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# Effect of Park Grassland Management on C-Fluxes in Temperate Ecosystem

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**ABSTRACT**

In this study the temporal variations in field soil respiration were investigated over a two year period, together with laboratory soil respiration rates in a park grassland at University of Essex, UK. Field soil respiration was measured with portable environmental gas monitor, while laboratory soil respiration was by incubation and titrimetric methods. Field soil respiration varied over time of day, sites and seasons, with the summer months recording the highest respiratory activity (127.8 and 69.8 mmol $m^{-2}$ $h^{-1}$ over two years respectively) while the winter months recorded the lowest field soil respiration rates (27.2 and 29.8 mmol $m^{-2}$ $h^{-1}$ for the same periods respectively). Soil temperature and water filled pore spaces (WFPS) also varied seasonally with highest temperature and lowest WFPS recorded in the summer months. Field soil respiration was dependent on either soil temperature or WFPS in first year only. A multiple regression analysis also recorded a significant relation between field soil respiration, temperature and WFPS ($R^2$ multiple = 0.5, FSR = 45.6 + 10.5T + 86.9 WFPS mmol $CO_2$ $m^{-2}$ $h^{-1}$) for the two years. Laboratory measurements are vital for explaining the factors that influence C-fluxes in the field.



## Introduction

Field based soil respiration gives an estimate of the $CO_2$ emissions from soil representing a combination of soil and root respiration (Ball and Drake, 1998). Although it is possible to estimate the relative contribution of the two components, the total estimate is useful, for example when calculating ecosystem carbon budgets. Soil respiration measurements are therefore routinely included in ecosystem studies. Such measurements are used as the basis for large scale estimations of $CO_2$ fluxes, which take into account temporal and seasonal changes (Orchard and Cook, 1983; Davidson et al, 1998; Davidson et al, 2000; Savage and Davidson, 2001; Houghton, 2002 and 2003; Janssens and Pilegaard, 2003; Savage and Davidson, 2003; Curiel-Yutse et al, 2004).

Some published data have shown a strong dependence of soil respiration on soil temperature and moisture (Singh and Gupta, 1977; Doran et al, 1988; Oberbauer et al, 1992; Raich and Schlesinger, 1992; Howard and Howard, 1993; Franzluebbers et al, 2002; Vanhala, 2002; Raich et al, 2002; Curiel-Yuste et al, 2003; Curiel-Yuste et al, 2004. For example Franzluebbers et al (2002) observed that soil temperature and moisture (assessed as water filled pore spaces –WFPS) interactions were highly significant for soil respiration; increasing soil temperature positively influenced soil respiration at high WFPS. Likewise, increasing WFPS had a positive influence on soil respiration at high soil temperature. Redman's multiple equations (Redman, 1978b) include factors for soil temperature, soil moisture and precipitation; these factors accounted for between 66 and 74% of variation in soil respiration. However, other works have failed to establish any significant relationship between either temperature and moisture. For example Vanhala (2002) noted decreases in soil respiration rates in spring and summer when temperature were higher. Also Ball et al (2000) investigated the correlation between soil temperature and soil respiration and could not detect any relationship, even though soil temperature varied between 17 and 25°C during the measurements.

In order to avoid the complexities of incorporating environmental conditions soil respiration measurements are often carried out in the laboratory where the conditions e.g temperature are most easily controlled and monitored. When the temperature and moisture are kept constant any variation in $CO_2$ emissions can usually be explained by other changes in the physical and chemical properties of the soil e.g soil organic carbon (SOC), soil organic nitrogen (SON), pH, water holding capacity (WHC). A laboratory respiration measurement therefore allows comparison of different soil and management and facilitates interpretation of the results (Singh and Gupta, 1977; Howard and Howard, 1993; Ball et al, 2000; Vanhala, 2002).

