# Estimation of daily soil $CO_2$ emission using instantaneous measurements

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## Introduction

Soils play an important role in regulating atmospheric $CO_2$ concentration, one of the primary greenhouse gases likely contributing to climate change. Research shows that if properly managed, agricultural lands could be an important sink for atmospheric $CO_2$. However, there are also concerns that soils could become a significant source of $CO_2$ to the atmosphere if global temperatures continue to rise.

Field measurement of $CO_2$ fluxes is an effective tool for estimating and comparing impacts of different land management practices on the soil carbon balance. Because soil $CO_2$ flux often varies markedly hour by hour, an automated continuous system would be the ideal way to measure the daily soil $CO_2$ flux. However, it may be impractical to deploy continuous chambers over multiple treatments with several replications per treatment. Therefore, many researchers use a portable gas exchange system to measure *instantaneous* soil $CO_2$ flux. Treatment means are used to calculate daily $CO_2$ flux by directly extrapolating the measurement to 24 h. However, there are concerns as to whether measurements of instantaneous $CO_2$ flux can adequately represent daily $CO_2$ flux.

The objective of this study was to determine if the equation developed by Parkin and Kaspar (2003) can be used to estimate daily average $CO_2$ flux in a semiarid agroecosystem.

## Materials and Methods

***Data collection:*** Instantaneous and diurnal $CO_2$ fluxes were observed from various treatments in several field experiments on a gently sloping Swinton silt loam (Typic Haploboroll) near the Semiarid Prairie Agricultural Research Centre, Swift Current, Saskatchewan, Canada from 1995 to 1996 and from 2003 to 2007. Hourly Ta was recorded at a nearby weather station. Excluding rainy day measurements, 55 diurnal $CO_2$ and corresponding soil temperatures (Ts) were taken under different treatments (measurements made at hourly intervals) in 2003, 2004, 2006 and 2007.

***Model:*** Parkin and Kaspar (2003) used the following equation to estimate daily average $CO_2$ emission with a single $CO_2$ flux measurement:

$$\text{Daily average } CO_2 \text{ Flux} = R \times Q^{(\mathrm{DAT}-T)/10}$$

where R is the measured $CO_2$ flux at a specific hour, T is the temperature at the time of flux measurement, DAT is the daily average temperature, and Q is the $Q_{10}$ factor (the ratio of respiration rates at temperatures differing by 10°C). They found that Eq. (1) using air temperature (Ta) successfully estimated pre-seeding soil daily $CO_2$ emission in two fields under no-till management.

***Parameterization and Validation:*** We randomly selected 30 diurnal measurements to calibrate $Q_{10}$ factors. The remaining data (25 diurnals) was used for model validation. The calibration was performed using nonlinear regression analysis (PROC NLIN). To estimate the uncertainty associated with the model this analysis was done for 1000 bootstrap re-sampling datasets from the calibration data. Then, Eq. 1 was run with the calibrated mean $Q_{10}$ factors to simulate daily average $CO_2$ flux in the validation dataset and 1000 bootstrap datasets generated from the validation data.

## Results and Discussion

Figure 1 shows mean diurnal changes of $CO_2$ flux and soil and air temperatures over a single day. $CO_2$ fluxes were lower than the daily mean in the morning and they were higher from 1100 to 2200 h. The $CO_2$ flux generally followed the change of Ts and Ta. This indicates that, depending on the time during the working day (0800–1700 h) when the instantaneous $CO_2$ flux is measured, the daily mean emission could either be over or under-estimated by linear extrapolation of the instantaneous value to 24 h. When precipitation did not occur, diurnal changes of soil moisture were small, therefore, had little effect on the change of $CO_2$ flux (Fig. 1). The change of $CO_2$ flux was closely associated with air and soil temperature.

