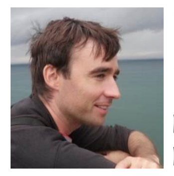

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Observations and Modeling of Moisture-Temperature-Substrate Interactions in Soils

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INTRODUCTION

- Soils store large amounts of organic carbon (C) which makes them an important component of the C cycle. However, the dynamics of soil organic carbon (SOC) and its interactions with climate and other ecosystem components remain poorly understood.
- This study looks at the combined effects of temperature, moisture and substrate on SOC decomposition and compares observations with output from a soil C model.
- The model is process based and thus simulates physical and chemical controls over C pools and fluxes.
- A number of mechanisms are tested in the model to find the best representation of the observations.

THE DATA

Two soils were incubated over a few months, both originating from the same site but with different histories. One is from a maize field (1.2 % SOC), the other is a C-depleted soil from a bare fallow experiment (BF, 0.6 % SOC) where plant growth has been prevented for several decades.

The following treatments were applied to each soil:

12 levels of moisture held constant, ranging from air-dry to saturation, in parallel samples.

3 levels of temperature (5, 20 and 35 °C) applied in sequence to each sample

Respiration as a proxy for SOC decomposition was estimated by measuring the increase in CO_2 at regular intervals in the sample flask headspace.

Results are summarized in Figure 1.

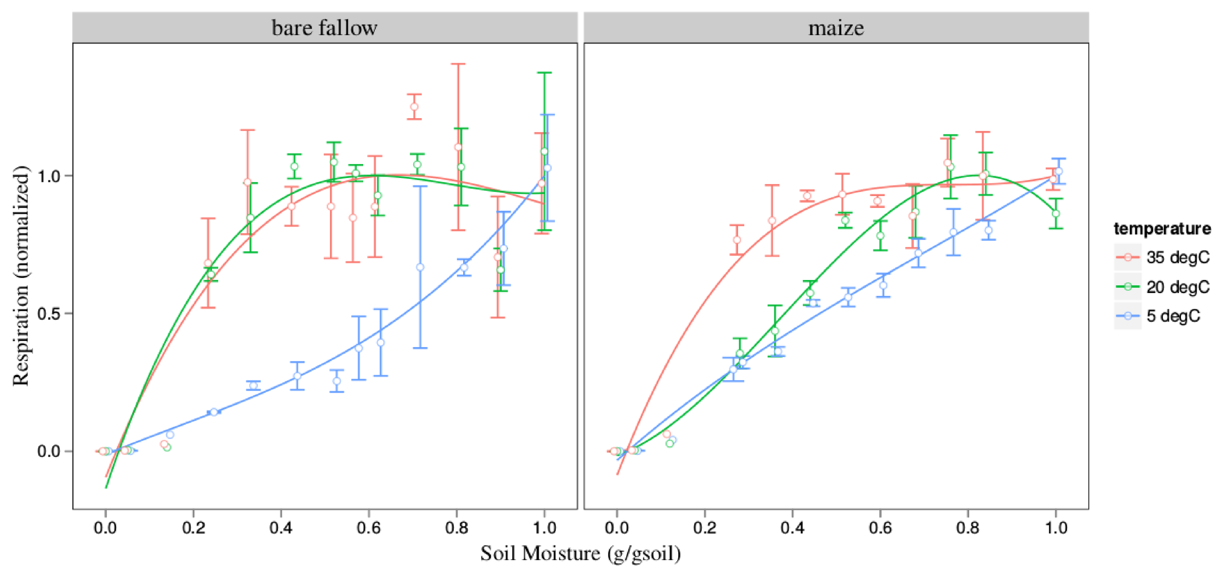

Figure 1
Observed data from incubated soils: averaged and normalized respiration rates vs moisture content at each of the 3 temperature treatments.

- At higher temperatures the moisture response plateaus before reaching saturation.
- At low temperatures the response increases until saturation.

THE MODEL

The model simulates enzyme driven organic matter decomposition. A diagram of the base model is shown in Figure 2.

The following components and processes are simulated:

- Carbon pools: particulate (PC), soluble (SC), enzyme (EC). Microbial (MC) is optional.
- Enzyme mediated decomposition of PC to soluble SC.
- Temperature (Arrhenius equation) and concentration (Michaelis-Menten kinetics) dependency of reaction rates.
- Effect of moisture on substrate availability (directly and through diffusion of DOC).
- Enzyme and microbial production and decay.

Note: because of the time frame involved, the adsorbed pool SCa was ignored in this study.

