Atmospheric Environment 84 (2014) 349–354

Contents lists available at ScienceDirect

Atmospheric Environment

journal homepage: www.elsevier.com/locate/atmosenv

Variation of NEE and its affecting factors in a vineyard of arid region of northwest China

W.H. Guo [a], S.Z. Kang [a,*], F.S. Li [b], S.E. Li [a]

[a] Center for Agricultural Water Research in China, China Agricultural University, Beijing 100083, China
[b] College of Agriculture, Guangxi University, Nanning, Guangxi 530005, China

HIGHLIGHTS

- Examined NEE variability and it was a carbon sinks.
- Diurnal variation of NEE was a "W" shape curve.
- Distinguish the main factors of the NEE.

ARTICLE INFO

Article history:
Received 15 July 2013
Received in revised form
21 November 2013
Accepted 25 November 2013

Keywords:
Net ecosystem CO_2 exchange
Eddy covariance
Vineyards
Arid region

ABSTRACT

To understand the variation of net ecosystem CO_2 exchange (NEE) in orchard ecosystem and it's affecting factors, carbon flux was measured using eddy covariance system in a wine vineyard in arid northwest China during 2008–2010. Results show that vineyard NEE was positive value at the early growth stage, higher negative value at the mid-growth stage, and lower negative value at the later growth stage. Diurnal variation of NEE was "W" shaped curve in sunny day, but "U" shaped curve in cloudy day. Irrigation and pruning did not affect diurnal variation shape of NEE, however, irrigation reduced the difference between maximal and minimal value of NEE and pruning reduced the carbon sink capacity. The main factors affecting hourly NEE were canopy conductance (g_c) and net radiation (R_n). The hourly NEE increased with the increase of g_c or R_n when g_c was less than 0.02 $m \cdot s^{-1}$ or R_n was between 0 and 200 $W \cdot m^{-2}$. The main factors affecting both daily and seasonal NEE were g_c, air temperature (T_a), atmospheric CO_2 density, vapour pressure deficit (VPD) and soil moisture content.

1. Introduction

Farmland and orchard ecosystem are directly affected by human activities, but most scientists focus on the farmland ecosystem. With new farming and management measures, such as zero tillage, minimum tillage and crop rotation, farmland may increase carbon uptake capacity and change itself into a carbon sink (Schimel et al., 2001). Studies show that diurnal variation of net ecosystem CO_2 exchange (NEE) at the top of winter wheat canopy is a single peak curve (Lin et al., 2008). Diurnal variation of NEE in maize is also a single peak curve (Zhang et al., 2008). Seasonal variation of NEE in rice is a "V" shaped curve (Feng et al., 2008). Temperature has an obvious effect on the NEE of winter wheat in early spring, while nighttime NEE has an exponential relationship with ground temperature of 0–10 cm (Li et al., 2007). In addition, hourly variations of NEE had a significant correlation with net radiation (Guo et al., 2006).

However, there are few studies on the NEE of orchard ecosystem, especially in arid orchard ecosystem. Due to low rainfall, high temperature difference between day and night and adequate sunlight in Shiyang river basin in the arid region of northwest China, the region is suitable for growing wine grape and has a large area of it, but the variation of NEE and its influencing factors are not clear. Thus the objectives of this study were to investigate the variation of vineyard NEE and main factors affecting the variation of NEE at different time scales after monitoring the variation of carbon flux in vineyard using eddy covariance system for three years.

2. Materials and methods

2.1. Experimental outline

The experiment was conducted at Shiyanghe Experimental Station for Water-saving in Agriculture and Ecology of China

* Corresponding author. Fax: +86 10 62737611.
E-mail addresses: guoweihuaaza@aliyun.com (W.H. Guo), kangsz@cau.edu.cn (S. Z. Kang).

1352-2310/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.atmosenv.2013.11.057

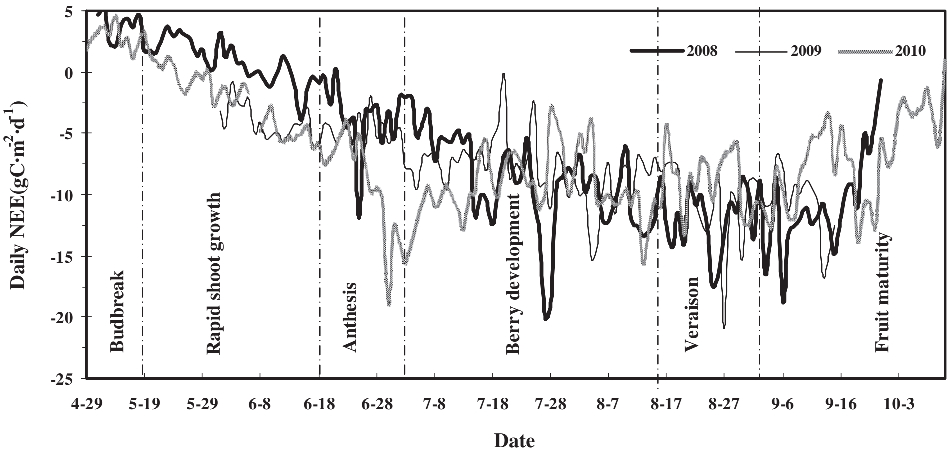

Fig. 1. Seasonal variation of vineyard NEE. NEE is net CO_2 exchange.

