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Carbon Budget Dynamics over a Rain-Fed Maize Agricultural Ecosystem in Northeast China and Its Regulation

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Abstract

Based on the eddy-covariance observation data over rain-fed maize agricultural ecosystem during 2005-2011, the dynamics of net ecosystem CO_2 exchange (NEE) and its control mechanism were analyzed in the present study. We found that the average carbon budget of non-growing season, growing season and annual were 153.16 - 202.03 g C/m^2, −689.36 - −488.17 g C/m^2, and −316.96 - −487.33 g C/m^2, respectively. Maize carbon content of grain yield was −226.6 - −339.94 g C/m^2, accounting for 55.4% of carbon budget in the growing season. From sowing to seven-leaf stage, the carbon budget of this ecosystem was characterized by carbon release, with the rate of 0.028 ± 0.0056 mg CO_2 m$^{-2}\cdot$s^{-1}. From seven-leaf to mature stage, the carbon budget was characterized by carbon absorption, with the rate of −0.256 ± 0.0693 mg CO_2 m$^{-2}\cdot$s^{-1}. The key meteorological factors affecting annual carbon budget included daily average temperature ($R = -0.81$, $P = 0.03$) and saturated vapor pressure deficit ($R = -0.64$, $P = 0.12$). At the same photosynthetically active radiation (PAR) level, CO_2 assimilation rate was linearly correlated with leaf area index ($P < 0.05$), and the slopes increased with PAR, indicating the increase in net ecosystem CO_2 exchange in growing season was unlikely to be resulted from the extension of growing season. On the contrary, the carbon sink of rain-fed maize ecosystem in growing season might be decreased by extending the growing season ahead of the sowing date.

Keywords

Rain-Fed Maize, Carbon Budget, Dynamics, Regulation Mechanism, Northeast China

1. Introduction

CO_2 concentration in the atmosphere is being increased mainly due to human activities. In order to predict accurately future climatic change and its influence, it is rather critical to understand the dynamics of CO_2 concentration in atmosphere [1]. In the short term, increasing CO_2 absorption of terrestrial ecosystems has become one way to reduce CO_2 concentration in the atmosphere [2]. Although the farmland accounts for 12% of global surface areas [3], the annual net ecosystem CO_2 exchange (NEE) of agricultural ecosystem is greater than other natural ecosystems [4]. Therefore, it is important to understand the carbon budget dynamics of different agricultural ecosystems and their regulations.

Northeast China, located in the east-Asian monsoon zone, has been warming and drying strongly during the latest 50 years [5]. The crop development and growth have been sharply influenced by the climate change in this region. Furthermore, agricultural ecosystem is one of main terrestrial ecosystem types in Northeast China, and its carbon budget plays an important role in the regional assessment of carbon budget. Maize is one of three major crops (Paddy rice, maize and wheat) in Northeast China, and its maize sown area is about 9.85×10^6 ha in 2011, accounting for 51.3% of grain sown area in Northeast China. The maize agricultural ecosystem in Northeast China is a typical rain-fed agriculture. Therefore, evaluating carbon budget dynamics of maize agricultural ecosystem in Northeast China and revealing its control mechanisms are critical to assess global carbon budget and to better understand the principle of carbon balance changes.

At present, eddy covariance technique has been widely used in quantifying carbon flux over agricultural ecosystem [6] [7] [8] [9], determining the effects of different agricultural measures on farmland carbon budget [10] [11] [12] [13], and exploring the control mechanisms of environmental factors on farmland carbon balance [14] [15]. However, these studies at present are mostly based on the short-term observation data, the results could not reveal the dynamics and control mechanisms of agricultural ecosystems on a year time scale. Generally, flux data of continuous many years (5 - 10 years) are needed to assess the inter-annual variation of carbon budget in agricultural ecosystem and its control mechanism at multi time scales [16]. Although the carbon budget and its affecting factors for rotation and un-tillage type of maize and soybean farmland are studied based on the flux data observed for a longer time [1] [4], there is little information on carbon budget of tillage rain-fed maize agricultural ecosystem with observation data of continuous years.

The objectives of this study are 1) to quantify NEE of rain-fed maize agricultural ecosystem at different development stages and different seasons (*i.e.*, the growing and non-growing seasons and annual); and 2) to reveal control mechanisms of carbon budget in the most common tillage and continued rain-fed maize agricultural ecosystem, based on long-term eddy covariance data over rain-fed maize agricultural ecosystem in Northeast China during 2005-2011.

2. Materials and Methods

2.1. Study Sites

The study site is located at Jinzhou Agricultural Ecosystem Field Experiment Station in the Northeast of China (41˚8'53"N, 121˚12'6"E, 23 m). The climate is temperate monsoon. Its mean annual air temperature and precipitation are 9.4˚C and 568.8 mm from 1951 to 2011, respectively. The nearly 70% of the annual precipitation occurs in summer (*i.e.*, June, July, and August). The soils are clay loams, typical brown soil. The soil pH value and soil organic matter in the depths from 0 to 40 cm are 6.3% and 1.36%, respectively.

The site is very flat and large fields with 43 ha, that provides sufficient upwind fetch with unstable condition. The maize was sowed in the end of April or the early of May after deep tillage and harvested in the end of September. The nitrogen fertilizer with 300 kg/ha has been applied in soil before the sowing. After harvest, the field goes into the fallow period until the next year maize sowed period.