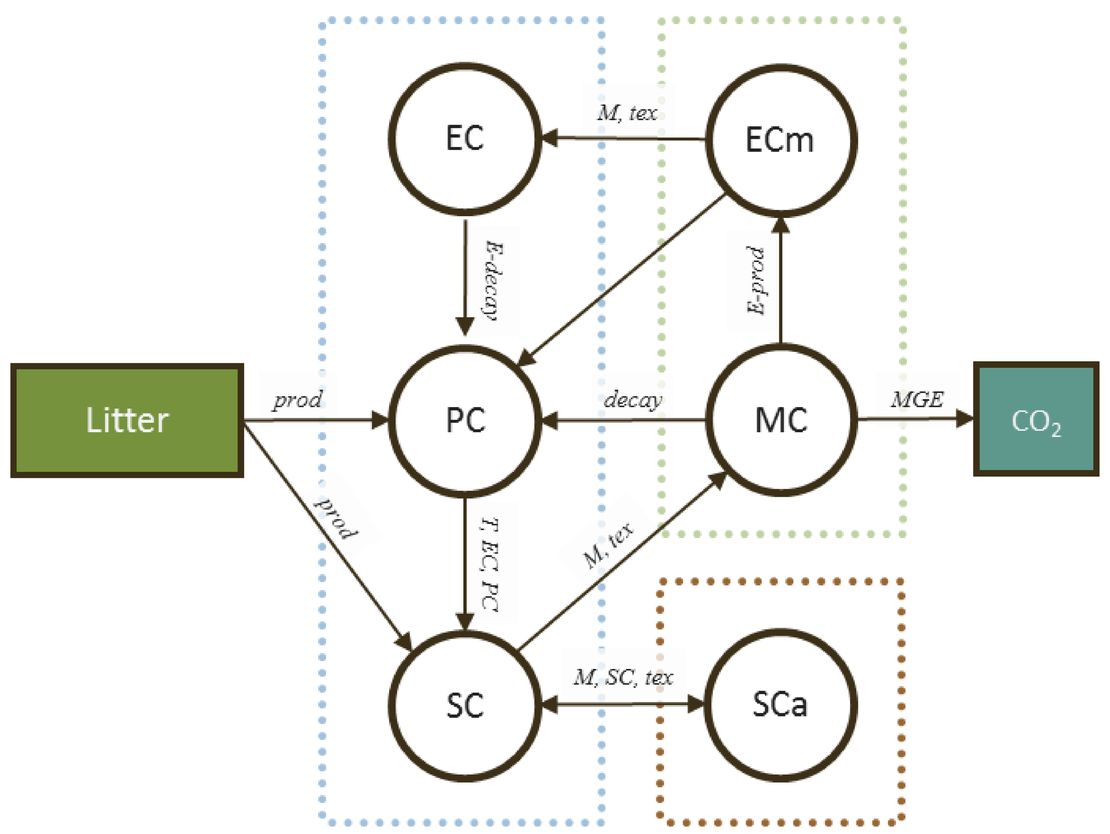

Figure 2
Model base structure.