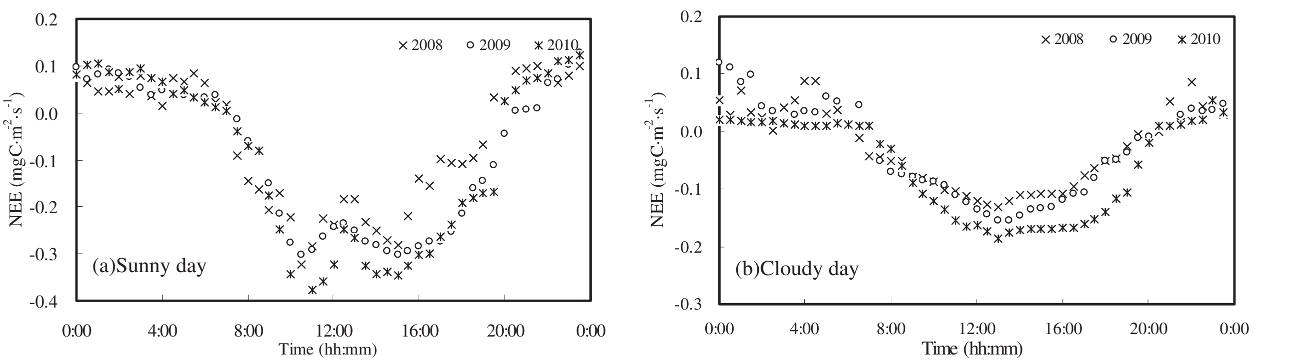

Fig. 2. Diurnal variation of vineyard NEE in sunny and cloudy days. Sunny days are 15 June 2008, 23 June 2009 and 20 June 2010, cloudy days are 3 July 2008, 27 June 2009 and 10 July 2010. NEE is net CO_2 exchange.

Agricultural University (37°51′N, 102°51′E, altitude 1585 m), located in Wuwei, Gansu Province of northwest China during 2008–2010. The site has high sunlight hours with a mean annual sunshine duration over 3000 h, mean annual temperature of 8 °C, frost-free days of 150 d and annual accumulated temperature (>0 °C) of 3550 °C. The region is limited in water resources with a mean annual precipitation of 164.4 mm and groundwater table of about 40–50 m. The experiment field is 1650 m long (south–north direction) and 1400 m wide (east–west direction). The experimental soil is irrigated desert soil (Siltigic-Orthic Anthrosols) and soil texture is sandy loam, with a mean dry bulk density of 1.45 g cm^{-3}, mean porosity of 52% and mean volumetric water content at field capacity of 0.35 cm^3 cm^{-3}. The experimental grapevines (Vitis vinifera L.cv Merlot) were planted in 1999 in east-west direction, with row spacing of 2.7 m and plant spacing of 1.0 m. The vineyard was furrow-irrigated 5 or 6 times during whole growth stage, with total irrigation of 300 mm each year.

2.2. Eddy covariance measurements

Eddy covariance system was located in the central south of the vineyard, 2.2 m above canopy, fetch length was from 300 to 1000 m. The eddy covariance sensor array included a CSAT3 three-dimensional sonic anemometer (Gill Instruments, UK), open-path H_2O & CO_2 analyzer (Li-Cor Inr., USA, Model LI-7500), HMP45C temperature and humidity sensor (Cambell Scientific, USA), NR-

