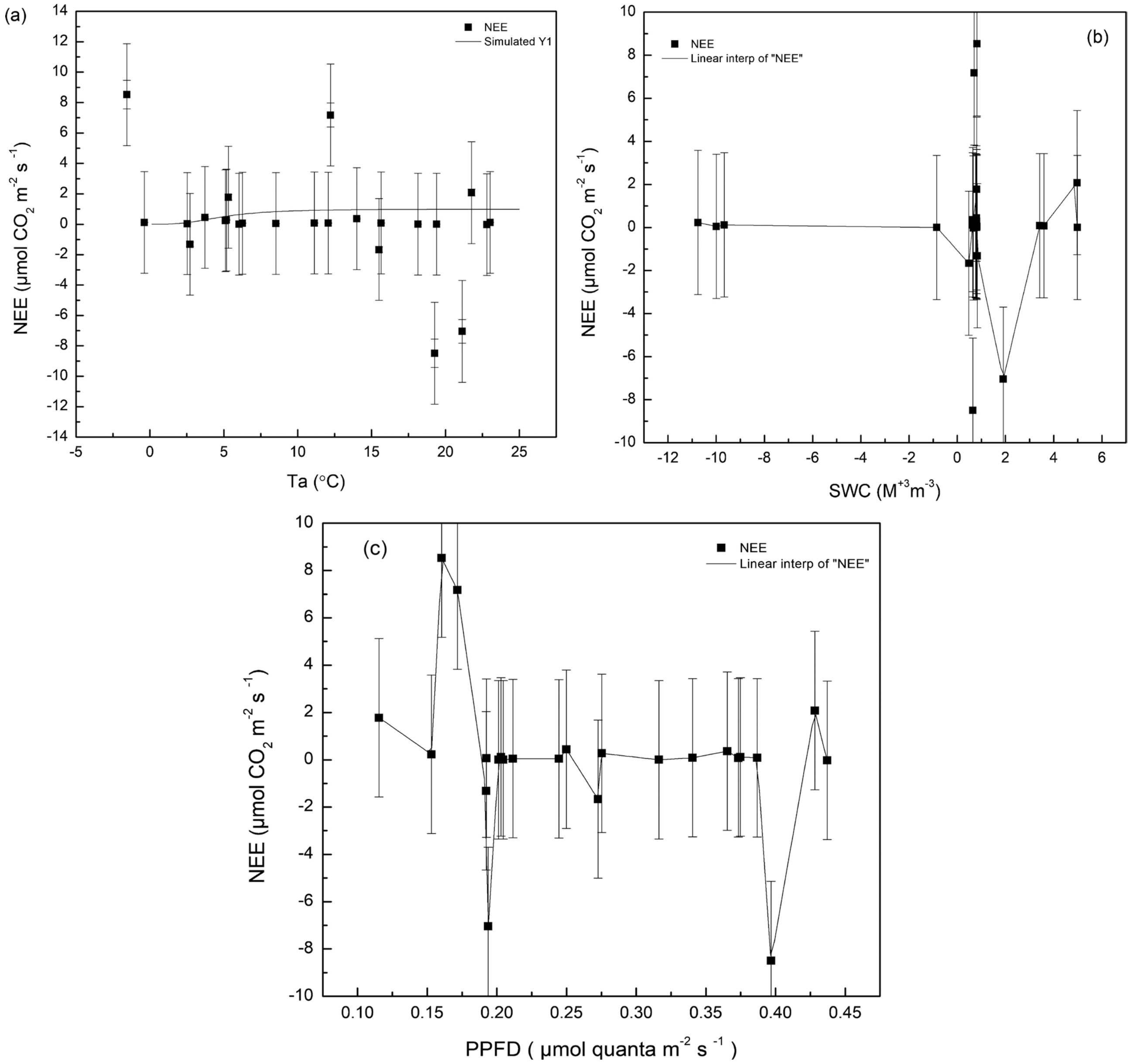

Figure 4. The correlation and variation between Net Ecosystem CO_2 Exchange and (a) Air temperature; (b) Soil Water Content and (c) Photosynthetic Photon Flux Density in peatland ecosystem of Central China through the two study years from January 2016 till December 2017.

4. Conclusion

This study determines that NEE in the peatland ecosystem of Central China shows seasonal variation which is not only dependent on air temperature, soil water content, soil temperature, and photosynthetic photon flux density, but also to some extent on the vegetation, which makes up the peatland ecosystem.

For each measurement, there is an unclear relationship between NEE and SWC, rainfall, PPFD, and air temperature. The results analysed the effect of environmental variables on NEE in the peatland. Long-term studies will be needed to clarify how these factors affect peatland and the changes they make to carbon sinks or sources for CO_2 flux.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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