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ORIGINAL ARTICLE

Comparison of net ecosystem CO_2 exchange in cropland and grassland with an automated closed chamber system

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Abstract Field measurements of net ecosystem CO_2 exchange (NEE) with high temporal resolution are essential to construct a meaningful ecosystem C balance. The objectives of this study were to monitor NEE in high temporal resolution in cropland and grassland between middle August and middle November (2006) at Kleinhohenheim, Germany and to evaluate NEE in autumn. A fully automated temperature controlled closed chamber system with an infrared CO_2 analyzer was used to measure NEE. The measured NEE varied between the two ecosystems depending on changes in above-ground vegetation and environmental factors. The diurnal NEE pattern of daytime CO_2 uptake and night time CO_2 release was evident in the grassland, but not in the cropland as the crops were harvested at the beginning of the measurement period. The grassland generally showed higher night time NEE, but lower daytime NEE than the cropland. Night time NEE showed exponential dependence on air and soil temperature, resulting in Q_{10} of 1.8 and 1.9 (for air temperature), 2.3 and 2.4 (for soil temperature) in the grassland and cropland, respectively. The average daily NEE was 2.77 and 1.86 g CO_2-C m^{-2} day^{-1} in the cropland and grassland, respectively. Both ecosystems were sources of CO_2, during 3 months in autumn, but the grassland emitted less CO_2 by 87.9 g CO_2-C m^{-2} than the cropland.

Keywords Net ecosystem CO_2 exchange · Automated closed chamber system · Cropland · Grassland · Infrared CO_2 analyzer

Introduction

The global atmospheric concentration of CO_2 has increased from a pre-industrial value of about 280–379 ppm in 2005 (IPCC 2007). The primary source of the increase in CO_2 is fossil fuel use, but land-use changes also make a contribution (IPCC

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2007). Kucharik et al. (2001) estimated that many soils in United States have lost 30–50 % of the C that they contained prior to cultivation. Cultivation of soil, by plowing or other tillage methods, enhances the decomposition of soil organic carbon (SOC) and CO_2 production (Lal 2004; Chen et al. 2007). The conversion of cropland to grassland is one of the most effective strategies for mitigating the current increase in atmospheric CO_2 (Chen et al. 2009), due to elimination of tillage, more extensive rooting systems, greater root biomass and prolonged and continuous litter input in grassland relative to cropland (Gebhart et al. 1994).

Soil sampling and analysis of C content is the traditional method for assessment of C sequestration under various land use (Kurganova et al. 2014). However this method has several shortcomings: (1) losses or gains in SOC over short- and medium-term are difficult to detect because of high antecedent amounts and large temporal and spatial variability, (2) the labor intensive nature of soil sampling, (3) an arbitrary choice of sampling depth, and (4) offer little insight into causes and effects of underlying processes because of poor temporal resolution (Baker and Griffis 2005; Liang et al. 2012). In contrast, net ecosystem CO_2 exchange (NEE) between the biosphere and the atmosphere represents the difference between carbon uptake and loss (Dore et al. 2003), and determines whether an ecosystem is sequestering or releasing CO_2 in short and long periods. Negative NEE values indicate net assimilation or CO_2 uptake, and positive NEE values indicate net respiration or CO_2 loss. Measurements of NEE are needed in order to determine the C sink-source status of ecosystems, to improve our knowledge of the basic processes of CO_2 exchange, and to analyze how C exchange varies with environmental variables (Flanagan et al. 2002).

Two common approaches for measuring NEE are eddy covariance (EC) and chamber methods, each with distinct advantages and limitations. EC is widely applied to measure NEE at large-scale level (between hundred meters to several kilometers) (Baldocchi 2003). The EC method has the advantage of continuous time coverage, and not disturbing the environment around the vegetation. However, the EC has its own weaknesses. The accuracy of this method is only true over steady atmospheric conditions, flat terrain, homogenous surfaces as certain theoretical assumptions have to be made (Baldocchi 2003). Chamber systems quantify fluxes over relatively smaller surfaces (generally up to 1 m^2), and has being a unique method for plot-size field experiments as well as for CO_2 partitioning studies (Hafner et al. 2012). The potential sources of error with chamber methods include soil and atmosphere temperature changes under the chamber, diffusion of light, reduced wind during measurement, soil disturbance during deployment of the chambers, changes in humidity under the chamber, adequate mixing of gasses within the chamber before measurement, perturbations of the natural atmosphere pressure fluctuations, alternation of CO_2 concentration disturbing the normal flux, the uncertainty of calculation methods associated with determining CO_2 emission rates under chambers (Lund et al. 1999; Pedersen et al. 2001; Davidson et al. 2002; Kutzbach et al. 2007; Parkin and Ventera 2010). They are also criticized because of discontinuity of measurements. However, the chamber methods allow quantification of CO_2 sources (Kuzyakov 2006) and are more precise during the night time as compared to EC (Baldocchi 2003).

The objective of this study was to monitor NEE in high temporal resolution in cropland and grassland in Kleinhohenheim, Southwest Germany with a fully automated temperature controlled closed chamber system. Previous investigations into CO_2 flux were focused on the growing-season (Craine and Wedin 2002; Suyker et al. 2004), with few reports available on the C budget in autumn. Yet, CO_2 flux during autumn is one of the key components of the annual carbon balance (Piao et al. 2008). Therefore, the period between middle August to middle November (2006) was chosen to compare NEE in cropland and grassland and to evaluate NEE in autumn. Moreover, to clarify the main drivers of NEE in autumn in these two ecosystems seasonal and diurnal variability were also investigated and related to relevant environmental variables.