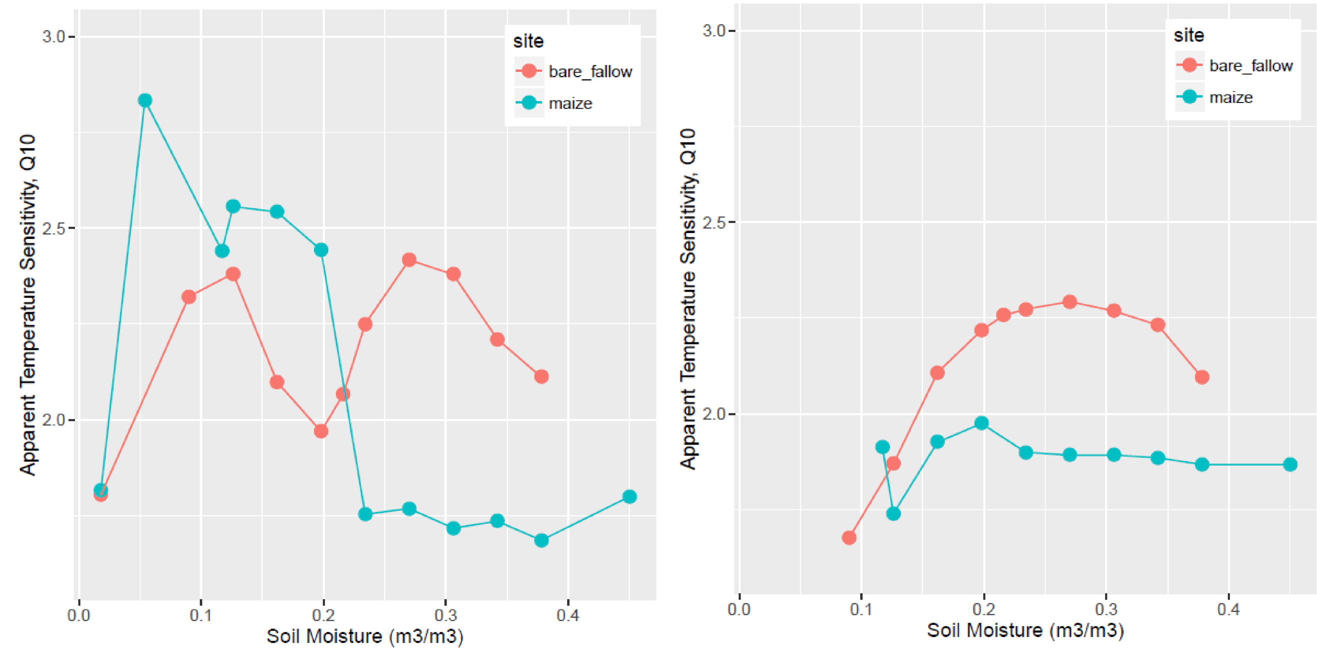

Figure 3
Apparent temperature sensitivity of observed (left panel) and modeled (right panel) soil respiration at different levels of soil moisture as obtained by fitting an exponential function. Q_{10} represents the proportional increase in the rate with a 10 degree increase in temperature).

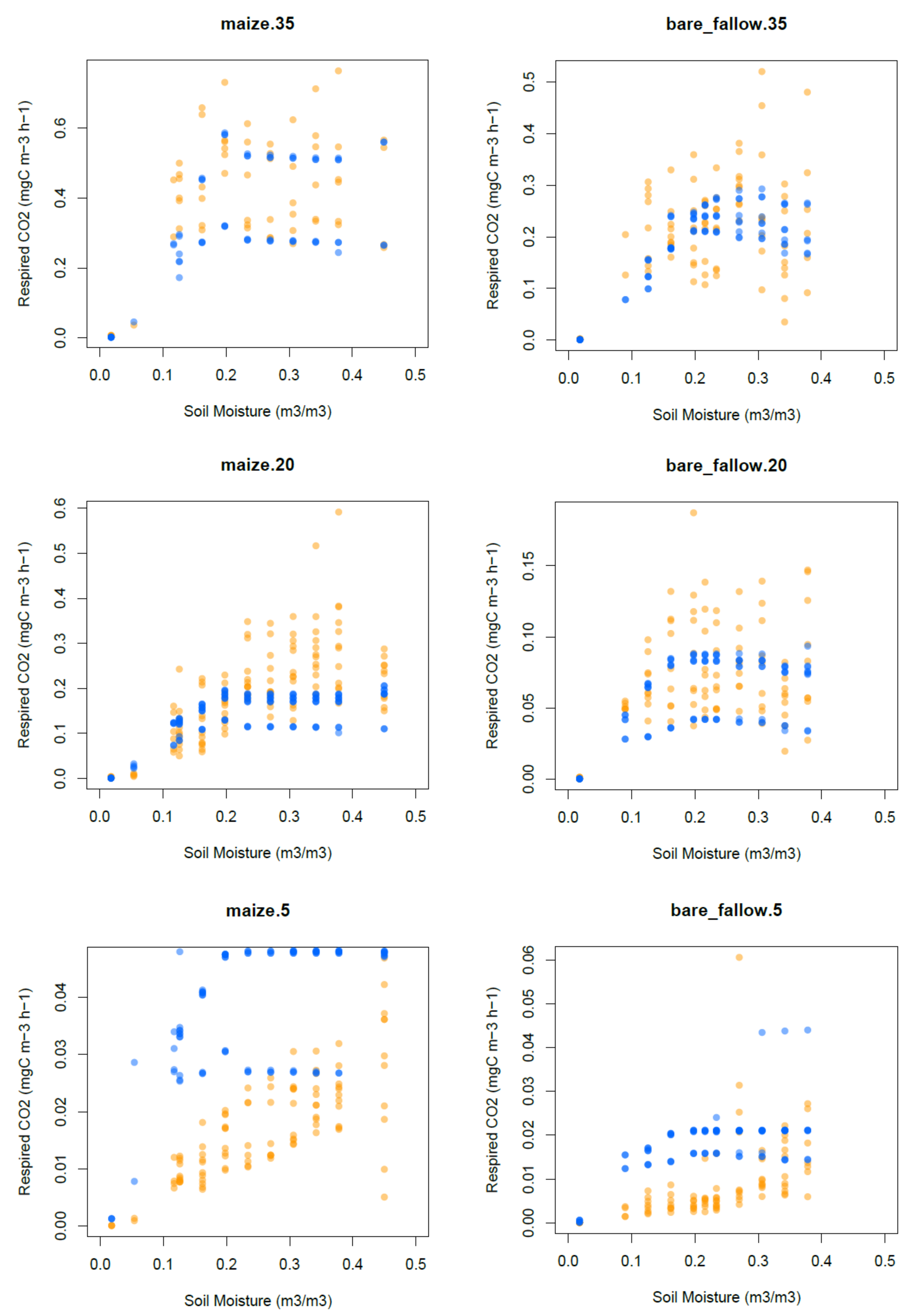

Figure 4
Respired CO_2 vs volumetric moisture from observations (yellow) and model (blue).