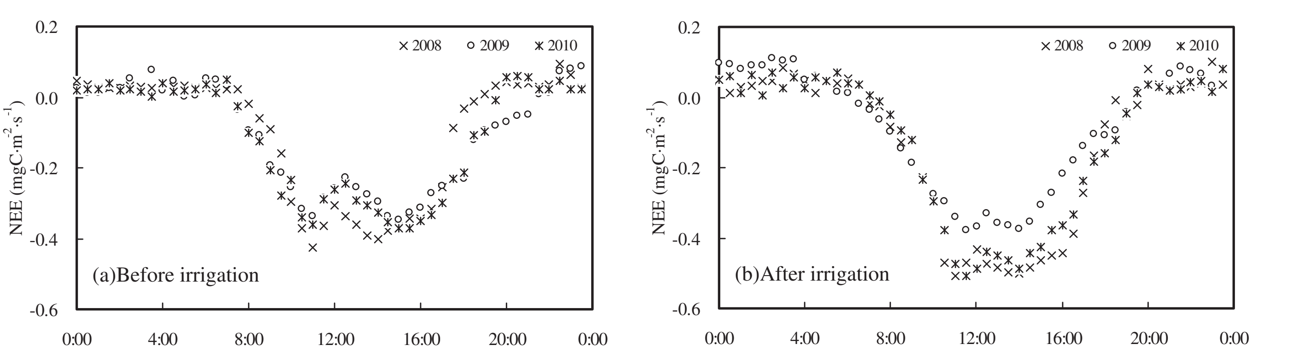

Fig. 3. Diurnal variation of vineyard NEE before and after irrigation. Irrigation days are 2 June 2008, 5 June 2009 and 10 June 2010. NEE is net CO_2 exchange.

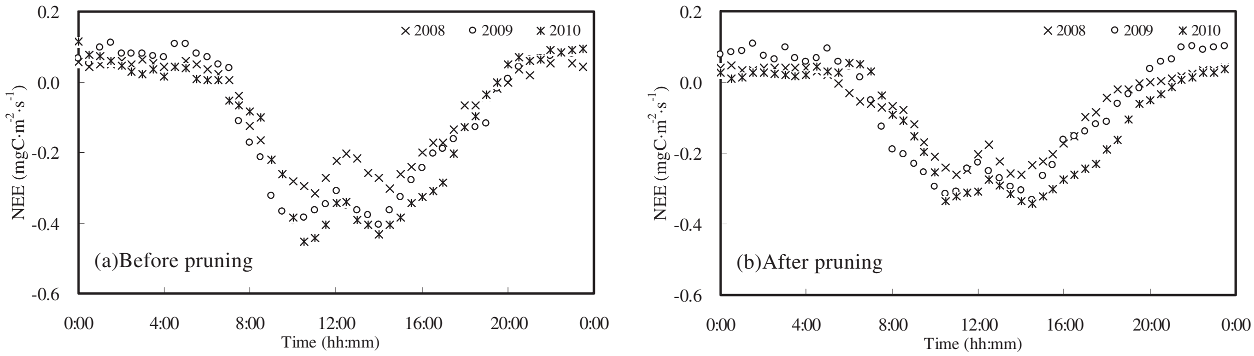

Fig. 4. Diurnal variation of vineyard NEE before and after pruning. Pruning days are 21 August 2008, 15 August 2009 and 16 August 2010. NEE is net CO_2 exchange.

LITE net radiometer (Kipp & Zonen, Holland), CS616 (Cambell Scientific, USA), soil moisture probes and CR5000 data logger (Cambell Scientific, USA). Wind speed, ultrasound virtual temperature, the densities of atmosphere, water vapour and CO_2 were measured by CSAT3 and Li-7500 every 0.1 s to obtain net CO_2 exchange above the canopy, latent and sensible heat. Average temperature and vapour pressure deficit can be measured by temperature and humidity probes every 30 min. Net radiometer was installed at 2.5 m height above the canopy. Soil moisture probes were buried at 10 cm layer both in the ditch and ridge to measure soil volumetric water content. All probes were connected with data logger, computing the average value of 30 min.

Fluxes were corrected for inadequate sensor frequency response (Zhu et al., 2004; Paw et al., 2000). And fluxes were adjusted for the variation in air density due to the transfer of water vapour (Webb et al., 1980; Wilczak et al., 2001). During nighttime, data were from the periods when $\overline{U}$ was greater than 2.5 m s^{-1} to minimize the interference related to insufficient turbulent mixing. Missing NEE data were interpolated using “average day and night method” (Falge et al., 2001).

3. Results and discussion

3.1. Seasonal variation of vineyard NEE

As shown in Fig. 1, seasonal variation of vineyard NEE was parabolic, which is similar to that of NEE in a forest ecosystem (Li et al., 2007). NEE before the rapid shoot growth stage in 2009 was not measured because of equipment problem; the early NEEs in 2008 and 2010 were slightly positive, indicating the vineyard was a weak carbon source, because the CO_2 absorbed by few leaves cannot offset that released by plants and soils at this stage. At the anthesis and berry development stages, the photosynthetic capacity increased rapidly, the NEE was negative, so the vineyard was a carbon sink. At the late berry development stage, NEE was high negative value and stable, with a mean NEE of −9 g C m^{-2} d^{-1}. At the fruit maturity stage, photosynthetic capacity reduced with the decrease of R_n and T_a, so the NEE decreased.