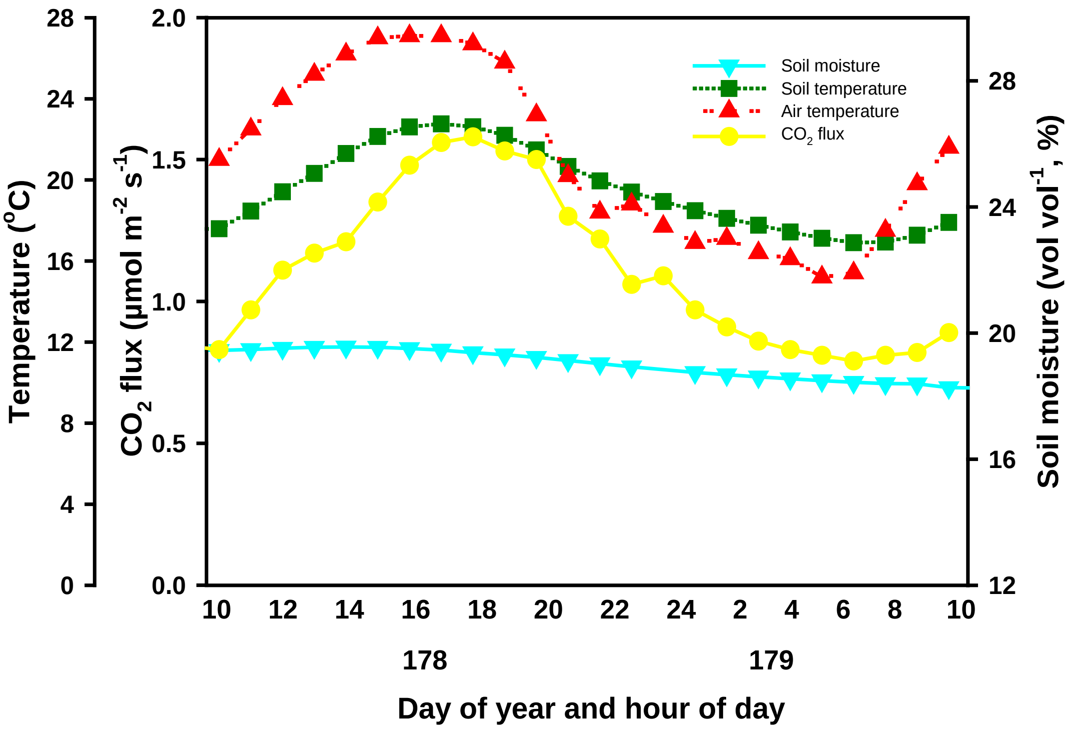


**Fig. 1. Diurnal changes of soil $CO_2$ flux, soil temperature, air temperature and volumetric water content.**

Calculated $Q_{10}$ factors using the calibration data and bootstrap samples were 1.97 for Ts and 1.59 for Ta (Table 1). Upper and lower bootstrap confidence limits were very close to the means for both Ts and Ta. The model estimated daily $CO_2$ emission with high precision (high Pearson correlation, *r*) and high accuracy (low root mean square error of prediction, RMSEP). Concordance correlation coefficient (CCC) is an indicator for both precision and accuracy. Values of CCC close to one indicate a good agreement between measurements and simulations. Table 3 shows that the CCC was high (> 0.82) for the model using either soil or air temperature. The model using Ts performed slightly better than that using Ta according to all the indicators (*r*, RMSEP and CCC). Validation results were very similar to calibration results, but the model using Ta performed slightly better than using Ts. Ta performed slightly better than using Ts.

**Table 1. Soil and air temperature-based $Q_{10}$ factors calculated using calibration and bootstrap re-sampling data and assessments on these two $Q_{10}$ factors for simulating daily average soil $CO_2$ flux in the calibration and validation datasets and their bootstrap samples by Pearson correlation (*r*), root mean square error of prediction (RMSEP) and concordance correlation (CCC).**

| | Soil temperature | | | Air temperature | | |
|---|---|---|---|---|---|---|
| Model | Mean | Lower[1] | Upper[2] | Mean | Lower[1] | Upper[2] |
| ***Calibration*** | | | | | | |
| $Q_{10}$ factor | 1.973 | 1.963 | 1.982 | 1.586 | 1.580 | 1.592 |
| *r*[3] | 0.899 | 0.898 | 0.900 | 0.887 | 0.886 | 0.888 |
| RMSEP | 0.052 | 0.051 | 0.052 | 0.059 | 0.059 | 0.060 |
| CCC[4] | 0.887 | 0.886 | 0.888 | 0.870 | 0.869 | 0.871 |
| ***Validation*** | | | | | | |
| *r*[3] | 0.835 | 0.834 | 0.835 | 0.856 | 0.856 | 0.857 |
| RMSEP | 0.049 | 0.048 | 0.049 | 0.044 | 0.044 | 0.045 |
| CCC[4] | 0.823 | 0.823 | 0.824 | 0.841 | 0.840 | 0.842 |

[1, 2]Lower and upper bootstrap confidence limits at $P = 0.05$, respectively.
[3]All Pearson correlation coefficients were significant at $P = 0.001$.
[4]All concordance correlations were different from zero at $P = 0.001$.

Different components of soil respiration (root respiration, respiration by heterotrophic organisms decomposing soil organic matter; respiration from surface residues) may respond differently to environmental factors. In a bare soil, where the heterotrophic respiration was the major source of $CO_2$ production, diurnal changes of soil $CO_2$ flux were highly correlated with soil surface temperature. Parkin and Kaspar (2003) indicated that Eq. (1) using Ts at 5 cm simulated daily average $CO_2$ flux poorly, but simulation results were improved when Ta was used. This suggests that a substantial portion of the $CO_2$ was emitted from surface residues. On cropped land, soil respiration was closely linked to current photosynthesis, therefore to irradiance and Ta rather than to

Ts. In our study, all simulations of daily average soil $CO_2$ performed well, including both crop and fallow soils and under both no-till and conventional tillage using either Ts or Ta.

It is clear that a relationship between temperature and $CO_2$ efflux described by Parkin and Kaspar (2003) can be used to estimate daily average $CO_2$ emission in the semiarid prairies.

## References

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