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The temporal and spatial variation of soil respiration in pepper (*Capsicum annuum* L.), eggplant (*Solanum melongena* L.) and maize (*Zea mays* L.) agro-ecosystems in Northwest of China

Caihong BAI[1], Yinli LIANG[1,2,*], Yanli ZHU[1], Yaoxiang GE[3], Xingjun LIN[2], Wenyan JIA[1]

[1]College of Resources and Environment, Northwest A & F University, Yangling, Shaanxi, 712100, P. R. China
[2]Institute of Soil and Water Conservation, Northwest A & F University, Yangling, Shaanxi, 712100, P. R. China
[3]College of Agronomy, Nanjing Agricultural University, Nanjing, 210095, P. R. China

[*]Corresponding author: liangyl@ms.iswc.ac.cn

Abstract

Soil respiration is a crucial factor in estimating the carbon budget accurately. In order to explore the temporal and the spatial variation of soil respiration in different agro-ecosystems, soil respiration and environmental factors were measured in pepper (*Capsicum annuum* L.), eggplant (*Solanum melongena* L.) and maize (*Zea mays* L.) ecosystems during the growing season from June to September in 2009. The pronounced seasonal and diurnal variations of soil respiration behaved similarly in the three ecosystems. The soil respiration reached a seasonal peak in July and a seasonal trough in September. The diurnal maximum values appeared between 1300h and 1500h, and the minimum values were between 0300h and 0500h. The seasonal and diurnal variations were significantly affected by soil temperature (Q_{10} value from 1.32 to 2.71) and air temperature (Q_{10} value from 1.25 to 2.03), but not significantly to soil moisture and air relative humidity in the three ecosystems. Soil respiration was measured near the plant, between plants in the rows (inter-plants) and between rows (inter-rows). The results showed a significant tendency of soil respiration near the plant > inter plants > inter rows in the maize ecosystem, but not in pepper and eggplant ecosystems, indicating spatial variation and vegetation type are needed to be considered when estimating carbon emissions from soil respiration.

Keywords: Diurnal variation; eggplant (*Solanum melongena* L.); maize (*Zea mays* L.); pepper (*Capsicum annuum* L.); Q_{10} value; seasonal variation; spatial variation.
Abbreviations: R_s (soil respiration), T (temperature), T_{soil} (soil temperature) and T_{air} (air temperature).

Introduction

Soil respiration is recognized as one of the primary pathways that release CO_2 from the soil into the atmosphere. The global CO_2 emission from soil respiration was estimated at approximately 75 $\times 10^{15}$ g C/yr; small changes in the magnitude of soil respiration could have a large effect on the concentration of CO_2 in the atmosphere (Schlesinger and Andrews, 2000). Agro-ecosystems are important terrestrial ecosystems, representing about 10.5% of the earth's surface, and their CO_2 emission amounts to 21% - 25% of anthropogenic greenhouse gases emission (Han et al., 2008). Therefore, soil respiration of agro-ecosystems is very important in the global carbon cycle and carbon budget. Soil respiration is a composite CO_2 emission process from the soil to the atmosphere. It is mainly due to soil micro-organisms and plant roots (Fang, Liu, et al., 1998). Soil temperature, soil moisture, micro-organisms, vegetation, litter fall, land use, pH, air temperature, latitude, and other factors affect soil respiration (Boone et al., 1998; Fang, Liu, et al., 1998; Carlisle et al., 2006; Han et al., 2007a; Tyree et al., 2008). However, soil temperature and soil moisture are the most important factors (Raich and Potter, 1995; Davidson et al., 1998).The cropland in Shaanxi province is 4,049,000 ha which accounts for about 3.2% of cropland in China, the soil respiration of agro-ecosystems in Shaanxi province is very important for carbon cycling in China; it is important to obtain accurate estimates of soil respiration and understand the environmental factors controlling its variability across agro-ecosystems in this area. Some research on soil respiration in this geographical area has been conducted, focused on forest, grassland and some croplands. For example, Shi et al. (2011) and Fu et al. (2010) investigated soil respiration in response to rain events in two typical forests and in relation to density in two shrubs, respectively. Zhang et al. (2011) determined the effect of temperature, moisture and other related factors (organic carbon, organic nitrogen, microbial biomass) on soil respiration under different land use types (forest land soil > grass land soil > orchard soil). Winter wheat is one of most important crops in this geographic area, Guan et al. (2011) studied the effects of two straw mulching (300 and 600 kg ha^{-1} straw mulching), plastic film mulching, and no mulching (CK) on the diurnal and seasonal soil respiration variations of a winter wheat field. Liu et al. (2006) separated soil respiration into root-derived respiration and soil-microbe-derived respiration by removing the shoot of wheat and soybean under field conditions. However, research on vegetable crops has beeen ignored, and as pepper, eggplant and maize are the major vegetables and crop in Shaanxi province in China, there is a need for appropriate soil respiration research. In addition, as soil respiration varies markedly in magnitude both in time and space, these factors must be taken into account when quantifying the amount of CO_2 released from the soil (Fang, Moncrieff, et al., 1998; Søe and Buchmann, 2005; Han et al., 2007a; Katayama et al., 2009). Therefore, an understanding of the temporal and spatial variation of soil respiration of the three studied agro-ecosystems presented in the present study will be useful for calculating carbon emission of agro-ecosystems more accurately, and for improving soil respiration modeling. The primary of objectives of this study are: (i) to investigate the seasonal and diurnal variation of soil respiration and environmental factors during the pepper, eggplant and maize growing season; (ii) to identify the spatial variation of soil respiration in the three agro-ecosystems.