Materials and methods

Study site

This study was carried out at Kleinhohenheim (Latitude: 48°43′N, Longitude: 9°13′E), located in Stuttgart, Southwest Germany, with mean annual temperature of 8.8 °C, and mean annual precipitation of 700 mm (altitude: 407 m above sea level).

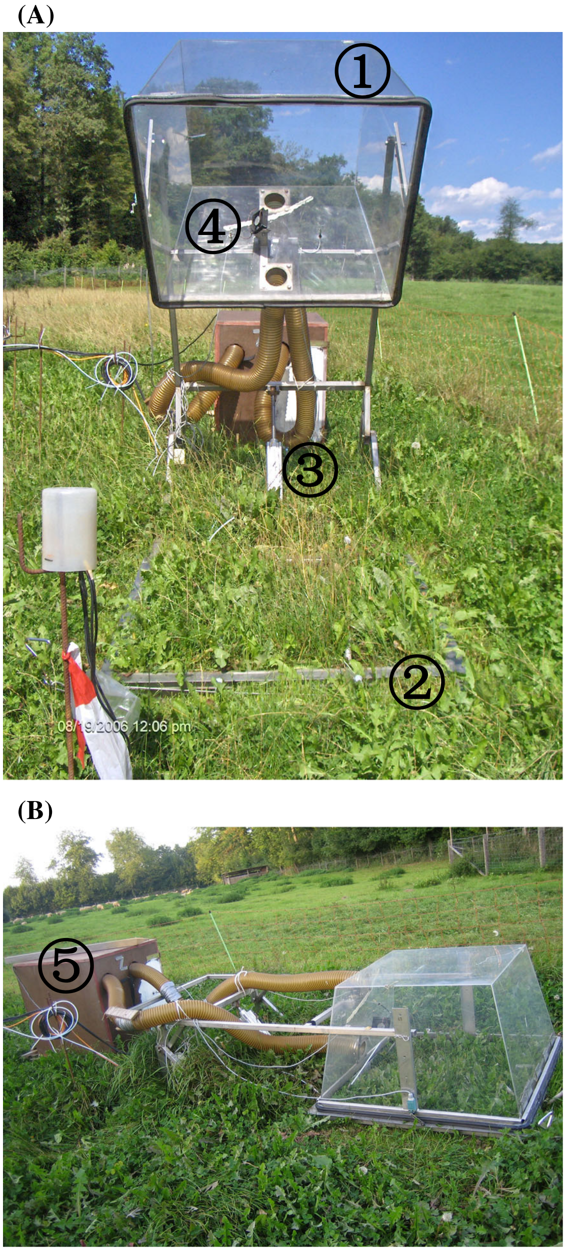


Fig. 1 Design of the automated closed chamber. **a** Between CO_2 measurements, the opening angle between the upper and the lower frame was 60°; **b** CO_2 measurements were undergoing; ① transparent plexiglass enclosure; ② metal frame; ③ cylinder; ④ fan; ⑤ air conditioner

Net ecosystem CO_2 exchange measurements were conducted in adjacent cropland and grassland with similar soil type (stagnic Luvisol according to WRB soil classification). The cropland has been managed as an organic farm system with tillage for about 20 years. The crop sequences in a 6-year rotation were vegetable in 2001/2002, summer wheat (*Triticum aestivum* L.) in 2002/2003, winter rye (*Lolium perenne* L.) in 2003/2004, carrots (*Daucus carota* L.) in 2004/2005, and summer wheat in 2005/2006. During our experiment period, summer wheat was harvested on August 20, 2006, and harvested wheat straw was removed. Winter rye was seeded on September 28, 2006. Weeds inside the chambers were removed by clipping at the soil surface and by hand removal of residue on September 12, 2006. The grassland was 25 years old and was dominated by *Alopecurus pratensis* (30 %), *Arrhenatherum elatius* (20 %), *Dactylis glomerata* (15 %) and *L. perenne* (10 %). It was not grazed during the measurement period. Grass inside the chambers was cut at the soil surface, and the cut grass was removed from the chambers on August 20, 2006 in order to investigate the effect of cutting on NEE. No fertilizers were added to either the cropland or the grassland during the duration of the study.

Automated net ecosystem CO_2 exchange measurements

NEE was measured using an automated closed chamber system, which was described in detail by Motz et al. (2001). The chamber includes a transparent plexiglass enclosure (allowing penetration of 90–96 % of the photosynthetically active radiation), an upper moving part of the frame, a lower static part of the frame. Between measurements, the opening angle between the upper frame and the soil surface was 60° (Fig. 1). The area that is being covered by the enclosure is 1 m^2, the enclosure is 60 cm in height and, since it is a few centimeters smaller at its top, has a volume of 512 L (Glatzel 1999).

Two chambers were installed in the cropland and grassland, respectively. The distance between the replicate chambers in each site was around 3 m. The metal frames were driven into the soil to 10 cm depth and the chambers were fastened to the soil using stainless steel screws. Since the maximum height of the grassland was usually <50 cm, the size of the chamber was appropriate for the purpose in grassland. In cropland, stainless extensions (1 m × 1 m × 0.4 m) were placed on the soil collar below the chamber from August 13 to 20, 2006.

One air compressor was equipped to control the opening and closure of the four chambers. Each chamber was equipped with an air conditioner to keep the air temperature inside the chamber consistent with outside air temperature when the chamber was closed (Fig. 1). A fan was attached inside the chamber to circulate air to ensure a uniform CO_2 concentration within the chamber when the chamber is closed (Fig. 1). An infrared CO_2 analyzer (IRGA, Li-Cor 6252, Li-Cor Inc., Lincoln, NE, USA) measured CO_2 concentration inside the chamber when the chamber was closed. The overall system operated automatically under the control of a computer.