3.2. Diurnal variation of vineyard NEE

3.2.1. Diurnal variation of NEE in sunny and cloudy day

Fig. 2 (a) shows that vineyard NEE was generally positive at night and dawn, after sunrise the NEE became negative, diurnal variation of vineyard NEE in sunny day was “W” shaped curve, maximal NEE appeared at 10:00–11:00 and 14:00–15:00 and minimal NEE appeared at 12:00–12:30. Zhang et al. (2008) indicated that the variation of maize NEE is asymmetric “U” shaped curve, and the maximal value usually appears at 14:00–15:00. The possible reason for this “W”-shaped curve is that before 11:00, carbon sink increases with the increasing of radiation intensity. However, with the further increase of temperature and radiation, plant transpiration intensifies. In order to ensure that the plant does not lose much water, stomatal conductance become smaller to reduce transpiration, but CO_2 is also limited to enter the plants as the photosynthetic substrate, so carbon sink reduces until the appearance of the minimal NEE. After the midday, the stomatal conductance become larger again with the decline of radiation and temperature, so carbon sink capacity increases again and has the second peak.

As shown in Fig. 2(b), diurnal variation of NEE in cloudy day was “U” shaped curve and the variation was relatively stable. This is because strong radiation at noon is obscured by the clouds in cloudy day, and grapes do not need a “light lunch”, so negative NEE does not reduce, but increases slightly. Compared to the sunny day, the negative NEE was relative weak in cloudy day due to most of the light blocked by the clouds, which was different from forest ecosystem (Goulden et al., 1997).

3.2.2. Diurnal variation of NEE before and after irrigation

Fig. 3 (a) and (b) show that diurnal variation of NEE was “W”-shaped curves before and after irrigation, but the curve was smoother after irrigation. And irrigation increased the maximal NEE significantly, because irrigation increased the stomatal conductance, and then led to higher daily negative NEE. Irrigation reduced the difference between maximal and minimal NEE. The reason is that as irrigation significantly increased soil moisture content, the plant can absorb water from the soil to compensate for water loss by transpiration under higher temperature and radiation condition at midday, so irrigation did not reduce NEE significantly at noon.

3.2.3. Diurnal variation of NEE before and after pruning

As shown in Fig. 4, diurnal variation of NEE was “W”-shaped curves before and after pruning, but pruning reduced the maximal NEE due to its lower total leaf area for photosynthesis. In addition, pruning did not significantly affect the difference between maximal and minimal NEE.

3.3. The NEE of grape ecosystem compare to other ecosystems

Annual NEE in the vineyard was −820, −824 and −961 g C m^{-2} yr^{-1}, and nighttime carbon loss was 214, 241 and 286 g C m^{-2} yr^{-1} for 3 years, respectively (Table 1). Compared to carbon source/sink in the grassland ecosystem (Table 1),

Table 1
Comparison of net CO_2 exchange under different ecosystems.

Researcher	Type of ecosystem	Year	Annual NEE (g C m^{-2} yr^{-1})	Day NEE (g C m^{-2} yr^{-1})	Night NEE (g C m^{-2} yr^{-1})	Night/ Day NEE	Latitude	Longitude
Andrew et al. (2003)	Grass land	1997	−274	−812	538	66.3%	36°56′N	96°41′W
		1998	−46	−548	502	91.6%		
		1999	−124	−634	510	80.4%		
Our research	Vineyard	2008	−820	−1034	214	20.7%	37°51′N	102°51′E
		2009	−824	−1065	241	22.7%		
		2010	−961	−1247	286	22.9%		
Mudge et al. (2011)	Intensively grazed dairy pasture	2008	−160 ± 50	–	–	–	37°46′S	175°22′E
		2009	−229 ± 50					
Hollinger et al. (2005)	Maize	1997	−532	–	–	–	40°3′N	88°18′W
	Maize	1999	−692					
	Winter wheat	2008	−326					
Ryuichi et al. (2007)	Larch forest	2001	−164	–	–	–	42°44′N	141°31′E
Pan et al. (2006)	Grassland	2002	−223	–	–	–	–	–
		2003	−249					
		1981–1993	−37 ± 26					
Valentini et al. (1996)	Beech forest	1993	−472	–	–	–	41°52′N	13°38′E
Schmidt et al. (2012)	Winter wheat	2007	−270 ± 19	–	–	–	50°52′N	6°27′E
Ma et al. (2007)	Savanna	2009	−270 ± 18	–	–	–	38°26′N	120°57′W
		2001–2006	−98 ± 51					
Suni et al. (2003)	Open grassland	2000–2006	38 ± 52	–	–	–	61°51′N	–
	Tree	2001–2006	−367 ± 55					
	Coniferous forest	1997–2001	−194					
Goulden et al. (1996)	Deciduous forest	1991–1995	−220	–	–	–	42°43′N	–
Arnaud et al. (2003)	Mixed forest	1997–2001	111	–	–	–	51°18′N	4°31′E
Matthias et al. (2012)	Maritime grassland	2004–2009	−184	–	–	–	52°30′N	6°40′W