Results

The seasonal variation of soil respiration

The seasonal variation patterns of soil respiration at 3 different positions (near the plant, inter-plants and inter-rows) were similar (Fig. 1). Soil respiration dramatically fluctuated during the growing season, but generally, increased from June onwards, reached a maximum in July, and then it began to decrease in late August, reaching the lowest value in September in all three ecosystems. The variation ranged from 0.83 to 4.63 µmol m^{-2} s^{-1} in the pepper ecosystem, from 1.44 to 4.30 µmol m^{-2} s^{-1} in the eggplant ecosystem, and from 1.24 to 5.08 µmol m^{-2} s^{-1} in the maize ecosystem. The highest variation range was in the maize ecosystem, and the lowest was in the eggplant ecosystem. In the three ecosystems, soil respiration varied at the 3 different positions (Fig. 1). The average soil respiration during the growing season had the following sequence: maize > pepper > eggplant at the near plant; eggplant > maize > pepper inter-plants; pepper > eggplant > maize in the inter-rows (Table 1). Furthermore, there were significant differences of average soil respiration during the growing season at the three positions in the maize ecosystems (Table 1). Soil respiration decreased as the distance from the plant increased in the maize ecosystem. The trend of the average soil respiration was: near the plant > inter-plants > inter-rows. However, this trend of soil respiration change with the distance was not exhibited in the pepper and the eggplant agro-ecosystems.

Correlation of soil respiration seasonal variation with environmental factors

Correlation analysis revealed that soil respiration of pepper, eggplant and maize ecosystems was influenced more strongly by season temperature than by moisture (Table 2). Both soil temperature and air temperature had significant positive correlations with the seasonal variability in soil respiration. There were significant negative correlations between soil moisture and soil respiration in pepper and maize ecosystems, and between air relative humidity and soil respiration in pepper and eggplant ecosystems, but the correlation coefficients were much lower. Table 3 shows the relationship between soil respiration and soil and air temperatures and the Q_{10} (the increment in soil respiration rate when temperature is increased by 10 °C) values. There was a highly significant exponential correlation between soil respiration and soil and air temperatures. During the growing season, soil respiration exhibited Q_{10} of 2.71, 1.84 and 2.70 of soil temperature in pepper, eggplant and maize ecosystems, respectively, and were higher than the Q_{10} values for air temperature. This is an indication that soil respiration was more sensitive to soil temperature change than air temperature change during the growing season. In addition, Q_{10} values of soil temperature and air temperature were quite similar in the pepper and maize ecosystems, and significantly higher than in the eggplant ecosystem. This indicated that the soil respiration of maize and pepper ecosystems was more sensitive to soil temperature change compared to the eggplant ecosystem.