The chamber system was installed on July 25, 2006. For each chamber, CO_2 concentrations were measured six times daily from August, 13 to November, 17, 2006, at about 2:00, 6:00, 10:00, 14:00, 18:00 and 22:00 respectively. Each chamber was sampled sequentially for 10 min after closure (we averaged the CO_2 concentration every minute by taking a reading every second and got 10 CO_2 data in 10 min).

The CO_2 gas flux was calculated from the linear increase or decrease in CO_2 concentrations (Maljanen et al. 2001). The linear regression was accepted if $R^2 > 0.95$.

Meteorology, soil and other parameter measurements

Climatic parameters such as soil temperature at 30 cm depth, air temperature at 2 m, and precipitation were measured from a nearby weather station at Kleinhohenheim (about 600 m away from the experimental plots). Soil volumetric water content in the 0–15 cm layer for each chamber was measured using time domain reflectometry at weekly interval from August 14 to November 12, 2006. Soil temperature at 15 cm depth in each chamber was also measured, however, due to the limited number of measurement times in our experiment, soil temperature at 30 cm depth from the weather station were used in the correlations analysis.

The relationship between night time NEE and temperature was expressed as an exponential function (Xu and Baldocchi 2004):

$$\mathrm{NEE}_{\text{night time}} = a\exp(bT) \tag{1}$$

where a and b are the empirical coefficients, and T is the soil temperature at 30 cm depth or air temperature at 2 m in this study.

The Q_{10} value can be calculated as

$$Q_{10} = \exp(10b) \tag{2}$$

where b is the value from Eq. (1).

Soil samples were collected from each chamber area on November 20, 2006. Soil cores (three cores from each chamber) were taken to 20 cm and separated into increments of 0–5, 5–10, and 10–20 cm. Soil bulk density samples were taken at the same soil depth intervals at one of the chambers in each sites. Soil organic C content (g kg^{-1}) was determined by dry combustion using a LECO RC 412 multiphase carbon analyzer. Total N (TN) content (g kg^{-1}) was determined by dry combustion using a LECO CN-2000 analyzer. Soil pH was measured in a 1:2.5 (w/v) soil to 0.01 M $CaCl_2$ solution with a glass electrode. Soil texture (0–20 cm) was determined by the pipette method (Schlichting et al. 1995).

Results

Weather conditions and soil physical and chemical characteristics

During our measurement period, air temperature ranged from −2.1 to 27.4 °C and soil temperature at 30 cm depth ranged from 6.3 to 18.6 °C (Fig. 2a, b). Total precipitation from Aug. 13 to Nov. 17 was 258 mm (Fig. 2c). Soil water content at 15 cm depth generally was higher in the grassland than in the cropland (Fig. 2d).

Soil pH was slightly acid in both cropland and grassland (Table 1). Soil textures were similar (silty loam) in the cropland and grassland. The grassland had higher SOC and TN contents and stocks than the cropland in the 0–5, 5–10, and 10–20 cm depth intervals. The grassland contained 82.1 % more SOC and 38.4 % more TN stocks than the cropland in the 0–20 cm depth interval.

Dynamics of net ecosystem CO_2 exchange

The net CO_2 exchange in the grassland ranged from 416.0 mg CO_2-C m^{-2} h^{-1} net assimilation to 474.1 mg CO_2-C m^{-2} h^{-1} net respiration (Fig. 3a). The average NEE was 77.6 mg CO_2-C m^{-2} h^{-1}. The cessation of net assimilation for 8 days after the cutting on day 232 can be seen from the absence of negative values from day 233 to day 240.