nighttime CO_2 release in the vineyard was about 50% of the grassland, but daytime CO_2 uptake was greater than grassland. The percentages of night CO_2 release to daytime CO_2 uptake for three years were 20.7%, 22.7% and 22.9% in the vineyard, while 66.3%, 91.6% and 80.4% in the grassland, respectively, indicating that carbon-sink efficiency is significantly higher in the vineyard than in the grassland. Compared to the forests and farmland ecosystems, annual negative NEE was grater in the vineyard than both ecosystems during the growth period, showing that the vineyard had stronger carbon-sink efficiency. High carbon sink of grape tree may be related to its physiological characteristics. The grape is suitable for growing under high light intensity and great temperature difference between day and night. Low ambient temperature during the night inhibits the respiration, which leads to lower positive NEE at night. In addition, grape fruits with high sugar content mean that more carbon is accumulated, also showing stronger carbon-sink efficiency.

3.4. Main factors affecting the variation of vineyard NEE at different time scales

3.4.1. Meteorological factor

As shown in Table 2, hourly NEE had better relationship with net radiation (R_n) ($R^2 = 0.43$), but had poor relationships with other meteorological factors. When R_n was between 0 and 200 W m^{-2}, hourly NEE increased rapidly with the increase of R_n ($NEE_{hour} = -0.0013R_n - 0.0335$). However, when R_n was higher than 200 W m^{-2}, it did not increase significantly with the increase of R_n. The possible reason is that there was a light saturation point for wine grape, i.e. about 200 W m^{-2} in this study.

Daily NEE had better relationship with air temperature (T_a), atmospheric CO_2 density and vapour pressure deficit (VPD), but had poor relationship with R_n (Table 1). When T_a was less than 25 °C, daily NEE increased with the increasing of T_a, and had a quadratic relationship with T_a ($NEE_{day} = -0.1532T_a^2 + 4.9181T_a - 44.687$).

Table 2
Relationship between net CO_2 exchange (NEE) and meteorological factors at different time scales. R_n is net radiation, T_a is air temperature and VPD is vapour pressure deficit.

Time scale	Meteorological factor	Relationship	R^2	*n*
Hourly	R_n (W m^{-2})	$NEE_{hour} = -0.0013R_n - 0.0335$	0.43	4569
		$NEE_{hour} = -0.0358R_n - 0.2944$	0.0025	2431
	CO_2 density (mg m^{-3})	$NEE_{hour} = -0.0001\ CO_2\ density - 0.1519$	0.0095	7000
	T_a (°C)	$NEE_{hour} = -0.0009T_a^2 - 0.0363T_a + 0.1336$	0.046	
	VPD (kPa)	$NEE_{hour} = -0.0544VPD^3 + 0.2716VPD^2 - 0.289VPD - 0.1664$	0.06	
Daily	R_n (W m^{-2})	$NEE_{day} = -0.0175R_n - 17.877$	0.14	180
	CO_2 density (mg m^{-3})	$NEE_{day} = -0.776\ CO_2\ density + 24.583$	0.42	
	T_a (°C)	$NEE_{day} = -0.1532T_a^2 + 4.9181T_a - 44.687$	0.88	113
		$NEE_{day} = -0.1749T_a^2 + 10.996T_a - 183.91$	0.96	67
	VPD (kPa)	$NEE_{day} = 7.8145VPD - 19.033$	0.52	180
Seasonal	R_n (W m^{-2})	$NEE_{growth} = -0.0409R_n - 16.321$	0.057	12
	CO_2 density (mg m^{-3})	$NEE_{growth} = -0.0526\ CO_2\ density + 15.315$	0.68	
	T_a (°C)	$NEE_{growth} = -13928T_a + 19.221$	0.84	
	VPD (kPa)	$NEE_{growth} = 13.311VPD\ -v20.47$	0.42	

However, when T_a was more than 25 °C, daily NEE decreased with the increasing of T_a ($NEE_{day} = -0.1749T_a^2 + 10.996T_a - 183.91$). Possible reason is that photosynthesis, as an enzymatic reaction, needs an optimum temperature, i.e. 25 °C in this study, when T_a is more than the optimum temperature, the enzyme activities for light and dark reactions decreases, thus the photosynthetic capacity reduces. Because CO_2 is a major substrate for photosynthesis (Baldocchi et al., 2000), daily NEE also increased with the increasing of atmospheric CO_2 density, and there was linear relationship between daily NEE and CO_2 density ($NEE_{day} = -0.776$ CO_2 density $+ 24.583$, $R^2 = 0.42$). However, daily NEE reduced with the increased VPD ($NEE_{day} = 7.8145VPD - 19.033$, $R^2 = 0.52$).