The relationship between field and laboratory soil respiration is not simple and the significance of laboratory respiration measurements for use in C-budgeting is difficult to assess. It is even difficult to extrapolate field based measurements for the estimation of net C-fluxes due to limited frequency of observations (Franzluebbers et al, 2002). More regional specific information has been suggested to be a priority area of research in grasslands and forests in order to better quantify their role in greenhouse gas emissions and potential C-sequestration (Pretty et al, 2002; Farage et al, 2005). The park grassland work is an addition to this global discourse

## Materials and Methods

### Site description

Wivenhoe park grassland, Essex is located 72 km east of London (51° 52¹, 0° 56¹, 50 m over datum (OD). The soil is an Argillic brown earthsoil of the Wix Series. The University Estate Office run routine maintenance of the rye-grassland, mowing of grasses and periodical draining of lakes located at the centre of the park to remove pollutants arising from detritus and algal blooms. Altogether, 2 mowing occasions were observed each in

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spring, summer and autumn of first year; and 3 in each season apart from winter in the second year. Five sample sites replicated four times were randomly selected. These sites were tagged at an equi-distance of 5 m diameter and revisited on each sampling occasion. In the same vein soil samples were taken for laboratory soil respiration measurements.

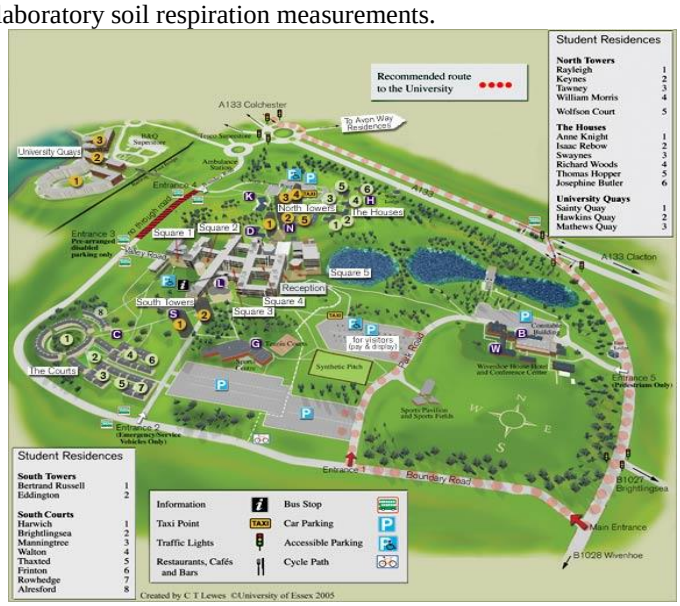


**Fig 1. Wivenhoe park grassland, University of Essex**

**Field Methods**

In situ soil respiration was measured using a portable environmental gas monitor (EGM-1, PP Systems, UK) linked to a soil respiration chamber (diameter 10 cm; SRC-1, PP Systems, UK) – Sowerby et al (2000). Each individual measurement took 4 – 5 min and was carried out by placing the respiration chamber over the soil. Respiratory activity was calculated from the $CO_2$ accumulation rate within the chamber as described by the manufacturers (Anon, 1990) and expressed as mmol $CO_2$ $m^{-2}$ $h^{-1}$. At the same time soil temperature at a depth of 10 cm was also recorded. In the first year measurements was done five times per month at 5 d intervals; which was reduced to three days per month in the second year at 10 d interval. All at three times of the d; 06 – 07; 12 – 13 and 18 – 19 hrs GMT. Hourly measurement of field respiration were done on the following days of the year: 58, 108, 207, and 320 in the first y and on d 31, 171, 303 and 360 in the second year.