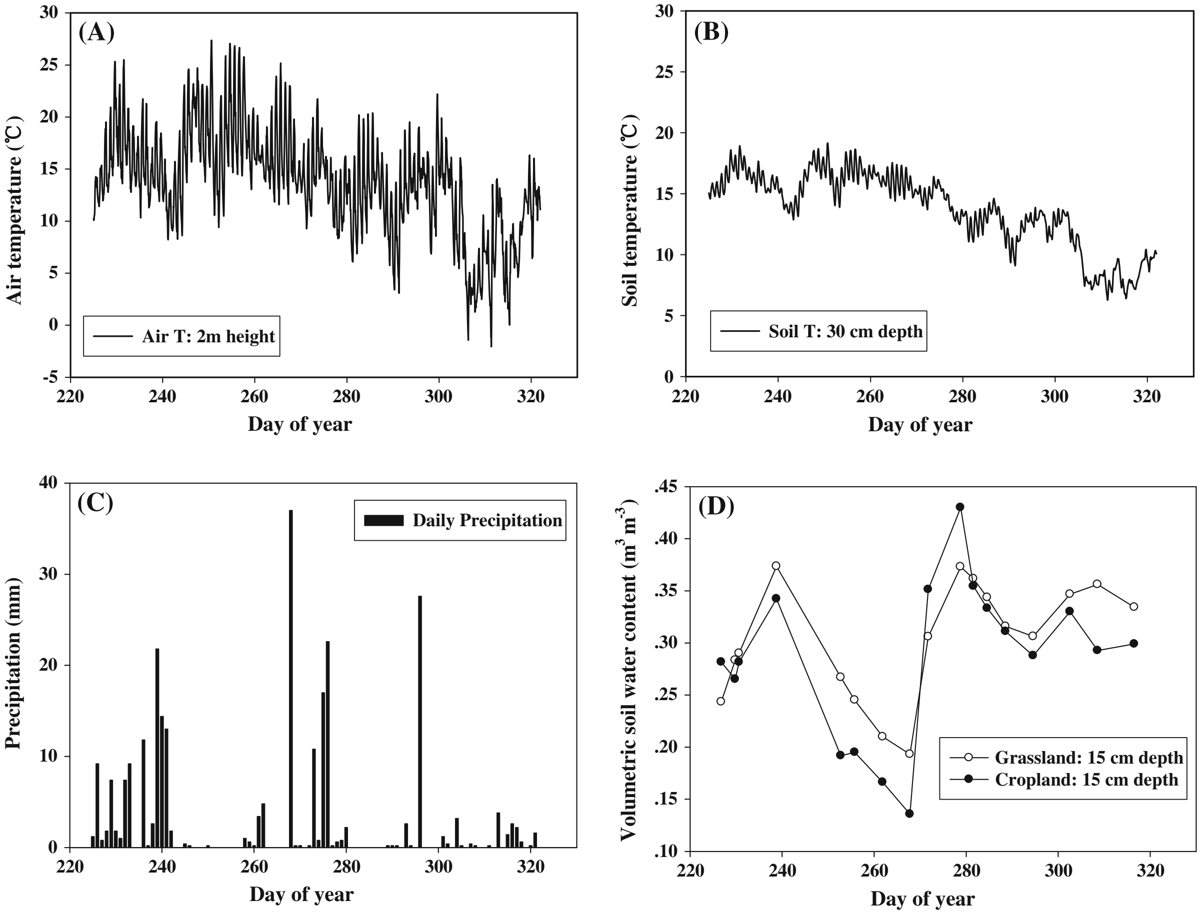


Fig. 2 **a** Air temperature at 2 m height; **b** soil temperature at 30 cm depth; **c** daily precipitation; **d** volumetric soil water content at 15 cm depth in the cropland and grassland from day 225 to day 321 in 2006 at Kleinhohenheim

NEE in the cropland ranged from −138.4 to 329.0 mg CO_2-C m^{-2} h^{-1} (Fig. 3b). The average NEE was 115.3 mg CO_2-C m^{-2} h^{-1}. Crops were in the senescence period at the beginning of our experiment (from days 225–232) and were harvested on day 232. The cropland showed no net CO_2 uptake from day 225 to day 249 and from day 256 to day 296 making the ecosystem a carbon source. The CO_2 uptake from day 250 to day 255 was connected with the photosynthetic activity of weeds. The cropland started CO_2 uptake on day 296 as rye grew up (it was seeded on day 271).

Compared with the cropland, the magnitude of net CO_2 uptake and net CO_2 loss was stronger in the grassland, and there were more cases of net CO_2 uptake in the grassland.

Daytime and night time net ecosystem CO_2 exchange

All NEE measurements were assigned to daytime or night time NEE with the aid of the sunrise and sunset times in Stuttgart in 2006 (www.timeanddate.com/worldclock/astronomy.html). Integrated daytime and night time NEE in the cropland and grassland were presented in Fig. 4a, b.

The night time NEE varied from 1.35 to 3.32 g CO_2-C m^{-2} day^{-1} in the grassland, and from 0.74 to 3.21 g CO_2-C m^{-2} day^{-1} in the cropland. The average night time NEE were 2.44 and 1.66 g CO_2-C m^{-2} day^{-1} in the grassland and cropland, respectively. The reduction in night time NEE in the grassland in response to the cutting on day 232 was

Table 1 Properties of the cropland and grassland soils at Kleinhohenheim

	Depth (cm)	Cropland	Grassland
pH	0–5	6.32	5.79
	5–10	6.33	5.77
	10–20	6.27	6.01
Bulk density (g cm^{-3})	0–5	1.30	1.19
	5–10	1.38	1.37
	10–20	1.42	1.39
SOC content (g kg^{-1})	0–5	10.53	27.72
	5–10	10.65	17.88
	10–20	10.77	17.95
TN content (g kg^{-1})	0–5	1.38	2.40
	5–10	1.24	1.57
	10–20	1.24	1.70
SOC stocks (Mg ha^{-1})	0–5	6.84	16.50
	5–10	7.35	12.25
	10–20	15.29	24.95
	0–20	29.48	53.69
TN stocks (Mg ha^{-1})	0–5	0.90	1.43
	5–10	0.86	1.08
	10–20	1.77	2.36
	0–20	3.52	4.87
Texture[a] (0–20 cm)	Sand (%)	3.9	5.9
	Silt (%)	78.4	73.0
	Clay (%)	17.7	21.0

[a] Sand 63–2,000 μm; silt 2–63 μm; clay <2 μm

apparent. The grassland generally showed higher night time NEE than the cropland (Fig. 4a).

The daytime NEE in the cropland ranged from −1.18 to 2.73 g CO_2-C m^{-2} day^{-1}, and the average daytime NEE was 1.05 g CO_2-C m^{-2} day^{-1}. The cropland usually showed a net loss of CO_2 during day time from day 225 to day 302. Maximum daytime net CO_2 loss of 3.48 g CO_2-C m^{-2} day^{-1} in the grassland was measured on day 303 after the cutting, and the CO_2 loss continued for several days until the grass grew up again. Maximum daytime net CO_2 loss of 4.82 g CO_2-C m^{-2} day^{-1} was observed in the grassland on day 233. The average daytime NEE in the grassland was −0.70 g CO_2-C m^{-2} day^{-1}. The grassland generally showed lower daytime NEE than the cropland (Fig. 4b).