Table 2 also shows that seasonal NEE had linear relationship with T_a ($NEE_{seasonal} = -1.3928T_a + 19.221$, $R^2 = 0.84$) or atmospheric CO_2 density ($NEE_{seasonal} = -0.0526$ CO_2 density $+ 15.315$, $R^2 = 0.68$). Seasonal NEE reduced with the increased VPD. However, there was poor relationship between seasonal NEE and net radiation ($R^2 = 0.06$).

3.4.2. Canopy conductance

As shown in Fig. 5 , when the canopy conductance (g_c) was lower than 0.02 m s^{-1}, the amount of CO_2 absorption mainly affected photosynthesis, and more CO_2 entered into the plants through the stomata with the increasing of g_c (Griffis et al., 2003), hourly NEE increased significantly. However, when g_c was higher than 0.02 m s^{-1}, CO_2 absorption reached the maximum demand of photosynthesis, so hourly NEE did not further increase. Daily NEE had similar relationship with g_c as hourly NEE, but there was linear relationship between seasonal NEE and g_c ($NEE = -113.48g_c - 6.7792$).

3.4.3. Soil moisture content

Fig. 6 shows that there was poor relationship between hourly NEE and soil moisture content at 0–10 cm layer, because the change in soil moisture content did not cause significant variation of NEE in a very short period. This was similar as the study on forest ecosystems (Malhi et al., 1999), although the correlation coefficients between daily and seasonal NEE and soil moisture content were lower, the increase in soil moisture content may increase daily and seasonal NEE in the vineyard.

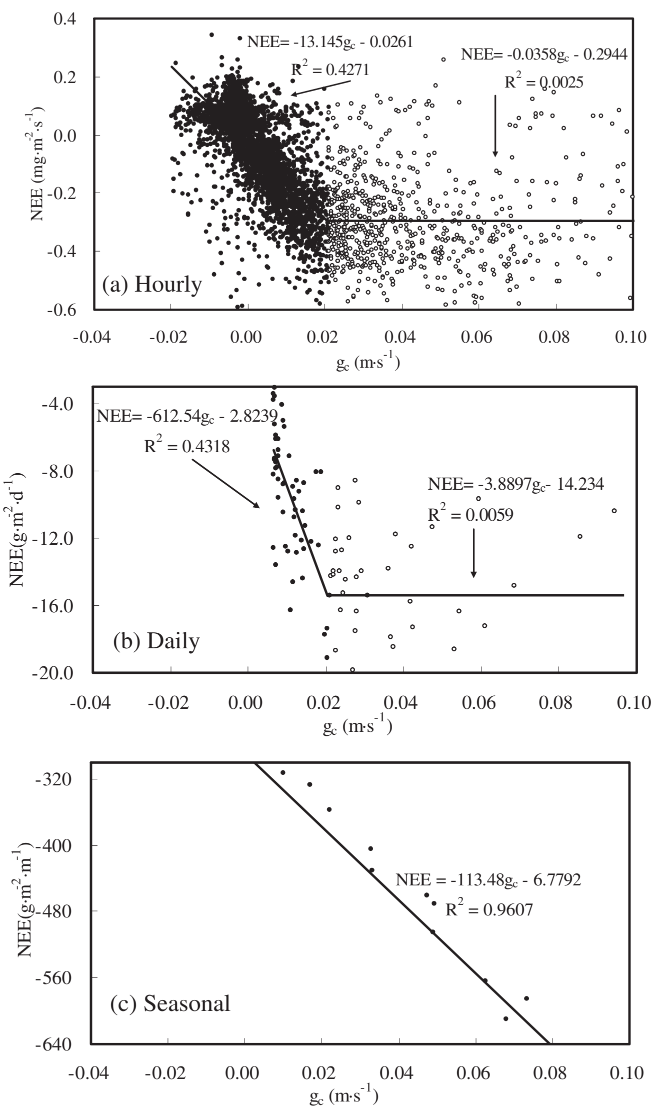

Fig. 5. Relationship between vineyard NEE and canopy conductance (g_c) at different time scales. NEE is net CO_2 exchange.