**Laboratory protocols**

Laboratory measurement of soil respiration was estimated using protocols described by Rowell (1994) and Alef (1998). Soil (50 g) at various WFPS was placed into a sealed conical flask (500 ml) containing 0.3 M NaOH (10 ml) suspended mid way in the flask. Flasks were incubated in the dark for 7 d. In assessments in which temperature was varied flasks were incubated at temperature between 6.5 and 30°C; whilst in those examining the influence of moisture, the moisture was varied from 25 – 50% WHC. At the end of the incubation period the amount of $CO_2$ present in the NaOH was determined by titration using 0.1 M HCl with phenolphthalein as the indicator. The end point was marked by the change of colour of the titrate from pink to colourless (Rowell, 1994). For comparison with field results laboratory soil respiration (g $CO_2$ $g^{-1}$ $s^{-1}$) was converted to mmol $CO_2$ $m^{-2}$ $h^{-1}$ (44 g $CO_2$ is contained in 1 mol or 1000 mmol or $10^6$ µmol $CO_2$) following the detailed procedure by Rowell (1994). Microbial C was estimated using the fumigation-incubation method (Jorgensen, 1998; Rowell, 1994). Moist soil (50 g) was placed in a vacuum dessicator along with a beaker containing 25 ml of ethanol-free chloroform. The dessicator was evacuated with a pump until the chloroform boiled for 5 min. The soils were left in the chloroform vapour for 24 h. After fumigation respiration was measured during a 10 d dark incubation at 25°C (Jorgensen, 1998; Rowell, 1994; Jenkinson and Powlson, 1976). According to these workers biomass C (mg $CO_2$-C $g^{-1}$) in neutral soils has been found to be 2.2 x F; where F is the C respired by the fumigated soil during a 10 d incubation period at 25°C minus that respired by the unfumigated control (Rowell, 1994; Jenkinson and Ladd, 1981). Soil pH was measured as follows. Air dry soil (10 g) was weighed into a bottle with a srew cap. Water from a measuring cylinder was added (25 ml) and shaken for 15 min on a mechanical shaker with a stirrer. The pH electrode was inserted and the suspension swirled over the electrodes. The pH was recorded after 30 s. Total C and N were measured using an automated CHNS/O analyser (Perkin Elmer). Air dry 2 mm sieved soil (0.02 – 0.06 mg) was wrapped in foils provided by Perkin Elmer, loaded in the CHNS/O automated analyser wells and set to run the normal cycle as prescribed for the analyser. The total carbon and nitrogen per air dry soil was calculated automatically by the analyser with reference to individual soil sample weight in % and this was further transformed to g $kg^{-1}$ by multiplication of each value by 10 (ASA-CSSA-SSSA, 1998). Gravimetric soil water content was determined in the laboratory. By aid of soil auger (5 cm diameter, volume 209.27 cm3) soil samples taken in the field at 0 – 20 cm; 50 g of each placed in an oven at 105°C for 24 h. After incubation the soil was cooled in a dessicator and reweighed to obtain the water content of the soil. The result was expressed relative to the mass of oven dry soil. WFPS was calculated as:

WFPS = SWC x Db (1 – Db/PD)

Where, SWC is soil water content (kg $kg^{-1}$), Db is bulk density (mg $m^{-3}$) and PD is particle density (22.65 mg $m^{-3}$) – Franzluebbers et al, (2002); Doran et al, (1998). Soil bulk density was determined by calculation using the mass of oven dry soil and volume of core,

**Statistical and data analysis**

The diurnal and seasonal effects on field and laboratory respiration was evaluated using two way analysis of variance (ANOVA). Effects at $P \leq 0.05$ was considered significant while that at $P \leq 0.01$ was considered to be highly significant (Zar, 1999). For regression analysis mmol $m^{-2}$ $h^{-1}$ was used for soil respiration and mg kg-1 for microbial biomass. Soil respiration was also regressed with soil temperature and WFPS (SXSTAT11.EXE version 1.0.7). Goodness of fit from predictions with each of the regression equations against actual values were expressed with the coefficient of determination ($R^2$(. An exponential function was used to fit the data from soil respiration with temperature and WFPS accounts for all dates, sites to enhance actual values of tested variables. Multiple correlation was tested on soil respiration, temperature and WFPS (SYSTAT, Version 7.0, SPSS INC.). WFPS of the 0 – 20 cm depth was used as the moisture variable in all analysis as this property integrates porosity and moisture variables (Franzluebbers et al; 2002; Franzluebbers, 1999; Doran et al, 1998).

**Results and Discussion**

Table 1 presents the soil characteristics (0 – 20 cm) of the five locations studied at Wivenhoe park grassland

**Diurnal and seasonal variations in field soil respiration**

Field soil respiration over a 24 h period show high levels of temporal and spatial variability. Field soil respiration was highest at evening (18 – 19 h GMT) during the winter months (Dec – Feb) in the first y with mean of 5 sites at 27.2 mmol $m^{-2}$

$h^{-1}$, while in the second y respiration was more uniform from midday (12 – 13 h GMT) to evening across the five sites with a mean of 29.8 mmol $m^{-2}$ $h^{-1}$. During the summer months (Jun – Aug) of the y 1 and 2 field soil respiration was highest at noon with mean of 127.8 and 69.8 mmol $CO_2$ $m^{-2}$ $h^{-1}$ respectively.