2.2. Eddy Covariance and Meteorological Measurements

Fluxes of carbon dioxide, water vapor and sensible were obtained by the eddy covariance method [16]. The observation system was composed of a three-dimensional ultrasonic anemometer (Model CSAT3: Campbell Scientific Instruments Inc., Logan, UT, USA) and an open-path infrared CO_2/H_2O gas analyzer (Model LI7500: LI-COR, Inc., Lincoln, NE, USA). The sensors were mounted 3.5 m above the ground.

The micro-meteorological data were also measured, including temperature and humidity (Model HMP45C, Vaisala Inc. Helsinki, Finland), precipitation (Model 52202, RM Young Co., Traverse City, MI, USA), wind speed and direction (034B, MetOne), net radiation (Model CNR1, Kipp and Zonen, Delft Netherlands), and photosynthetically active radiation (PAR) (Model Li190SB, LI-COR, Inc., Logan, UT, USA) and soil temperature (Model Platinum RTD, Omega Engineering Stamford, CT, USA).

2.3. Flux Data Processing

The raw data time series with a frequency of 10 Hz were calculated into the half flux data using the EdiRE software package [17]. Process procedure included the spike detection [18], coordinate rotate [19], spectral loss correction [6], and WPL-correction [20], The energy balance was examined by calculated linear regressions between the sum of latent heat and sensible heat and the value of net radiation subtract soil heat storage. The slope and intercept ranges of the regression function was 0.72 - 0.79 and 6.08 - 19.72 W/m^2. Instrument malfunction, poor weather and low turbulent mixing will result with data gap [21]. 2.72% - 14.62% of annual data missed was attributed to the instrument malfunction and power failure. Low turbulent mixing (friction velocity less than 0.1 m/s), rainfall and other unpredictable situation caused another 15.80% - 33.11% data missed. The numbers of the valid data in 2005-2011 are 68.39%, 69.58%, 74.89%, 64.03%, 70.40%, 57.04% and 64.27% of annual data, respectively. For this study, the short gap data (<3 h) were filled with linear interpolation, but the larger gap data (>3 h) were filled with LookUp table method [21].

2.4. Calculation of GPP and R_{eco}

The ecosystem respiration (R_{eco}) was evaluated using the Vant Hoff equation [Equation (1)]:

$$R_{eco} = R_0 \exp\left(bT_s\right) \tag{1}$$

where R_0 is the respiration at 0˚C. R_0 and b are the regression parameters. The Vant Hoff equation was fitted using the soil temperature at 5 cm depth and the NEE at night when the friction velocity u* > 0.1 m/s. the parameter value were used to evaluate the R_{eco} at daytime. The net ecosystem production (NEP) and gross primary production (GPP) were calculated using the following equation:

$$\text{NEP} = -\text{NEE} \tag{2}$$

$$\text{GPP} = R_{eco} + \text{NEP} \tag{3}$$

2.5. Maize Phenology, Grain Yield

The maize phenology was observed every day after sowing seed according to the China Agriculture Meteorological Observation Criterion. The 40 maize plants were harvested at mature stage. The grain yield per square meter was calculated using the grain yield of the average single maize plant multiply to planting density per square meter. The carbon content in maize grain was calculated as follows:

$$C_{gr} = \left(1 - W_g\right) \cdot F_c \cdot Y \tag{4}$$

where C_{gr} is the carbon content of grain in unit area (g C/m^2), W_g represents the water content of maize grain (15.5%), F_c denotes the carbon conversion efficiency of maize grain (0.447), and Y is the grain in unit area (g Grain/m^2) [1].