Diurnal variation of soil respiration

Soil respiration measurements in pepper, eggplant and maize ecosystems were conducted every two hours on the 2nd July, 15th August and 28th September (Fig. 2). Soil respiration exhibited a similar diurnal undulate variation with a minimum value between 0300 and 0500h in the morning, and a maximum value between 1300 and 1500h in the afternoon, in the three ecosystems. The soil respiration in the three representative days ranged from 1.86 to 5.91 µmol m^{-2} s^{-1} in the pepper ecosystem, from 1.55 to 5.61 µmol m^{-2} s^{-1} in the eggplant ecosystem and from 1.52 to 6.31µmol m^{-2} s^{-1} in the maize ecosystem. The variation range was the largest in the maize ecosystem (4.69 µmol m^{-2} s^{-1}), whilst the pepper and eggplant ecosystems had almost same variation range (4.05 and 4.06 µmol m^{-2} s^{-1}). The diurnal average daily soil respiration sequences were maize > pepper > eggplant on 2nd July and 15th August, and eggplant > pepper > maize on 26th September (Table 4). As soil respiration decreased the most in the maize ecosystem, and the least in the eggplant ecosystem, the maize ecosystem had the largest seasonal variation. There was significant spatial variation found in the maize ecosystem (Table 3). Soil respiration decreased with increased distance from the plant. The trend was the same as found for seasonal variation. However, there were no significant spatial variations in pepper and eggplant ecosystems.

Regression relationship between diurnal soil respiration and soil and air temperatures

Regression analysis revealed an exponential relationship between soil respiration and soil and air temperatures (Table 5). The Q_{10} value ranged from 1.32 to 1.98 for soil temperature, which was higher than for the air temperature (1.25 to 1.57) in the three ecosystems in the three representative days. The results indicated that soil respiration was controlled more by soil temperature than by air temperature.
However, the Q_{10} value variation ranges for soil temperature and air temperature were similar in the three ecosystems: 1.29 - 1.84 in the pepper ecosystem, 1.25 - 1.82 in the eggplant ecosystem, and 1.28 - 1.98in the maize ecosystem.

Discussion

Spatial patterns of soil respiration

The major sources of soil respiration are plant root respiration and soil microbial respiration. In some ecosystems, spatial heterogeneity of soil respiration was affected by root biomass and microbial biomass (Xu and Qi, 2001; Franklin and Mills, 2003; Subke et al., 2003). Pangle and Seiler (2002) observed annual mean CO_2 efflux rates near seedlings that were on average 41% higher than rates in plots away from the influence of seedling roots in a 2-year-old loblolly pine plantation. In this study, soil respiration in the maize ecosystem presented a strong spatial variation. The highest soil respiration was near the plant, the lowest was in the inter-rows. The results were consistent with the maize ecosystem soil respiration analysis by Han et al. (2007a) with the same soil respiration pattern “near the plant” > “inter-plant” > “inter-rows”. However, the soil respiration near the pepper and eggplant were not significantly higher than away from the plants. The reason for this difference is not known; it may be due to the effect of roots and microbial community. The dicotyledonous pepper and eggplant have tap root systems with main root and lateral root development which grow almost vertically throughout. However, the monocotyledonous maize has a shallower fibrous root system, the roots concentrate mostly in the surface soil layers (Gregory, 2006). In addition, microbial communities in pepper, eggplant and maize ecosystems were affected by three different root exudates (Bais et al., 2006; Nannipieri et al., 2008). These

Table 1. Soil respiration of pepper, eggplant and maize ecosystems at near plant, inter-plants and inter-rows during the growing eason

Positions	Soil Respiration (μmol m^{-2} s^{-1}) (Growing Season Mean ± SE)		
	Pepper	Eggplant	Maize
Near Plant	3.39±0.30a	2.99±0.55a	3.78±0.26a
Inter-plants	2.64±0.34a	3.25±0.70a	2.94±0.25b
Inter-rows	3.35±0.35a	2.74±0.85a	2.67±0.34b
Mean	3.13±0.24	2.99±0.15	3.13±0.33

Values followed by the same letter in each column show no significant differences (*P*<0.05).