By autumn (Sep – Nov) of y 1 field soil respiration was highest in the evening with mean of 45.3 mmol m-2 h-1 and in the morning (6 – 7 h GMT) of y 2 with 54.9 mmol $m^{-2}$ $h^{-1}$ . The summer time had the highest respiratory activity. Monthly field soil respiration gave significant differences between times of day and sites during the months of Jan, Feb and Aug of y 1 and Jun, Sep and Dec of y 2 (2 way ANOVA, P≤0.01. The highest field soil respiration was recorded in Aug of y 1 (168.2 mmol $CO_2$ $m^{-2}$ $h^{-1}$ and Jun of y 2 with 70.9 mmol $m^{-2}$ h-1. Overall the highest respiratory activity occurred in summer where the means across 5 sites was 78.7 mmol $CO_2$ $m^{-2}$ $h^{-1}$. Statistical significant variations (2 way ANOVA, P≤0.01 were also recorded between time of the day and sites during the summer.

**The relationship between soil temperature, WFPS and soil respiration**

Soil temperature was warmest in the evening during winter in yr 1 (4.8 ± 1.6°C) and in the morning in y 2 (3.6 ± 1.1°C). During spring, soil temperature was warmest in the evening in y 1 (12.3 ± 3.1 °C) and in the morning of y 2 (9.9 ± 2.6°C).

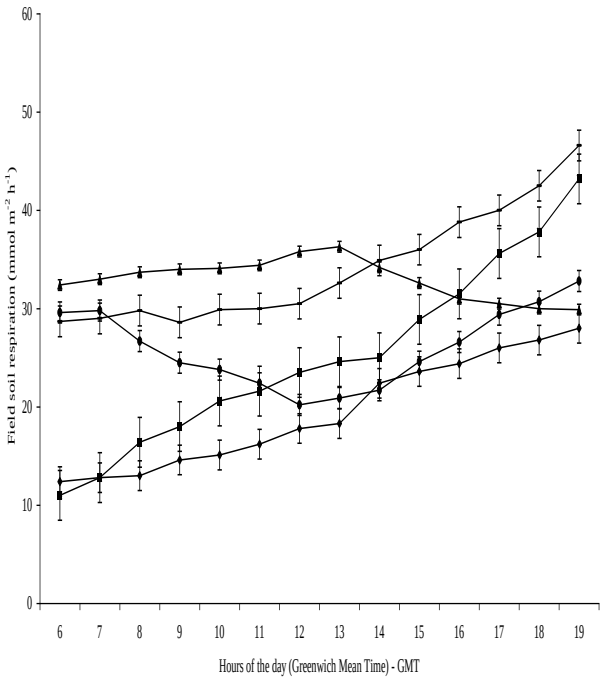


**Fig 2. Field soil respiration at various hrs of the d at Wivenhoe park grassland (mmol $CO^2$ $m^{-2}$ $h^{-1}$)**

In the summer the warmest soil temperature was recorded at noon in y 1 (18.2 ± 1.9°C) and in the evening of y 2 (18.8 ± 2.6°C). During autumn the warmest soil temperature was recoded at noon in y 1 (13.4 ± 0.6°C) and same time in y 2 (17.4 ± 3.4°C). Field soil respiration was dependent on soil temperature and WFPS ($R^2$ multiple = 0.5, FSR = 45.6 + 10.5T + 86.9WFPS mmol $CO_2$ $m^{-2}$ $h^{-1}$. WFPS did not vary significantly with time of sampling or with sites. WFPS was highest in spring (0.66 + 0.13 $m^3$ $m^{-3}$) followed by winter (0.55 + 0.15 m3 m-3) and least in summer (0.39 + 0.14 $m^3$ $m^{-3}$).

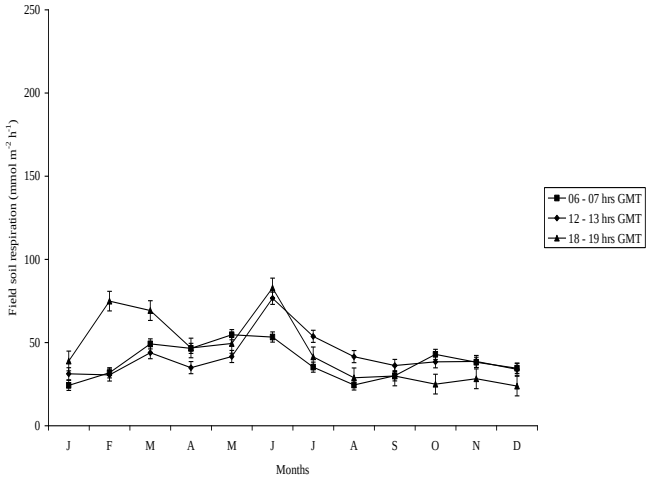


**Fig 3. Monthly time course field soil respiration at Wivenhoe park grassland (mmol $CO_2$ $m^{-2}$ $h^{-1}$). Bars represent standard error of means**