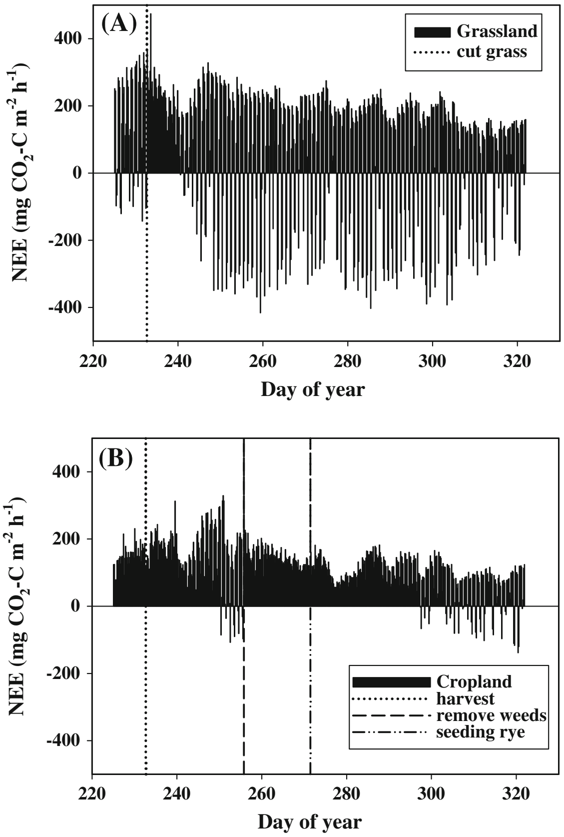


Fig. 3 NEE at **a** grassland; **b** cropland from day 225 to day 321 in 2006 at Kleinhohenheim. One bar presents one measurement. Also shown were events of the cutting of grass, harvest, weeds removal, seeding rye in the cropland

Daily and cumulative net ecosystem CO_2 exchange

The average daily NEE was 2.77 g CO_2-C and 1.86 g CO_2-C m^{-2} day^{-1} in the cropland and grassland, respectively. The daily NEE in both ecosystem tended to decrease during the autumn (Fig. 4c).

Both ecosystems were sources of CO_2 across our experimental period but more C was lost from cropland (268.4 g CO_2-C m^{-2}) compared to grassland (180.5 g CO_2-C m^{-2}) (Fig. 4d).

Diurnal variation in net ecosystem CO_2 exchange

The diurnal NEE variation patterns of daytime uptake and night time release were evident in the grassland,

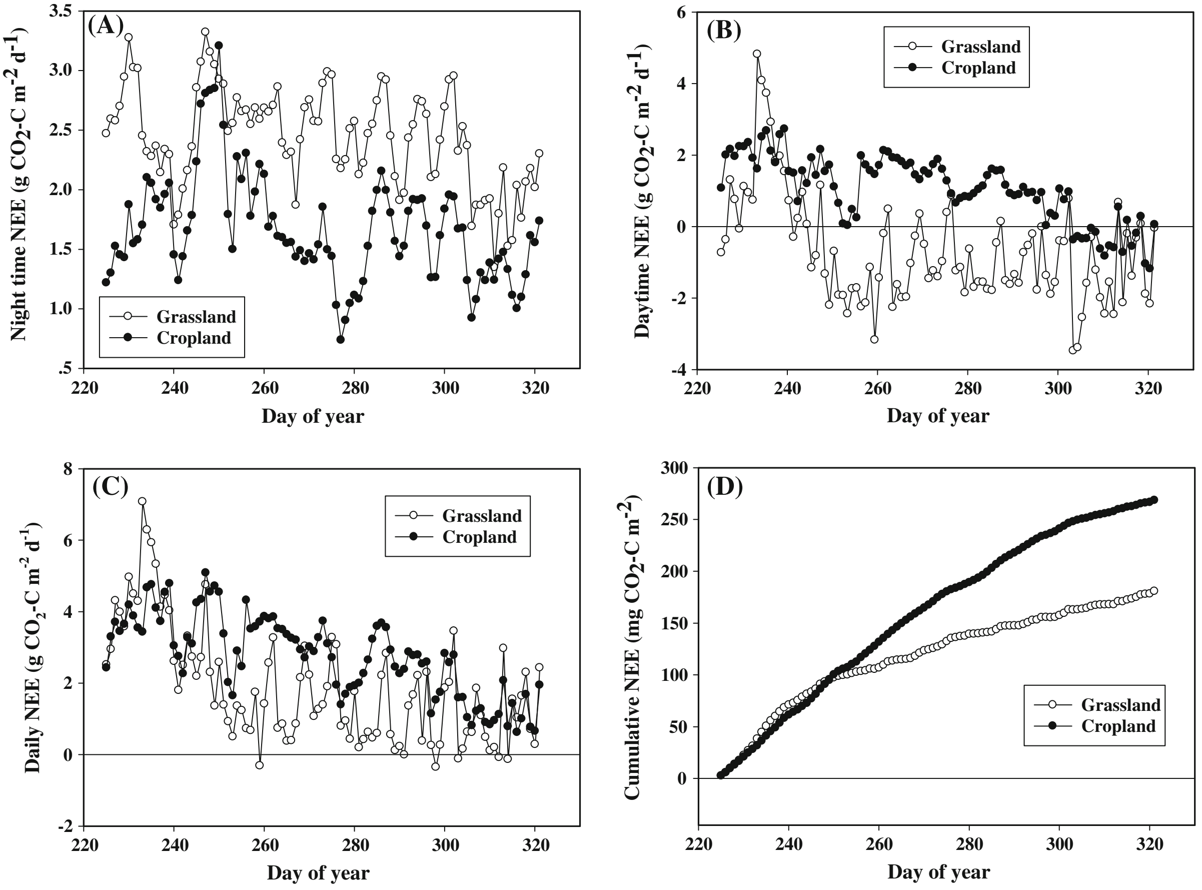


Fig. 4 **a** Night time NEE; **b** daytime NEE; **c** daily NEE; **d** cumulative NEE in the grassland and cropland from day 225 to day 321 in 2006 at Kleinhohenheim