3. Results

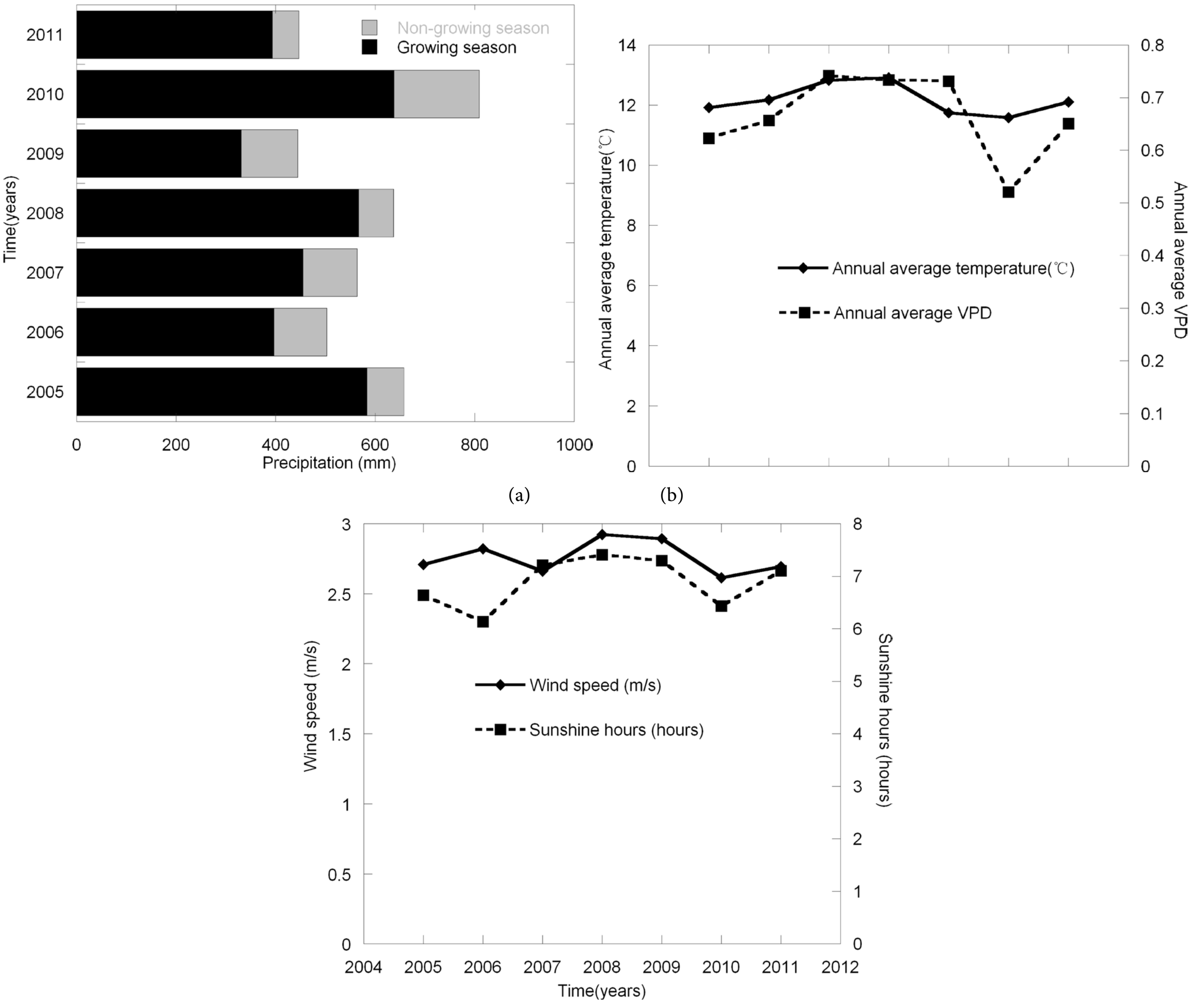
3.1. Meteorological Elements

From 2005 to 2011, the range of precipitation was 444.2 - 809.3 mm, 330.5 - 637.5 mm and 53.7 - 171.8 mm for annual, growing season, and non-growing season, respectively, and the mean precipitation was 580.3 mm, 480.5 mm and 99.8 mm, respectively (**Figure 1(a)**). Mean annual air temperature fluctuated between 11.59˚C and 12.91˚C with the mean value of 12.24˚C. Furthermore, mean annual air temperature for the nearly 3 years tended to be lower (**Figure 1(b)**). The minimum and maximum values of saturated vapor pressure deficit (VPD) were 0.52 and 0.74, respectively (**Figure 1(b)**). The mean annual sun hours varied from 6.13 to 7.41 h with the mean value of 6.77 h (**Figure 1(c)**). The mean annual wind speed varied from 2.61 to 2.92 m/s (**Figure 1(c)**).

3.2. NEE Dynamics

3.2.1. NEE in Non-Growing Season

During 2005-2011, half-hour CO_2 exchange in non-growing season represented



(a) (b)

(c)

Figure 1. Annual variation of meteorological factors in the study area.

carbon release, with the rate of 0.030 - 0.039 mg $CO_2/m^2 \cdot s$ ·and the mean value 0.033 mg $CO_2/m^2 \cdot s$. The maximum half-hour CO_2 release ranged from 0.343 to 0.621 mg $CO_2/m^2 \cdot s$, with the mean value 0.485 mg $CO_2/m^2 \cdot s$. Because weeds often occurred during the transition stage between non-growing season and growing season, the CO_2 was assimilated with the maximum rate of 0.102 - 0.597 mg $CO_2/m^2 \cdot s$ and the mean value 0.363 mg $CO_2/m^2 \cdot s$ (Figure 2). In one year, the non-growing season was divided into spring and winter non-growing seasons. The amount of CO_2 release during spring and winter fluctuated about 300 g CO_2/m^2, e.g., the mean total CO_2 release in winter and spring non-growing season were 337.16 and 273.76 g CO_2/m^2, respectively (Figure 3). The carbon release in non-growing season varied between 153.16 and 202.13 g C/m^2 with the mean value 168.59 g C/m^2 from 2005 to 2011 (Table 1).