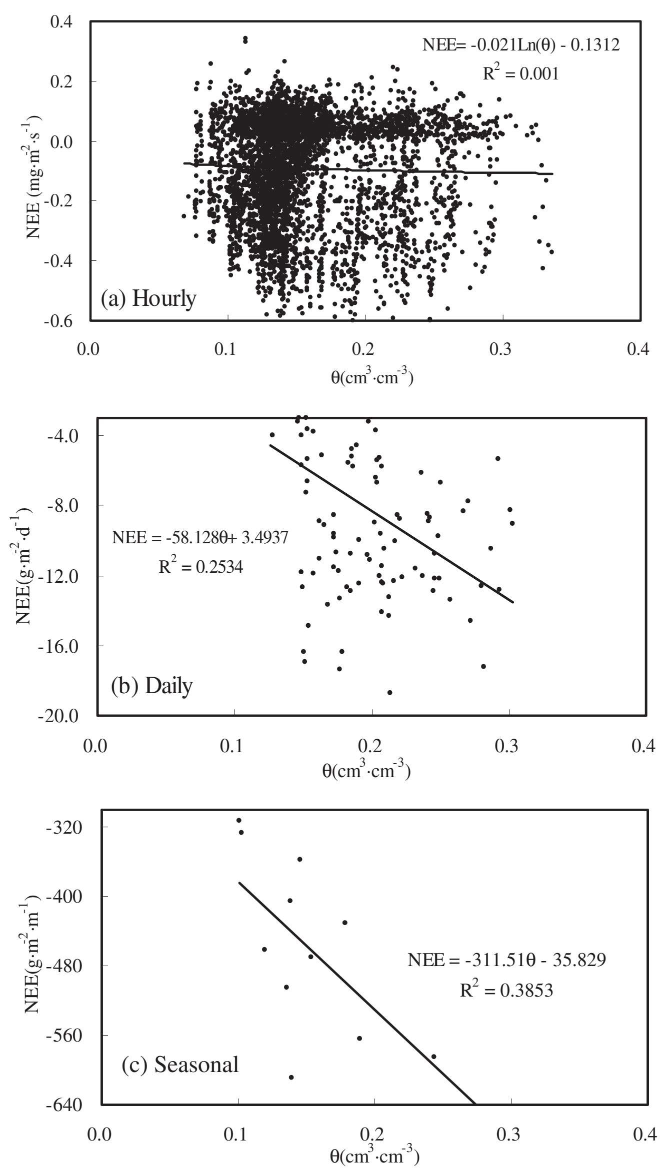

Fig. 6. Relationship between vineyard NEE and soil moisture content at different time scales. NEE is net CO_2 exchange.

4. Conclusions

This study was the first using eddy covariance system to measure the carbon flux in a wine vineyard. Our study show that vineyard NEE was positive value at the early growth stage, higher negative value at the mid-growth stage and lower negative value at later growth stage. In general, daytime NEE in sunny day was positive, nighttime NEE was negative and diurnal variation of NEE was a "W" shape curve. The diurnal variation of NEE in cloudy day was parabolic, and its peak NEE was less than that in sunny day. Irrigation and pruning did not affect the diurnal variation of NEE, but irrigation decreased the difference between maximal and minimal NEE and pruning reduced daytime NEE. The main factors affecting the variation of hourly NEE were canopy conductance and net radiation. Canopy conductance, temperature, atmospheric CO_2 density, vapour pressure deficit and soil moisture content were main factors affecting both daily and seasonal NEE.

Acknowledgements

This research was supported by the National Natural Science Foundation of China (50939005), the National High–Tech 863 Project of China (2011AA100502) and Chinese Universities Scientific Fund (2012yj120)).