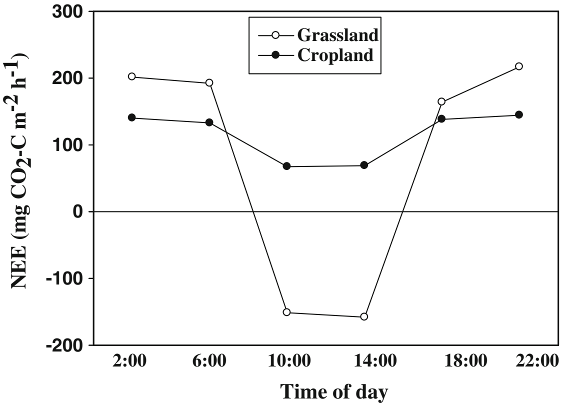


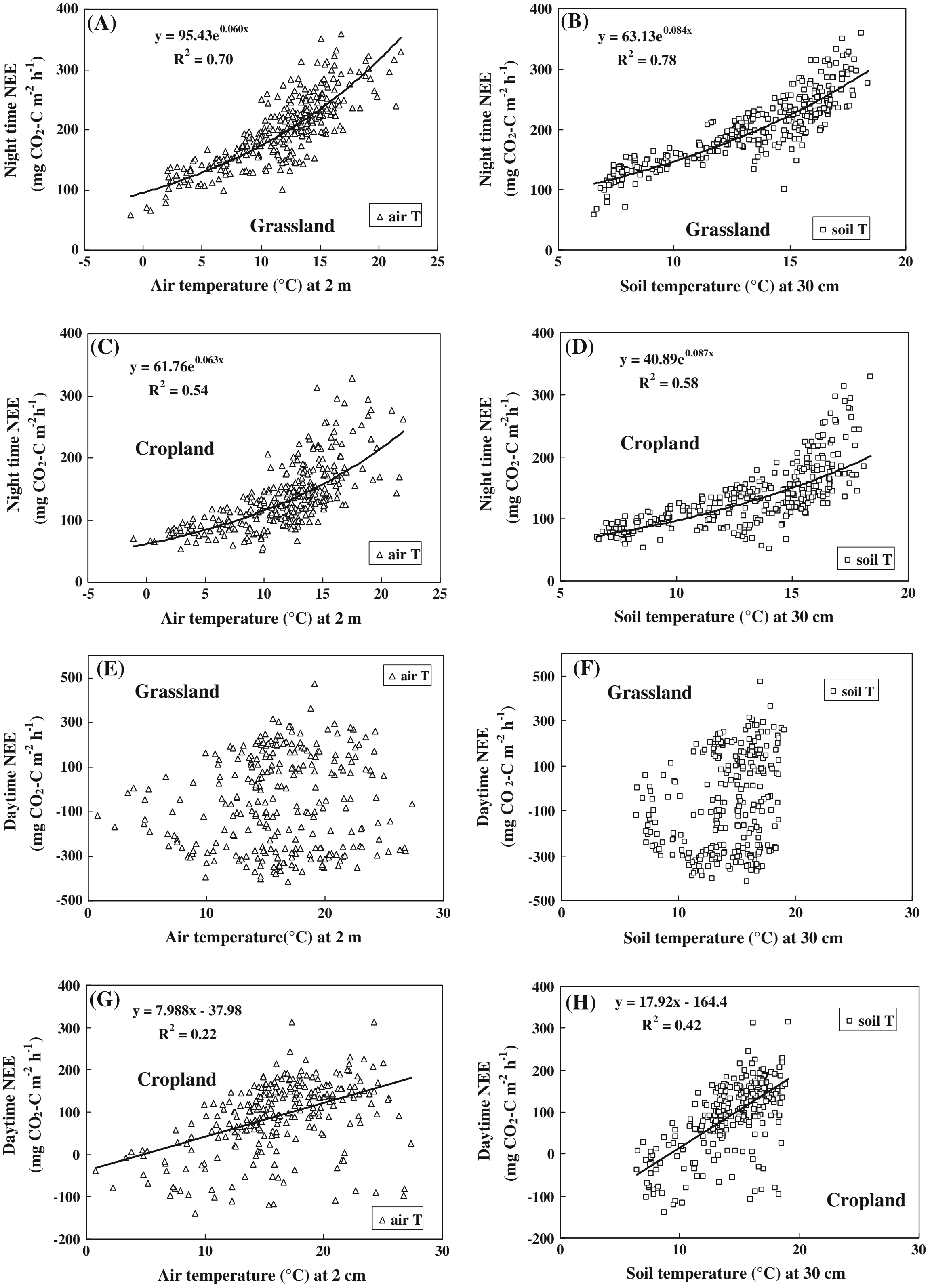
Fig. 5 Average diurnal NEE in the cropland and grassland from day 225 to day 321 in 2006 at Kleinhohenheim

but not in the cropland (Fig. 5). The cropland exhibited net CO_2 release at all the six measurements of the day, while the average NEE at 10:00 and 14:00 were lower than those at the rest four measurements, respectively.

Response of net ecosystem CO_2 exchange to environmental variables

Night time NEE was related to soil temperature at 30 cm depth ($R^2 = 0.78$, $p < 0.05$ for grassland, and $R^2 = 0.58$, $p < 0.05$ for cropland) and air temperature at 2 m height ($R^2 = 0.70$, $p < 0.05$ for grassland, and $R^2 = 0.54$, $p < 0.05$ for cropland) in both ecosystems (Fig. 6a–d).