3.2.2. NEE in Growing Season

The CO_2 exchange in growing season from 2005 to 2011 was shown as carbon

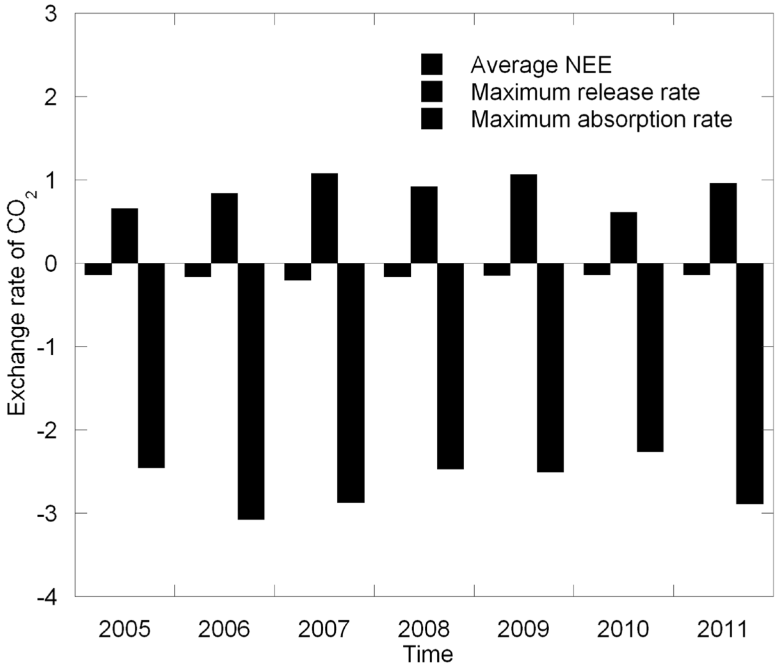


Figure 2. Half-hour NEE rate in non-growing season of maize from 2005 to 2011.

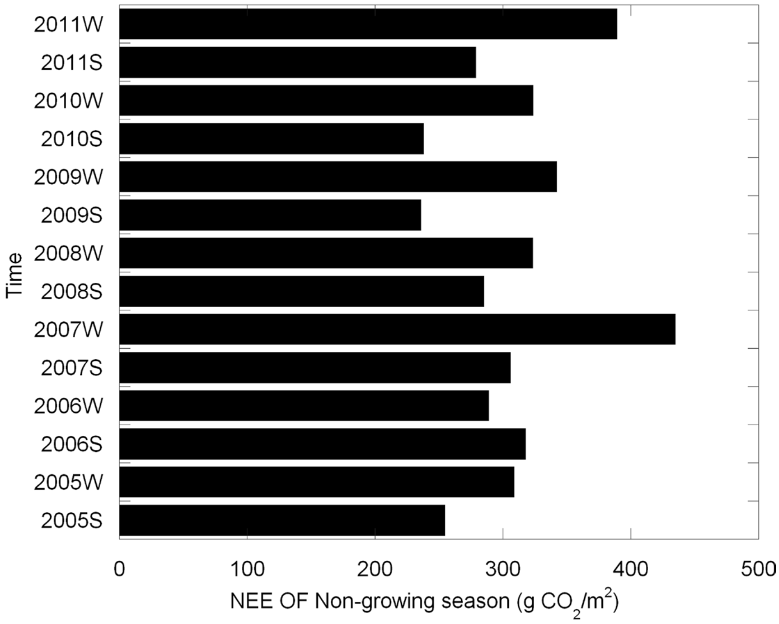


Figure 3. Total NEE in non-growing season of maize. W: winter; S: spring.

assimilation, with the fluctuating rate between −0.138 and −0.202 mg $CO_2/m^2 \cdot s$. The maximum and minimum values occurred in 2007 and 2010, respectively. The average annual CO_2 assimilating rate was −0.158 mg $CO_2/m^2 \cdot s$. For day timescale, the CO_2 budget was shown as carbon release at night and assimilation in the day time. The maximum value of CO_2 release varied between 0.061 and 1.079 mg $CO_2/m^2 \cdot s$, with the average annual value of 0.875 mg $CO_2/m^2 \cdot s$. The maximum value of CO_2 assimilation ranged from −2.261 to −3.078 mg $CO_2/m^2 \cdot s$, with the average annual value of −2.641 mg $CO_2/m^2 \cdot s$ (Figure 4). From 2005 to

Table 1. Carbon content in maize grain and NEE of annual, non-growing season and growing season in maize agricultural ecosystem.

	NEE of annual (g C/m^2)	NEE of growing season (g C/m^2)	NEE of non-growing season (g C/m^2)	Carbon content of the grain (g C/m^2)	Carbon content of others (g C/m^2)
2005	−334.61	−488.21	153.60	−283.29	−51.32
2006	−385.49	−551.02	165.53	−339.94	−45.55
2007	−487.33	−689.36	202.03	−334.26	−153.07
2008	−418.33	−584.20	165.87	−324.45	−93.88
2009	−354.34	−511.99	157.65	−311.59	−42.75
2010	−335.01	−488.17	153.16	−226.60	−108.41
2011	−316.96	−499.28	182.32	−284.13	−32.83
Average	−376.01	−544.61	168.59	−300.61	−75.40
Total	−2632.07	−3812.23	1180.16	2104.26	−527.812

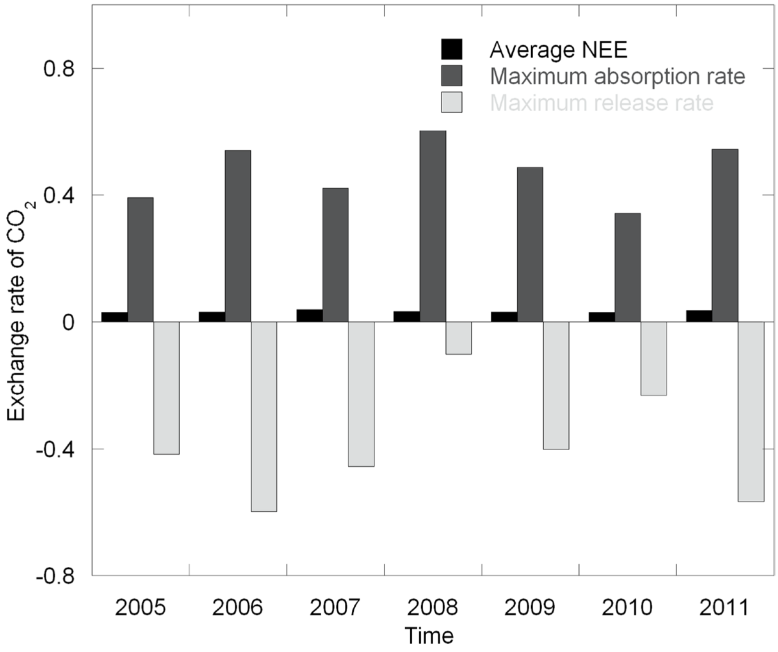


Figure 4. Half-hour NEE rate in growing season of maize from 2005 to 2011.