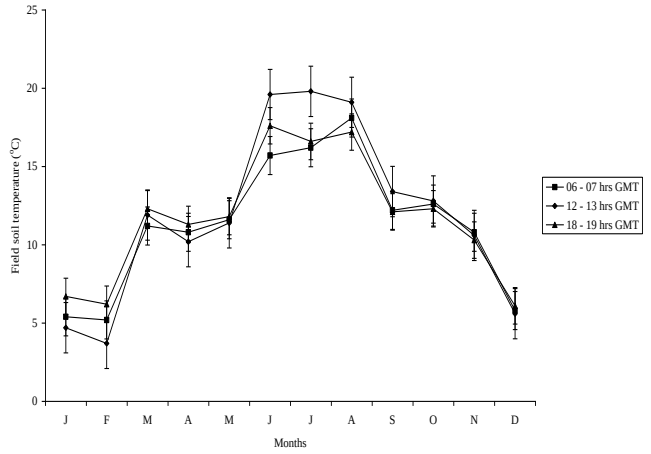


**Fig 4. Monthly time course soil temperature at Wivenhoe park grassland (°C). Bars represent standard error of means**

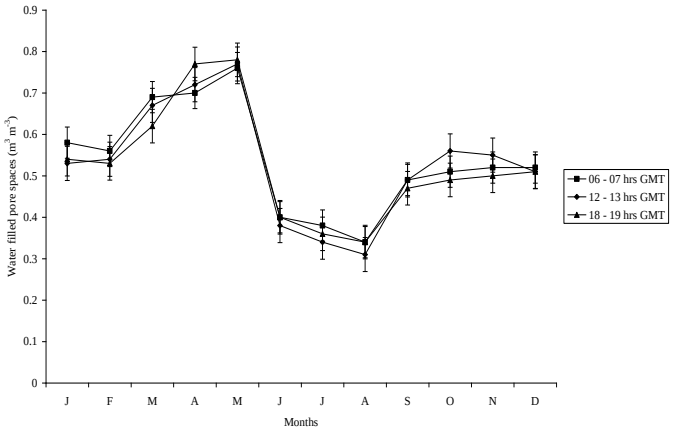


**Fig 5. Monthly time course WFPS at Wivenhoe park grassland ($m^3$ $m^{-3}$). Bars represent standard error of means**

**Laboratory respiration with natural and manipulated soil and moisture conditions**

Laboratory soil respiration carried out on samples under 25°C but natural WFPS showed statistical significant variation (2 way ANOVA, P≤1%). There was no site statistical significant difference for all months; but statistical times of d x sites (2 way ANOVA, P≤1%). At constant moisture (45% WHC) laboratory soil respiration increased with temperature. Likewise at 25°C soil respiration increased with WHC.

**Table 1. Soil characteristics (0 – 20 cm) of the five locations studied at Wivenhoe park grassland. Each value is mean ± standard error of 2 y**

| Soil parameter | Site 1 | Site 2 | Site 3 | Site 4 | Site 5 |
|---|---|---|---|---|---|
| pH | 5.80 ± 1.03 | 6.06 ± 1.04 | 5.56 ± 0.92 | 5.29 ± 1.06 | 6.06 ± 1.29 |
| Total C (g $kg^{-1}$) | 33.30 ± 12.95 | 109.5 ± 61.8 | 101.6 ± 30.7 | 73.4 ± 34.8 | 80.0 ± 34.8 |
| Total N (g $kg^{-1}$) | 4.16 ± 2.86 | 8.26 ± 3.16 | 16.4 ± 18.6 | 8.72 ± 4.66 | 6.0 ± 1.14 |
| Bulk density (g $^{cm-3}$) | 0.66 ± 0.08 | 0.44 ± 0.11 | 0.48 ± 0.11 | 0.49 ± 0.09 | 0.40 ± 0.13 |

On the other hand laboratory soil respiration at constant temperature and moisture were not statistically different for samples collected at the same time.