When the daytime NEE was plotted against the air or soil temperature in the grassland, no single temperature function was found to describe the variations in daytime NEE (Fig. 6e, f). However, a much better linear relationship was found between daytime NEE and air and soil temperature in the


(A)
y = 95.43e^0.060x
R^2 = 0.70
Grassland
△ air T
Night time NEE (mg CO2-C m-2 h-1)
Air temperature (°C) at 2 m
400
300
200
100
0
-5
0
5
10
15
20
25
(B)
y = 63.13e^0.084x
R^2 = 0.78
Grassland
□ soil T
Night time NEE (mg CO2-C m-2 h-1)
Soil temperature (°C) at 30 cm
400
300
200
100
0
5
10
15
20
(C)
y = 61.76e^0.063x
R^2 = 0.54
Cropland
△ air T
Night time NEE (mg CO2-C m-2 h-1)
Air temperature (°C) at 2 m
400
300
200
100
0
-5
0
5
10
15
20
25
(D)
y = 40.89e^0.087x
R^2 = 0.58
Cropland
□ soil T
Night time NEE (mg CO2-C m-2 h-1)
Soil temperature (°C) at 30 cm
400
300
200
100
0
5
10
15
20
(E)
Grassland
△ air T
Daytime NEE (mg CO2-C m-2 h-1)
Air temperature(°C) at 2 m
500
300
100
-100
-300
-500
0
10
20
30
(F)
Grassland
□ soil T
Daytime NEE (mg CO2-C m-2 h-1)
Soil temperature (°C) at 30 cm
500
300
100
-100
-300
-500
0
10
20
30
(G)
y = 7.988x - 37.98
R^2 = 0.22
Cropland
△ air T
Daytime NEE (mg CO2-C m-2 h-1)
Air temperature (°C) at 2 cm
400
300
200
100
0
-100
-200
0
10
20
30
(H)
y = 17.92x - 164.4
R^2 = 0.42
Cropland
□ soil T
Daytime NEE (mg CO2-C m-2 h-1)
Soil temperature (°C) at 30 cm
400
300
200
100
0
-100
-200
0
10
20
30

◀ **Fig. 6** Relationships between night time NEE and air temperature at 2 m in the grassland (**a**); night time NEE and soil temperature at 30 cm depth in grassland (**b**); night time NEE and air temperature in the cropland (**c**); night time NEE and soil temperature in the cropland (**d**); daytime NEE and air temperature in the grassland (**e**); daytime NEE and soil temperature in the grassland (**f**); daytime NEE and air temperature in the cropland (**g**); and daytime NEE and soil temperature in the cropland (**h**) from day 225 to day 321 in 2006 at Kleinhohenheim

cropland (Fig. 6g, h, $R^2 = 0.22$ for air temperature, $p < 0.05$; $R^2 = 0.42$ for soil temperature, $p < 0.05$).

We plotted NEE from the cropland and grassland as a function of soil water content or precipitation, no significant correlations were observed with soil water content or precipitation (Figures not shown).

Discussion

Automated closed chamber system

The exchange of CO_2 between a vegetated surface and the atmosphere is an important component of the global C cycle. Accordingly, accurate and continuous measurements of surface-atmosphere gas exchange are essential to construct a meaningful ecosystem C balance. Chamber artifacts and bias can cause serious errors in CO_2 flux measurements (Davidson et al. 2002), but they can be minimized or avoided with proper chamber designs.

The automated closed chamber system described in our study has several advantages over non-automated chambers. The enclosures are made of transparent plexiglass with 90–96 % transmission. Therefore, photosynthesis inside the chamber was minimally reduced, making it possible to measure NEE. Non-automated chambers at best provide a continuous temporal resolution on the order of days, weeks or months due to sampling and analysis limitations (Ambus and Robertson 1998). Fully automated closed chambers presented in this study offer a means of continuous measurements at short intervals (six times per day at 4 h interval), allowing not only day and night time high frequency measurements, but also measurements in extreme uncomfortable conditions (e.g. hot and raining weather conditions). The advantage of monitoring CO_2 exchange also during nighttime is of particular importance for the determination of ecosystem respiration and, thus, for C balance studies (Steduto et al. 2002). An infrared gas analyzer was used to measure CO_2 concentration in our study, which is better than gas chromatography and alkali-absorption methods due to its instantaneous CO_2 data acquisition and without need for subsampling. Minimizing the time that the chamber is over the vegetation (10 min) minimizes the artifact caused by altering the CO_2 concentration gradient within the soil profile and between the soil-atmosphere and the chamber headspace (Davidson et al. 2002). Moreover, the air conditioner equipped with each chamber minimized the temperature differences caused by chambers. Overall, automated closed chamber system presented in this work provides a useful means for obtaining continuous day and night CO_2 flux data at plot-size scale.

Carbon dioxide net ecosystem exchange in cropland and grassland

The two important processes affecting carbon balance of a terrestrial ecosystem are photosynthesis of above-ground vegetation and ecosystem respiration. When photosynthesis becomes significant, the net flux is directed downward and vice versa. The measured NEE varied between the two ecosystems depending on changes in above-ground vegetation and environmental factors. The maximum CO_2 uptake was 416 mg CO_2-C m^{-2} h^{-1} in the grassland (Fig. 3a), which was similar to the grassland at the Siggen research site in Germany with closed chamber method (similar to ours but with semi-transparent closures) (450–500 mg CO_2-C m^{-2} h^{-1}, Glatzel 1999), and the Northern temperate grassland in Canada (347–607 mg CO_2-C m^{-2} h^{-1}, Flanagan et al. 2002). Similarly, we compared the maximum CO_2 emission in the grassland (474 mg CO_2-C m^{-2} h^{-1}) at our site with other studies. It was lower than the studies by Glatzel (1999) (720–800 mg CO_2-C m^{-2} h^{-1}), Dugas et al. (1999) (650 mg CO_2-C m^{-2} h^{-1}), but higher than the report by Miranda et al. (1997) (87–217 mg CO_2-C m^{-2} h^{-1}). Both of the maximum CO_2 uptake 138 mg CO_2-C m^{-2} h^{-1} and emission values (329 mg CO_2-C m^{-2} h^{-1}) in the cropland at our site were lower than the maize-soybean agroecosystems in USA (Verma et al. 2005). These differences are caused by such factors as ecosystems, management, climate, and soils, as well as the differences in the method used and the measurement period.