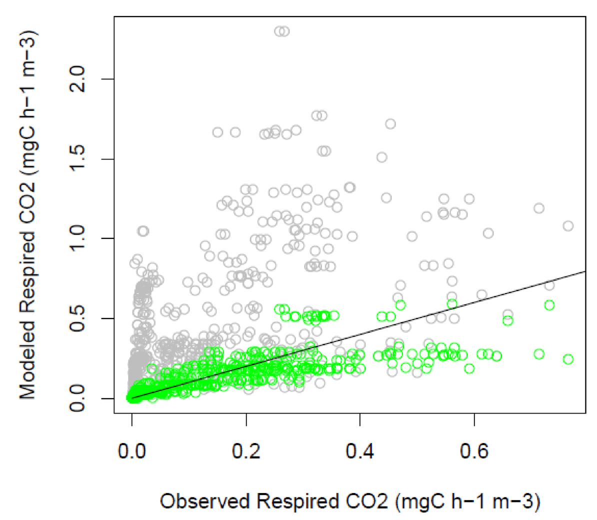

Figure 5
Model vs observed values before and after parameter optimization (gray and green respectively). Model includes P2.

MODEL CALIBRATION

Model parameters were optimized against the incubation data using R package FME (Nelder-Mead method).

Parameter initial values were taken from literature when available, and were given broad but realistic boundary values as determined from literature or theory (Table 1).

Several model variants were optimized by selectively including/excluding the following properties:

- P1: DOC and enzyme concentrations affected by water content.
- P2: available PC depending on moisture with max at field capacity.
- P3: direct temperature effect on diffusion of DOC.
- P4: SOC concentration effect on diffusion of DOC.
- P5: explicit microbial pool.

Figure 5 shows model vs data for one model version.

Table 1

parameter	initial	lower	upper	optimized
f_CA_bf	0.2	0.01	0.9	0.036
f_CA_mz	0.2	0.01	0.9	0.355
f_CD	0.001	1.00E-04	0.005	0.0050
f_CEm	0.001	1.00E-04	0.005	0.00020
f_CEw	0.001	1.00E-04	0.005	0.0048
r_ed_ref	0.001	1.00E-04	0.01	0.00024
V_D_ref	1	0.01	10	0.30
K_D_ref	20000	10000	5.00E+05	73712
E_V	47	30	100	98
E_K	30	20	40	35
f_gr_ref	0.7	0.5	0.8	0.53
f_de	0.01	0.001	0.1	0.0020
psi_Rth	15000	13000	17000	16950
D_0	0.36	0.00036	36	5.25

RESULTS

- Observations showed that the responses of soil respiration to moisture, temperature and substrate are interdependent:
  - Temperature sensitivity varies both as a function of moisture and with soil type (i.e. with SOC quantity/quality) (Figure 3).
  - The moisture response changes less with soil type (SOC quantity/quality) but is strongly affected by temperature (Figure 1 and 4).
- A number of processes to explain the observations were tested. The base model including only P2 (i.e. available PC depending on moisture with max at field capacity) gave best results. This version was used to create the plots shown. From this, a number of conclusions can be drawn.
- Relationship with temperature:
  - The difference in Q_{10} between soils at higher moisture levels was well captured by the model. This is highly significant as such differences are exclusively the result of substrate interactions in the model. The intrinsic temperature sensitivity (E_V) is fixed, equal for both soils and higher than the apparent sensitivity.
  - The variability in Q_{10} at lower moisture levels was not well captured by the model. This may be the result of high noise to signal in the data as well as missing processes in the model.
- Relationship with moisture:
  1. The model was highly capable of reproducing the common plateau-like response. Such a response is not prescribed and an example of interacting processes.
  2. The model was better at capturing the shape of the relationship and scatter in the data at high temperatures. Interestingly, the model seems to capture cases where there is an optimum at intermediate water content (Figure 4, bare fallow), even if there is no O_2 limitation in the model.
  3. At lower temperatures the model reproduced variability comparable to observations, but the magnitude and shape of the relationship were not well captured.