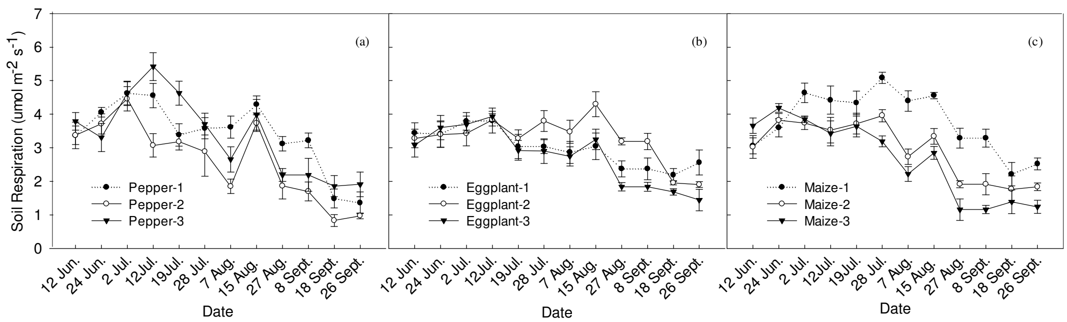

Fig 1. Soil respiration variation (mean ± SD) of pepper(a), eggplant(b) and maize(c) ecosystems during the growing season (1,2 and 3 represent different measurement positions: 1 near plant, 2 inter-plants, 3 inter-rows).

Table 2. Correlation coefficients of soil respiration to environmental factors

Factors	Pepper		Eggplant		Maize	
	Pearson correlation	Sig. (2-tailed)	Pearson correlation	Sig. (2-tailed)	Pearson correlation	Sig. (2-tailed)
Soil Temperature	0.748***	0.000	0.621***	0.000	0.773***	0.000
Air Temperature	0.746***	0.000	0.668***	0.000	0.587***	0.000
Soil Moisture	-0.336*	0.028	-0.324	0.054	-0.398*	0.016
Air Relative Humidity	-0.467**	0.004	-0.384*	0.021	-0.256	0.131

* Correlation is significant at the 0.05 level. **. Correlation is significant at the 0.01 level.

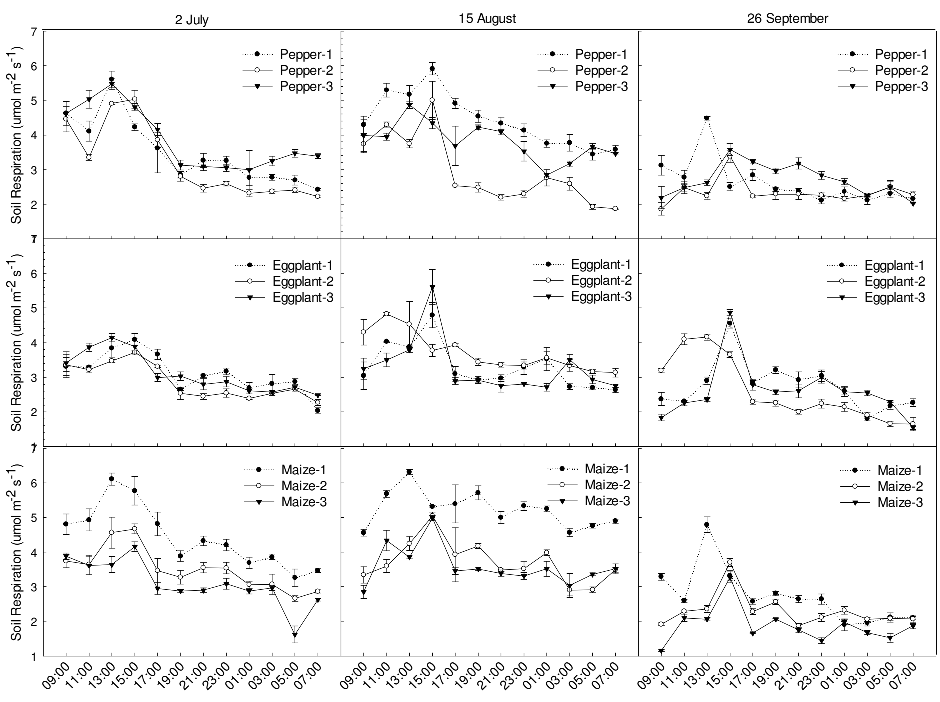

Fig 2. Soil respiration variations (mean ± SD) of pepper, eggplant and maize ecosystems within 24 hour on the 2nd July, 15th August and 28th September (1, 2 and 3 represent measurement positions, 1 near plant, 2 inter-plants, 3 inter-rows)

differences possibly resulted in the different soil respiration spatial variation in different agro-ecosystems. Thus, in order to accurately estimate soil respiration, the spatial variation should have been taken into account. Maestre and Cortina (2003) also suggested that the spatial variation of vegetation and surface soil features may be relevant for the accurate estimation of CO_2 efflux in the ecosystem. It is still a challenge to accurately estimate soil respiration, more vegetation types and further detailed research is needed in the future.