References

Andrew, E.S., Shashi, B.V., George, G.B., et al., 2003. Interannual variability in net CO_2 exchange of a native tallgrass prairie. Global Change Biol. 9, 255–265.
Arnaud, C., Andrew, S.K., Johan, N., Ivan, A.J., Jorge, C.Y., Reinhart, C., 2003. Net ecosystem CO_2 exchange of mixed forest in Belgium over 5 years. Agric. Forest Meteorol. 119, 209–227.
Baldocchi, D., Finnigan, J., Wilson, K., Paw, K.T., Falge, E., 2000. On measuring net ecosystem carbon exchange over tall vegetation on complex terrain. Bound-Lay. Meteorol. 96, 257–291.
Falge, E., Baldocchi, D., Olson, R.J., et al., 2001. Gap filling strategies for long term energy flux data sets. Agric. Forest Meteorol. 107, 71–77.
Feng, M., Gong, S., Wei, L., Zhang, W.H., Hu, F.X., Zhang, C.H., Xiao, J.X., 2008. A study on the features of CO_2 concentration and flux changes and WUE in rice field. Acta Jiangxi Agric. Univer. Sinica 30, 927–932.
Goulden, M.L., Daube, B.C., Fan, M., Sutton, D.J., bazzaz, A., Munger, J.W., Wofsy, S.C., 1997. Physiological response of a black spruce forest to the weather. J. Geophys. Res. 102, 28987–28996.
Goulden, M.L., Munger, J.W., Fan, S.M., Daube, B.C., Wofsy, S.C., 1996. Measurements of carbon storage by long-term eddy correlation: methods and a critical assessment of accuracy. Global Change Biol. 2, 169–182.
Guo, J., Li, Y., Mei, X., 2006. Diurnal variation of instantaneous carbon dioxide flux and water use efficiency of winter wheat at field scale and analysis of influencing factors. Chin. J. Eco-Agric. 14, 78–81.
Griffis, T.J., Black, T.A., Morgenstern, K., Barr, A.G., Nesic, Z., Drewitt, G.B., Gaumont-Guay, D., McCaughey, J.H., 2003. Ecophysiological controls on the carbon balances of three southern boreal forests. Agric. Forest Meteorol. 117, 53–71.
Hollinger, S.E., Bernacchi, C.J., Meyer, T.P., 2005. Carbon budget mature no-till ecosystem in North Central Regional of the United States. Agric. Forest Meteorol. 130, 59–69.
Li, L., Zhang, H.L., Chen, F., Li, S.J., 2007. CO_2 flux and its correlation with soil temperature in winter wheat growth season under different tillage measures. Chin. J. Appl. Ecol. 18, 2765–2770.
Lin, T.B., Wang, Z.Q., Song, X.L., Qu, Y.W., Meng, Z.Y., 2008. CO_2 flux and impact factors in winter wheat field ecosystem. Chin. J. Appl. Ecol. 16, 1458–1463.
Ma, S., Baldocchi, D.D., Xu, L.K., 2007. Inter-annual variability in carbon dioxide exchange of an oak/grass savanna and open grassland in California. Agric. Forest Meteorol. 147, 157–171.
Malhi, Y., Baldocchi, D.D., Jarvis, P.G., 1999. The carbon balance of tropical temperate and boreal forests. Plant. Cell. Environ. 22, 715–740.
Matthias, P., Owen, C., Gerard, K., 2012. Management and climate effects on carbon dioxide and energy exchanges in a maritime grassland. Agric. Ecosyst. Environ. 158, 132–146.
Mudge, P.L., Wallace, D.F., Rutledge, S., Campbell, D.I., Schipper, L.A., Hosking, C.L., 2011. Carbon balance of an intensively grazed temperate pasture in two climatically contrasting years. Agric. Ecosyst. Environ. 144, 271–280.
Pan, Y.D., Luo, T.X., Birdsey, R., Hom, J., Melillo, J., 2006. New estimates of carbon storage and sequestration in China's forests: effects of age-class and method on inventory-based carbon estimation. Clim. Change 67, 211–236.
Paw, U., Baldocchi, D.D., Meyers, T.P., Wilson, K.B., 2000. Correction of eddy covariance measurements incorporating both advective effects and density fluxes. Bound-Lay. Meteorol. 97, 487–511.
Ryuichi, H., Takashi, H., Nobuko, S., et al., 2007. Seasonal and interannual variations in carbon dioxide exchange of a temperate larch forest. Agric. Forest Meteorol. 147, 110–124.
Schmidt, M., Reichenau, T.G., Fiener, P., Schneider, K., 2012. The carbon budget of a winter wheat field: an eddy covariance analysis of seasonal and inter-annual variability. Agric. Forest Meteorol. 165, 114–126.
Schimel, D.S., House, J.I., Hibbard, K.A., et al., 2001. Recent patterns and mechanisms of carbon exchange by terrestrial ecosystems. Nature 414, 169–172.
Suni, T., Berninger, F., Markkanen, T., et al., 2003. Inter-annual variability and timing of growing-season CO_2 exchange in a boreal forest. J. Geophys. Res. 108 (D9). http://dx.doi.org/10.1029/2002JD002381.
Valentini, R., Angelis, P.D., Matteucci, G., Monaco, R., Dore, S., Scarascia Mucnozza, G.E., 1996. Seasonal net carbon dioxide exchange of a beech forest with the atmosphere. Global Change Biol. 2, 199–207.
Webb, E.K., Pearman, G.I., Leuning, R., 1980. Correction of flux measurements for density effects due to heat and water vapour. Q. J. R. Meteorolog. Soc. 106, 85–100.
Wilczak, J.M., Oncley, S.P., Stage, S.A., 2001. Sonic anemometer tilt correction algorithms. Bound-Lay. Meteorol. 99, 127–150.
Zhang, Y.Q., Shen, Y.J., LIU, C.M., et al., 2008. Measurement and analysis of water, heat and CO_2 flux from a farmland in the north China plain. Acta. Geog. Sinica 57, 333–342.
Zhu, Z.L., Sun, X.M., Yuan, G., 2004. Related to non-flat underlying surface vorticity flux correction method and its application in China FLUX. Sci. China (Ser. D) 34, 37–45.