2011, carbon assimilation in growing season varied as a single peak curve, *i.e.*, the value tended to first increase and then decrease, likely related to annual meteorological conditions. The value of carbon assimilation in growing season in 2005-2011 ranged from −488.17 to −689.36 g C/m^2, with the average annual value of −544.61 g C/m^2 (**Table 1**).

During the process of maize growth, the CO_2 flux represented CO_2 release from sowing to seven leaf stages. The CO_2 exchange rates from sowing to emergence, emergence to three leaf and three leaf to seven leaf stages were 0.032 mg $CO_2/m^2 \cdot s$, 0.032 mg $CO_2/m^2 \cdot s$ and 0.022 mg $CO_2/m^2 \cdot s$, respectively. From seven leaf stage to mature, CO_2 was assimilated with a single peak curve of assimilating rate. The maximum value of −0.374 mg $CO_2/m^2 \cdot s$ occurred during flowering to milking stages, and there was the maximum fluctuation in this period (**Figure 5**).

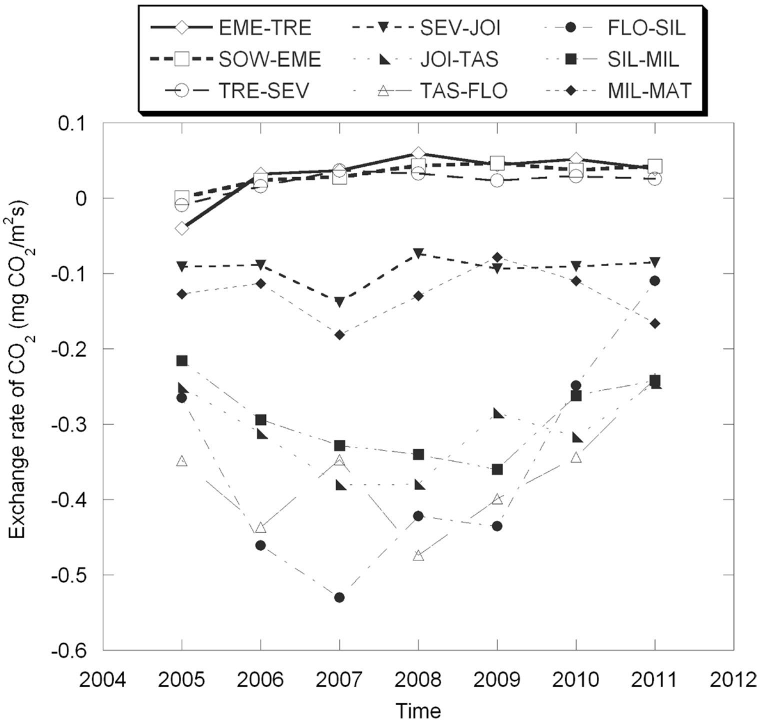


Figure 5. NEE rate at different development stages of maize from 2005 to 2011.

3.2.3. Annual NEE

The NEE showed carbon assimilation during growing season and carbon release during non-growing season, furthermore; carbon assimilating rate was far greater than carbon release rate. The CO_2 release in growing season might be resulted from continuous rainy weather. During growing season, carbon assimilation appeared as a single peak curve with the maximum in July and the minimum in both early May and late September. During non-growing season, CO_2 release was characterized by small shake (**Figure 6**). Carbon budget in rain-fed maize agricultural ecosystem was characterized by carbon sinks from 2005 to 2011, and annual carbon sink varied between −316.96 and −487.33 g C/m^2 and the average annual value was −367.01 g C/m^2 (**Table 1**).

3.3. NEE Regulation

3.3.1. Meteorological Regulation

The key factor influencing NEE in non-growing season was air temperature. Especially, the lowest air temperature was significantly correlated to NEE with the correlation coefficient of 0.72 ($P < 0.05$). The higher the lowest air temperature was, the more the NEE was. In growing season, the main meteorological factors affecting NEE included the maximum air temperature, vapor pressure deficit (VPD) and sun hours. As for annual NEE, the most important affecting factor was mean air temperature ($R = -0.81$, $P < 0.05$), followed by VPD ($R = -0.64$, $P < 0.1$). During maize reproductive growth, the NEE was significantly affected by meteorological factors, especially the air temperature, VPD, sun hours and precipitation (**Table 2**).