Environmental factors affected the seasonal variation of soil respiration

Seasonal variations in soil respiration are generally attributed to changes in soil and air temperatures (Sánchez et al., 2003; Subke et al., 2003; Han et al., 2007b). In this study, soil respiration fluctuated dramatically during the growing season, however, there was a peak in July and a trough in September all three agro-ecosystems. Correlation analysis showed that soil respiration was more significantly related to soil and air temperature. Soil moisture and air relative humidity influenced soil respiration much less and were negative effects. Han et al. (2007b) found a maximum soil respiration at the end July and a minimum beginning of May in a maize ecosystem with clear relation to the changing soil temperature. Shi et al. (2006) measured soil CO_2 effluxes over 2 years in a winter wheat ecosystem on the Tibetan Plateau, with minimum values in January, the coldest month in the year, and maximum values in June, around the booting and flowering stage of winter wheat. CO_2 effluxes followed a similar trend to the soil temperature change rather than the soil moisture, when water is not limited. In the present study, irrigation was managed during the growing season, and water was not limited. When temperature increased, dormant microbes are activated and the amounts of active microbial species are increased. This increased activity of microbial species participated in increasing soil respiration (Andrews et al., 2000). Furthermore with increasing temperature the photosynthesis of the plant and the photo assimilate translocation from the above ground tissues to the roots were accelerated and root respiration was activated (Han et al., 2007b). Therefore, soil temperature and air temperature exerted the dominant control over the seasonal variation of soil respiration. Q_{10} is defined as the increment in soil respiration rate when temperature is increased by 10 °C, it determines the rate of change of soil respiration with respect to temperature. Q_{10} is the most important parameter for soil respiration, and it broadly describes the sensitivity of soil respiration to temperature. (Raich and Potter, 1995; Almagro et al., 2009). Shi et al. (2006) found the highest correlation between soil respiration and temperature at 5 cm depth temperature. Therefore, in the present study, the soil temperature at 5 cm depth and air temperature were both measured. Soil respiration was sensitive to both soil and air temperatures, Q_{10} ranged from 1.84 to 2.71 for the soil temperature and from 1.55 to 2.03 for the air temperature. Ding et al. (2007) also found that seasonal soil respiration was significantly affected by soil temperature, with a Q_{10} from 1.90 to 2.88, but not by soil moisture, in a maize ecosystem. The temperature sensitivity of soil respiration may depend on the relative contribution of roots and the associated rhizosphere microbiota (including mycorrhizae) to the total soil CO_2 efflux (Boone et al., 1998). Soil temperature is more easily affected the root respiration and microbial activities than air temperature, Q_{10} values were higher for soil temperature than for air temperature. Soil respiration was more sensitive to soil temperature than air temperature during the growing season in three ecosystems.

Response of soil respiration to soil and air temperatures at diurnal scale

In this study, soil respiration of three ecosystems presented similar variation patterns in the three representative days. Soil respiration fluctuated greatly within a 24 hour period with the peak at 1300 and 1500h and a trough at 0300 and 0500h in the three agro-ecosystems. The results were in accordance with other research on diurnal variation with minimum value around early morning and maximum value around noon in maize and wheat ecosystems, which were correlated with the trend of soil temperature (Shi et al., 2006; Han et al., 2007b). Moreover, the results show a significant exponential relationship between soil respiration and soil temperature at 5 cm depth and the air temperature. Q_{10} values for soil temperature (1.32-1.98) were slightly higher than the values for air temperature (1.25-1.57). Soil respiration was more sensitive to soil temperature than air temperature, which is same as seasonal soil respiration variation.