The wide variations in field soil respiration especially during winter and summer may be due to several factors: changes in weather and climatic conditions, particularly temperature and moisture; soil physico-chemical properties and aboveground biomass. In this work, higher temperature led to increased soil respiratory activity during summer. In winter lower temperature irrespective of higher WFPS led to reduction in soil respiration. It is likely that soil respiration rates during the winter months may have been limited by low temperature. It is also likely that the above ground biomass arising from grasses and trees in the vicinity of the sites led to rhizosphere deposition of C. Franzluebbers et al (1995,2002) linked this summer time with highest radiation potential to mass production of readily utilizable photosynthates and translocation below ground. Osman (1971) noted that root respiration can be up to 50% higher when exposed to photosynthetically active radiation. Similarly, Pumpanen et al (2003) attributed the differences between measured and predicted $CO_2$ fluxes during the autumn and the spring to seasonal variations in the proportion of root respiration and in the temperature response. Boone et al (1998) and Widen and Majdi (2001) reported percentage of soil $CO_2$ flux as emanating from roots which was higher on summer and lower in winter occasioned by changes in root biomass and production. In this work differentiation between root and soil respiration was not carried out. Future studies at that may account for the observed change in daily and seasonal respiration.

The variations in laboratory soil respiration at fixed temperature and natural WFPS show the effects of moisture. The increase in laboratory soil respiration at manipulated soil moisture and temperature adds to similar findings by Davidson et al (1998). Other factors may be physico-chemical properties of the soil like pH, total C and Nitrogen as well as microbial biomass. Some precautionary measures have been recommended in the assessment of soil respiration. For example, Franzluebbers et al (2002) cautioned that falling below base levels of either temperature (≈10°C) or WFPS (≈0.4 m3 m-3) can subdue or negate the expected positive response in soil respiration if improvement in another controlling variable e.g growth rate were to occur. In another account, Boone et al (1998) and Majdi (2001) linked root and rhizosphere respiration to be temperature sensitive. The temperature sensitivity reflected not only the respiration of roots but also respiration by mycorrhiza and the decomposition of labile root-derived organic material (detritus and exudates) by microbiota in the rhizosphere. Pumpanen and fellow workers (2003) observed faster $CO_2$ diffusion from dry soil during dry period because of increased air filled pore space which occurred during the drought. According to these workers, air filled pore space is the main factor affecting the diffusion rate. In another investigation in two New England forests by Savage and Davidson (2001) upland sites had consistently greater rates of respiration than wetlands. Prolonged drought periods at the Havard Forest resulted in decreased soil respiration rates in the uplands particularly once the moisture contents decreased below about 150 kPa. In contrast, wetland respiration increased upon drying. Interannual variation was lower at the Howland Forest and the effects of low moisture content on respiration rates were not subtle. The onset of spring was variable among years at both forests owing to variation in both temperature and precipitation and contributed to 33 – 59% of the annual variability in total C release. In another study in a forest beech, Janssens and Pilegaard (2003) observed large seasonal changes in the $Q_{10}$ of soil respiration. Despite the higher wintertime $Q_{10}$'s (23 for 2°C) the absolute response of soil respiration to temperature was smaller in winter than in summer. This according to the authors was based on the assumption that in absolute numbers, the temperature sensitivity of soil respiration depends not only on $Q_{10}$ but also on the rate of soil respiration which is highly reduced in winter. Nonetheless, the $Q_{10}$ of soil respiration in winter was larger than could be explained by the decreasing respiration rate only. Curiel-Yuste et al (2003) seasonal $Q_{10}$ was found to be dependent on the amplitude of the seasonal changes in soil respiration which under the particular climatic and edaphic conditions of forest sites were significantly larger in deciduous forests. In their study soil respiration was positively correlated with the seasonal changes in leaf area index (LAI) a measure of the deciduousness of the vegetation. They also showed the large differences in seasonal $Q_{10}$ were not entirely due to different sensitivities but due to different seasonal patterns of plant activity in the evergreen and deciduous plants of the site.

**Conclusion**

This work has demonstrated the temporal and spatial variations in soil respiration. It shows the effects of environmental changes particularly temperature and moisture. The laboratory results helped in the estimation of potential flux. However, since these environmental variables are difficult to control under field condition, laboratory incubation becomes a supplementary approach. This is the condition by which root and respiration can be separated. Laboratory studies can enhance manipulation of incubation media as nutrient management under natural conditions face similar environmental conditions.

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