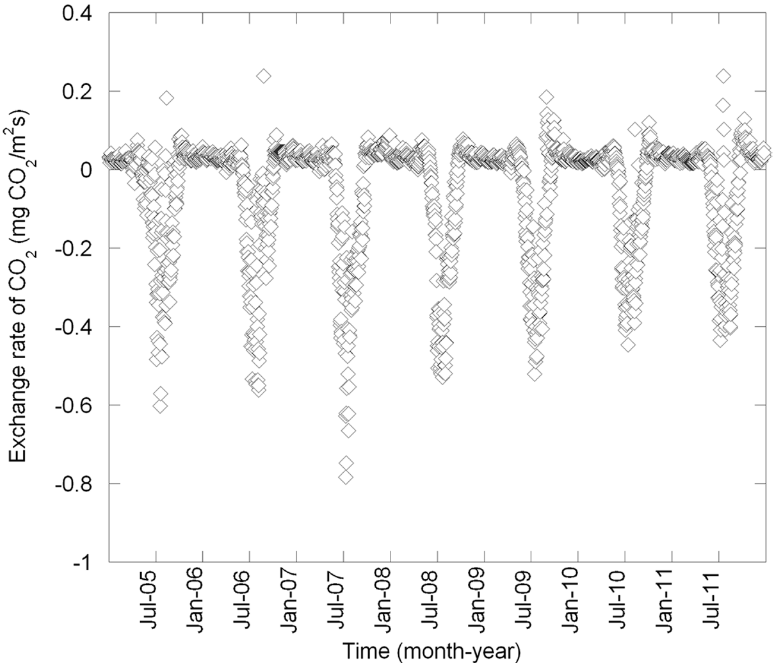


Figure 6. Daily mean NEE rate over maize agricultural ecosystem from 2005 to 2011.

Table 2. Relationship between meteorological factors and exchange rate of NEE at different development stage of maize.

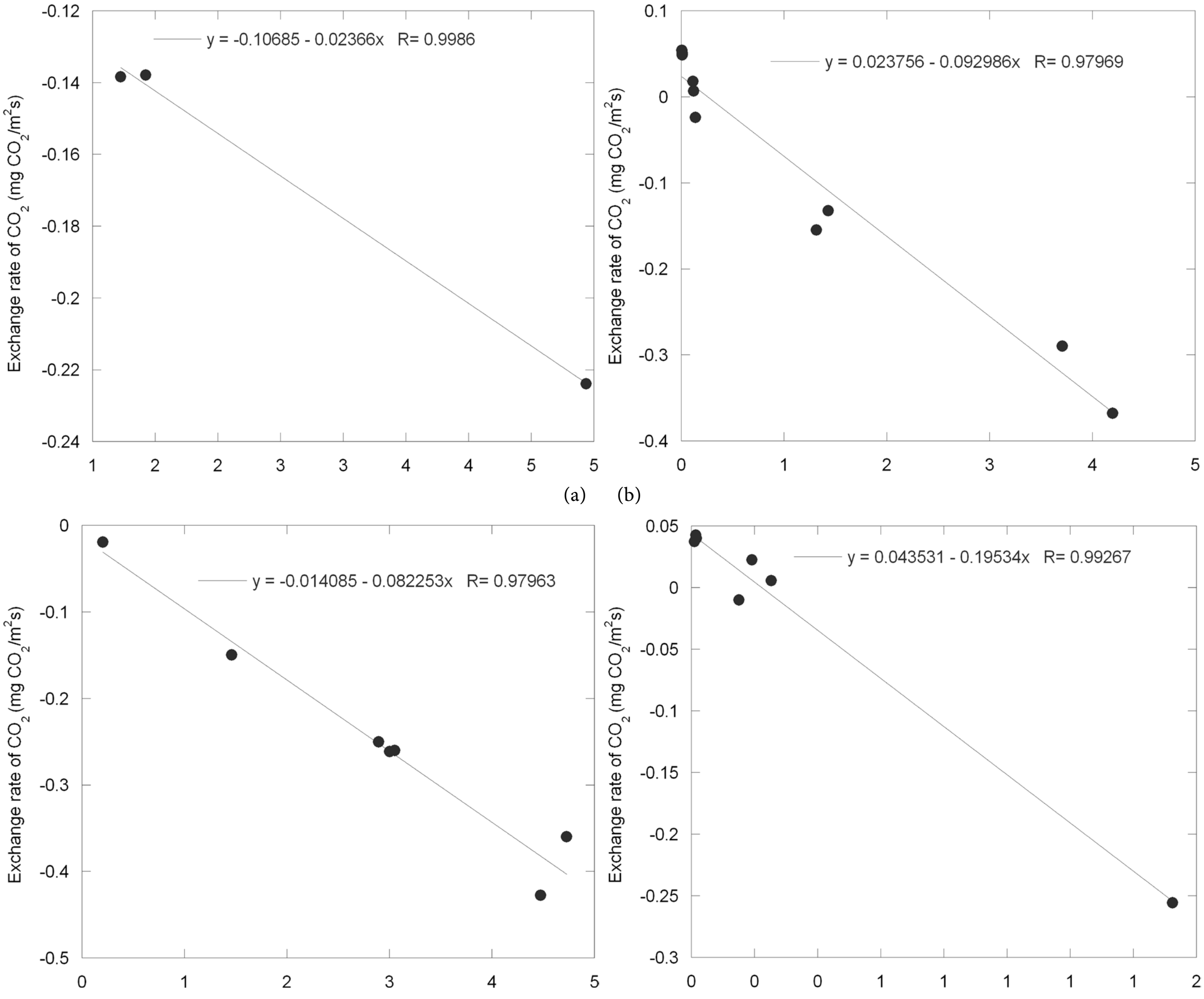
	Rainfall	Average air pressure (pa)	Average air temperature (˚C)	Average water pressure (pa)	Average relative humidity (%)	Average saturated vapor pressure deficit (pa)	Average sunshine hours (hours)	Minimum air temperature (˚C)	Maximum air temperature (˚C)
SOW-EME	0.38	0.30	−0.29	−0.13	−0.01	−0.12	−0.27	−0.31	−0.29
EME-TRE	−0.94***	−0.28	0.25	0.05	−0.12	0.16	0.48	−0.22	0.34
TRE-SEV	−0.42	−0.04	−0.17	−0.49	−0.26	0.17	0.19	−0.52	0.07
SEV-JOI	0.53	0.28	0.06	−0.20	−0.12	0.18	−0.40	0.29	0.12
JOI-TAS	−0.37	−0.39	−0.15	−0.35	−0.19	0.12	0.19	−0.22	−0.03
TAS-FLO	0.35	−0.25	−0.54	0.54	0.84**	−0.86**	−0.87**	−0.02	−0.68
FLO-SIL	−0.07	−0.23	−0.13	0.33	0.48	−0.44	−0.40	0.25	−0.38
SIL-MIL	0.79*	−0.42	−0.60	0.61	0.84**	−0.85**	−0.73*	0.03	−0.81*
MIL-MAT	0.60	−0.18	−0.58	0.15	0.45	−0.52	−0.65	−0.24	−0.61
Growing season	0.17	0.30	−0.53	0.63	0.65	−0.73*	−0.61	0.19	−0.89**
Non-growing season	−0.28	0.52	0.65	0.44	0.28	0.19	0.02	0.72*	0.54
Annual	0.13	0.15	−0.81*	0.49	0.16	−0.64	−0.32	−0.65	−0.77*