Materials and methods

Experiment site description and experimental design

The field experiment was conducted with pepper, eggplant and maize at the experimental station of the Institute of Soil and Water Conservation Northwest A & F University in the Shaanxi province of China (34°14'-34°20' N, 107°59'-108°08' E). The region is located in warm temperate zone, the mean annual temperature is about 12.9°C, and the annual precipitation is about 884.0 mm. The study site is relatively flat with slopes <3. The soil type is a Black Loam, with a pH value of 7.3. The organic matter content is 8.4 g kg^{-1} and total N is 0.78 g kg^{-1}. Wheat was planted in this site prior to the experiment. The experiment used a randomized block design with three replications, the plots sizes were 14.4 m^2 (6.0 m × 2.4 m). All plots were managed in the same way. Maize, pepper and eggplant were planted and transplanted on the 3rd June, harvested on the 28th September. Plants were planted 60 cm apart in rows. The distance inter-plants was 50 cm. Urea at 75 kg ha^{-1}, P_2O_5 at 125 kg ha^{-1} and K_2O at 75 kg ha^{-1} were applied as a base fertilizer. Further urea at 75kg ha^{-1}, P_2O_5 at 75 kg ha^{-1} and K_2O at 75 kg ha^{-1} were applied on the 8th July 2009 and 10th August 2009.

Soil respiration measurements

Soil respiration was measured during the growing season (June–September) in 2009 with a soil respiration chamber (LI-6400-09, Li-Cor, Inc., Lincoln, NE) connected to a portable infrared gas analyzer (IRGA, LI-6400, Li-Cor, Inc., Lincoln, NE). Soil respiration measured at 0900h was used to study seasonal variation (Li et al., 2010). To minimize soil surface disturbances, the chambers were mounted on PVC soil collars sharpened at the bottom and inserted 2 cm into the soil. The soil collars had a height of 4.5 cm and a diameter of 11 cm, and were installed five days before the measurements. The collar on each experimental plot was placed near the plants (about 5cm from the plant), inter-plants (about 25cm from the plants) and inter-rows (in the middle of 4 plants, about 39cm from the plants). The calculation of the soil respiration was done automatically by fitting a quadratic equation to the relationship between the increasing CO_2 concentration and elapsed time. It took 1–2 min to do one measurement. Three replicate measurements were made on each collar on each observation day. Soil respiration was measured every two hours from 0700h to the next day at 0500h am on 2nd July, 15th August and

Table 3. Regression equations between soil respiration (R_s) and soil temperature (T_{soil}) and air temperature (T_{air}) during the growing season.

Crops	Temperature	Equation	R^2	Q_{10}
Pepper	T_{soil}	R_s=0.2870$e^{0.0997T}$	0.64^{**}	2.71
	T_{air}	R_s=0.4466$e^{0.0709T}$	0.72^{***}	2.03
Eggplant	T_{soil}	R_s=0.7045$e^{0.0609T}$	0.54^{**}	1.84
	T_{air}	R_s=0.9113$e^{0.0436T}$	0.71^{***}	1.55
Maize	T_{soil}	R_s=0.3085$e^{0.0993T}$	0.83^{***}	2.70
	T_{air}	R_s=0.5682$e^{0.0662T}$	0.78^{***}	1.94

**. Correlation is significant at the 0.01 level. ***. Correlation is significant at the 0.001 level.

Table 4. Soil respiration daily mean of pepper, eggplant and maize ecosystems at near plant, inter-plants and inter-rows.

Date	Positions	Soil Respiration (μmol m^{-2} s^{-1}) (Daily Mean ± SE)		
		Pepper	Eggplant	Maize
2 July	Near Plant	3.52±0.28a	3.12±0.57a	4.42±0.26a
	Inter-plants	3.23±0.31a	2.87±0.15a	3.51±0.18b
	Inter-rows	3.87±0.28a	3.12±0.17a	3.10±0.19b
	Mean	3.54±0.19	3.04±0.08	3.68±0.39
15 Aug.	Near Plant	4.43±0.22a	3.30±0.65a	5.23±0.15a
	Inter-plants	2.95±0.29b	3.73±0.56a	3.72±0.17b
	Inter-rows	3.82±0.16a	3.29±0.81a	3.59±0.17b
	Mean	3.73±0.43	3.44±0.15	4.18±0.53
26 Sept.	Near Plant	2.63±0.19a	2.75±0.70a	2.73±0.23a
	Inter-plants	2.35±0.10a	2.60±0.92a	2.30±0.14ab
	Inter-rows	2.71±0.13a	2.60±0.82a	1.88±0.15b
	Mean	2.56±0.11	2.65±0.05	2.30±0.25

Values followed by the same letter in each column show no significant differences (P<0.05).