The diurnal NEE pattern of daytime uptake and night time release was evident in the grassland, but not in the cropland as there were no plants during most of the time of the measurement period. Similar diurnal patterns were described in other researches (Flanagan et al. 2002; Xu and Baldocchi 2004). The pattern and amplitude of the diurnal courses of NEE change with season, and depend mainly on leaf area index and incident photosynthetically active radiation (Xu and Baldocchi 2004).

The higher levels of SOC stocks in the top 20 cm in the grassland than the cropland could partly explain the difference in the night time NEE between the grassland and cropland (higher night time NEE in the grassland than in the cropland). During our experiment, the cropland was harvested, and so was devoid of vegetation, while the grassland still maintained green. The higher night time CO_2 flux in the grassland can also be partly attributed to the respiration of the grass and greater C allocated belowground because of daytime photosynthesis. More daytime canopy photosynthetic assimilation in the grassland suggested that the grassland had higher potential to capture C than the cropland especially in autumn. Hence, the grassland usually had lower daytime NEE and daily NEE than the cropland (Fig. 4b, c), and as a result, the grassland emitted less CO_2 by 87.9 g CO_2-C m^{-2} than the cropland at the end of our experiment (Fig. 4d).

The obvious impact of cutting in the grassland was the cessation of net assimilation because of the decrease in daytime canopy photosynthesis. The decrease in the night time NEE could be in part due to the removal of respiring plant material. Additionally, cutting aboveground material decreases root metabolism and consequently the amount of root exudates (Kuzyakov et al. 2002), leading to less new carbon sources available to heterotrophy (Craine and Wedin 2002). Similarly, the development of the weeds and the growth of rye in the cropland resulted in CO_2 uptake. In contrast, moving weeds in the cropland caused the absence of CO_2 uptake. Our study implied that CO_2 exchange is greatly affected by plant physiological controls over photosynthate production and allocation belowground (Kuzyakov and Gavrichkova 2010).

Dependence on environmental parameters

Temperature is an important environmental factor affecting soil/ecosystem respiration. Night time NEE were dominated by respiration rather than photosynthesis, which were equivalent to ecosystem respiration. The night time NEE increased exponentially with air temperature and soil temperature in both grassland and cropland (Fig. 6a–d). Similar exponential relationship between ecosystem respiration and temperature has been reported by earlier researches (Glatzel 1999; Suyker et al. 2004; Xu and Baldocchi 2004). Q_{10} values are a convenient index to reflect the different temperature sensitivities for autotrophic and heterotrophic respiration and the turnover times of the multiple carbon pools (Xu and Baldocchi 2004). From Eq. (2), Q_{10} were estimated to be 1.8 and 1.9 (for air temperature), 2.3 and 2.4 (for soil temperature) in the grassland and cropland, respectively (Fig. 6a–d). Raich and Schlesinger (1992) showed that the global median Q_{10} value was 2.4 for different ecosystem, similar to our results. High temperature sensitivity may include the direct physiological effect of temperature on root and microbial activities and the indirect effect related to photosynthetic assimilation and carbon allocation to roots (Xu and Baldocchi 2004).

Generally, daytime NEE in the cropland was dominated by soil respiration, as there were no vegetation in the cropland most of the time in autumn. As expected, a linear function gave the best fit between daytime NEE and soil and air temperature (Fig. 5g, h). In most cases, daytime NEE in the grassland was dominated by photosynthesis as ecosystem respiration was balanced by photosynthesis. The daytime NEE in the grassland showed no relationship with soil or air temperature (Fig. 6e, f). Some researchers suggested that variations in daytime CO_2 exchange are primarily controlled by photosynthetically active radiation, green leaf area index (Suyker et al. 2004). In this study, no correlation was found between NEE and soil moisture in the grassland or the cropland, this was probably due to the fact that during the short course of the experiment, soil moisture was not a limiting factor. Important was also that the soil moisture varied within much longer periods compared to daily dynamics of NEE. Similarly, Maljanen et al. (2001) reported that soil respiration was less closely associated with soil moisture or precipitation, as the water table level in their study site was usually very low (deeper than 1 m) during the summer. However, other studies showed that soil moisture is an important control on soil respiration in arid and semi-arid ecosystems (Xu and Qi 2001; Tang and Baldocchi 2005).

Conclusions

The fully automated closed chamber system with IRGA provides a useful means for obtaining continuous day and night CO_2 flux data at plot-size scale. Moreover, the air conditioner equipped with each chamber minimized the temperature differences caused by chambers.

The period between middle August to middle November (2006) was chosen to compare NEE in cropland after harvest and grassland with automated closed chambers and to evaluate NEE in autumn at Kleinhohenheim, Southwest Germany. The grassland generally showed higher night time NEE, but lower daytime NEE and daily NEE than the cropland. The diurnal NEE pattern of daytime uptake and night time release was pronounced in the grassland, but not in the cropland as there were no plants during most of the time of the measurement period. Night time NEE showed exponential relationships with air and soil temperature in the cropland and grassland, daytime NEE in the cropland followed a linear function of soil and air temperature. In autumn both ecosystems were sources of CO_2 but more C was lost from cropland (268.4 g CO_2-C m^{-2}) compared to grassland (180.5 g CO_2-C m^{-2}).

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