Notes: *: $P < 0.05$; **: $P < 0.01$; ***: $P < 0.001$. Development stage: SOW-EME: Sow seed to seedling emergence; EME-TRE: Seedling emergence to trefoil; TRE-SEV: Trefoil to seven leaf; SEV-JOI: Seven leaf to joint; JOI-TAS: Joint to tassel; TAS-FLO: Tassel to flower; FLO-SIL: Flower to silk; SIL-MIL: Silk to milk; MIL-MAT: Milk to mature.

3.3.2. Biological Regulation

There was a significant influence of maize leaf area index (LAI) on NEE. When PAR changed little, CO_2 assimilating rate increased with LAI. For example, when PAR was 400 - 600 μmol/m²·s, 600 - 800 μmol/m²·s, 800 - 1000 μmol/m²·s and more than 1000 μmol/m²·s, the squared correlation coefficient between NEE and LAI were 0.997 ($P < 0.001$), 0.956 ($P < 0.001$), 0.961 ($P < 0.001$) and 0.985 ($P < 0.001$), respectively. At these four levels of PAR, the slopes of linear functions between NEE and LAI were −0.0237, −0.0816, −0.0935 and −0.1957, respectively (**Figure 7**), indicating that variation extent of CO_2 assimilation was caused by LAI. Therefore, the more the PAR was, the stronger effect of LAI on the NEE was.

Total amount of carbon budget during growing season was determined by time length of maize development stage. The relationships between NEE had a positive related with days of growing season ($R = 0.63$), days from sowing to seven leaf stage ($R = 0.58$), and a negative related with days from seven leaf to mature stage ($R = 0.37$), indicating that the longer the growing season and the time from sowing to seven leaf stage were, the less the CO_2 assimilation was, and the longer the time from seven leaf to mature stage was, the more the CO_2 assimilation was.



(a) (b)

(c) (d)

Figure 7. Relationship between leaf area index and NEE under different PAR levels in maize agricultural ecosystem. The grading of mean PAR from 8:00 am to 4:00 pm: (a): 400 - 600 μmol/m²·s, (b): 600 - 800 μmol/m²·s, (c): 800 - 1000 μmol/m²·s, (d): >1000 μmol/m²·s.

Therefore, the growing season was extended owing to the prolonged time from sowing to seven leaf stage so that the NEE during growing season decreased. The sowing stage was negatively correlated with the NEE during the growing season, *i.e.*, the earlier the sowing was, the longer the early stage of maize development was, and the function of carbon sink was weaken.

4. Discussion

During non-growing season, the mean and range of NEE in rain-fed maize agricultural ecosystem in Northeast China were 168.59 g C/m^2 and 153.16 - 202.03 g C/m^2, respectively, slightly lower than in the rain-fed maize in Nebraska (170 - 255 g C/m^2) [4]. During growing season, the mean and range of NEE were −544.61 and −689.36 - −488.17 g C/m^2, respectively, higher than that over summer maize in Yucheng (−165.6 g C/m^2 and −120.1 g C/m^2) [8], rice in Sanjiang plain (−530 g C/m^2) [22], and winter wheat in Anhui (−326.87 g C/m^2) [23]. For annual NEE, the mean and range of NEE were −376.01 g C/m^2 and −316.96 - −487.33 g C/m^2, respectively, higher than in forest ecosystems in temperate zone, such as Harvest forest (−200 g C/m^2) [24], Howland forest (−174 g C/m^2) [25] and Changbai mountains (−169 - −187 g C/m^2) [26], but lower than in subtropical forests, such as Dinghu mountain (−441.2 - −563 g C/m^2) [27] and Qinanyanzhou (−553 - −645 g C/m^2) [28]. The average annual NEE in the present study was much higher than in grassland ecosystem, such as tall grass steppe (−50 - −275 g C/m^2) [11], temperate grassland (18 - −20 g C/m^2) [29], and Mediterranean grassland (30 - −130 g C/m^2) [30].