Table 5. Regression equations between soil respiration (R_s) and soil temperature (T_{soil}) and air temperature (T_{air})

Crops	Temperature	Date	Equation	R^2	Q_{10}
Pepper	T_{soil}	2 July	R_s=0.9874$e^{0.0421T}$	0.67^{**}	1.52
		15 Aug.	R_s=0.7495$e^{0.0608T}$	0.75^{***}	1.84
		26 Sept.	R_s=0.9382$e^{0.0466T}$	0.84^{***}	1.59
	T_{air}	2 July	R_s=1.4101$e^{0.0292T}$	0.33^{*}	1.34
		15 Aug.	R_s=1.2610$e^{0.0366T}$	0.61^{**}	1.44
		26 Sept.	R_s=1.4165$e^{0.0257T}$	0.71^{**}	1.29
Eggplant	T_{soil}	2 July	R_s=1.2903$e^{0.0284T}$	0.79^{***}	1.33
		15 Aug.	R_s=1.0470$e^{0.0448T}$	0.73^{***}	1.57
		26 Sept.	R_s=0.7074$e^{0.0598T}$	0.56^{*}	1.82
	T_{air}	2 July	R_s=1.5121$e^{0.0222T}$	0.47^{*}	1.25
		15 Aug.	R_s=1.5000$e^{0.0281T}$	0.44^{**}	1.32
		26 Sept.	R_s=0.9534$e^{0.0443T}$	0.55^{**}	1.56
Maize	T_{soil}	2 July	R_s=1.6085$e^{0.0277T}$	0.72^{***}	1.32
		15 Aug.	R_s=2.0151$e^{0.0289T}$	0.23^{*}	1.34
		26 Sept.	R_s=0.5450$e^{0.0682T}$	0.52^{**}	1.98
	T_{air}	2 July	R_s=1.6924$e^{0.0247T}$	0.49^{*}	1.28
		15 Aug.	R_s=2.0307$e^{0.0244T}$	0.67^{**}	1.28
		26 Sept.	R_s=0.7914$e^{0.0454T}$	0.68^{**}	1.57

* Correlation is significant at the 0.05 level. **. Correlation is significant at the 0.01 level. ***. Correlation is significant at the 0.001 level

23rd September in 2009 to study the diurnal variation.

Environmental factors Measurements

Soil temperature was measured at 5 cm soil depth simultaneously with a copper/constantan thermocouple penetration probe (LI-6400-09 TC, Li-Cor) in the vicinity of the soil collars. Soil moisture (0–5 cm depth) in the vicinity of the soil collar was monitored with a portable sensor (MPM-160, Sentek, Australia). In addition, the air temperature and air relative humidity were measured automatically by HOBO (Vaisala, Helsinki, Finland) located in the middle of the plot area at a height of 1.5m.

Data processing and statistical analysis

The relationship between soil respiration (R_s) and soil and air temperatures was modelled by an exponential function:

R_s=a exp(bT) (1)

where a and b are regression coefficient, T is the temperature.

The Q_{10} value was calculated using the following equation:

Q_{10} = exp (b×10) (2)

where b is regression coefficient of equation (1) (Boone et al., 1998; Xu and Qi, 2001). All statistical analyses were performed using the SPSS 16.0 package (SPSS, Chicago, IL, USA) and SigmaPlot 12.0.

Conclusions

In the present study, seasonal and diurnal variations in soil respiration were similar in each of the three ecosystems. Soil respiration fluctuated dramatically with the maximum values in July and the minimum values in September during the growing season. The diurnal maximum values appeared between 1300 and 1500h, the minimum values appeared between 0300 and 0500h. Soil respiration was associated with soil temperature and air temperature rather than with soil moisture and air relative humidity. Soil respiration was more sensitive to soil temperature at 5 cm depth than air temperature. Significant spatial variations were found for the maize ecosystem, but not for the pepper and eggplant ecosystems. It is important to consider spatial variation and vegetation type when estimating the carbon emission from soil respiration.

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