In the present study, the mean rate of CO_2 release was 0.033 mg CO_2/m^2·s during non-growing season from 2005 to 2011. Carbon release could be decreased by 2.85 g CO_2/m^2·d due to shortening non-growing season. The mean rate of CO_2 assimilation during growing season was −0.158 mg CO_2/m^2·s, 5 times higher than during non-growing season. The variation of NEE in each development stage of maize was quite large. For example, from sowing to three leaf stage of about 36 days, the carbon budget appeared CO_2 release with the rate of 0.029 mg CO_2/m^2·s, which was consistent with the result that there is CO_2 absorption in maize ecosystem after 30 - 35 days of sowing [4]. The absorption rate exponentially increased from seven leaf to flowering stage and reached the maximum value of −0.375 mg CO_2/m^2·s. From flowering to mature stage, the CO_2 absorption rate gradually decreased and reached the minimum value of −0.125 mg CO_2/m^2·s in mature stage. The period of CO_2 absorption was from seven leaf to mature stage of an average of 112 days. Therefore, the effects of the extension at different development stages on the NEE are various. Although the time length of CO_2 release was two times longer than that of CO_2 absorption, the annual CO_2 exchange was characterized by carbon sink. This carbon was changed into grain production of maize. The carbon content of the grain production ranged between −226.6 and −339.94 g C/m^2, with the mean value of 300.61 g C/m^2 (**Table 1**), which was slightly lower than that in non-tillage maize agricultural ecosystem in USA (−392.0 g C/m^2). Except for the grain production, the mean CO_2 exchange was −75.4 g C/m^2, characterized by carbon sink. The harvest index in ecosystem was 0.554 ± 0.058 slightly more than the value raised by Hollinger *et al.* (2005) [1].

Temperature is an important factor affecting the carbon balance of terrestrial ecosystems [31] [32]. In the present study, we found that air temperature significantly affected carbon balance of maize agricultural ecosystem, and especially the highest air temperature was positively correlated with carbon budget in both growing season and total one year ($P < 0.05$). The highest air temperature reflects temperature condition in daytime during growing season, and has direct effects on plant photosynthesis. The higher the daytime temperature is, the stronger photosynthetic rate is. Generally, higher VPD may cause stoma to close. Therefore, VPD reflects, to a certain extent, the ability of ecosystem carbon budget. For example, in the forest ecosystem, VPD can explain about 45% variation of carbon exchange [26]. At ecosystem level, when VPD is less than 1 kPa, gross ecosystem productivity (GEP) will rise with increasing VPD; but when VPD is greater than 1 kPa, GEP decreased with rising VPD [33]. VPD had significant impact on carbon exchange in rain-fed maize agricultural ecosystem of this study. At annual level, NEE increased with rising VPD, which meant VPD was less than 1 kPa. The length of photosynthetic time is mirrored by sunshine duration. The longer the sunshine duration is, the more the CO_2 absorption is. Therefore, the climate warming may enhance carbon absorption capacity in growing season and result in the increase of carbon release in non-growing season and annual carbon sequestration. For example, years of 2007 and 2008 with higher mean annual air temperatures showed higher NEE. The rainfall can affect NEE over rain-fed maize agricultural ecosystem. Such as, in the late development stage, the positive correlation between rainfall and NEE appeared much stronger, indicating that the increase of precipitation caused the decreasing NEE. When the precipitation was in the range of 400 - 800 mm during the growing season, the CO_2 absorption decreased with the rise of rainfall. Air temperature and precipitation in 2008 were higher than in 2007 (**Figure 1(a)** and **Figure 1(b)**), therefore, NEE in 2007 was much more than in 2008 (**Table 1**). In recent years, the climate tended to be warmer and drier in Northeast China [5]. This trend of climate could lead to the increase of carbon sink in rain-fed maize agricultural ecosystem in Northeast China.

Photosynthetic active radiation and leaf area index were two key biological factors affecting plant photosynthesis. The response intensity of photosynthesis rate to leaf area index increased with increasing PAR. Therefore, in the late period of growing season, the amount of PAR determined NEE of agricultural ecosystem. For example, during the period from seven-leaf to mature stage, long-time continuous overcast and rainy days could cause the sharp decline of annual CO_2 absorption. The advance of sowing can lengthen the early stage of maize development so that it cannot increase CO_2 absorption during growing season. Therefore, how to make clear the development period of maize in response to climate change is helpful to better assess the carbon budget of maize responding to climate change.

5. Conclusion

This study revealed carbon budget characteristics in non-growing season, growing season and annual based on the eddy-covariance observation data during 2005-2011. These conditions fluctuate from year to year and can cause the variety of carbon sink capacity. The proportion of the carbon budget in the growing season transformed into carbon content of maize grain yield was determined. The result provides a technical method for carbon budget assessment of warm temperate rain-fed maize ecosystem. The characteristics of carbon budget in different growth stages of maize were determined. There are carbon source in the maize seedling stage and the carbon sink in the middle and growth stage of maize. The differences of daily average temperature and saturated vapor pressure are the key factors affecting the carbon budget in maize fields.

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