Archived Soil Incubations Manuscript Figures

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Notes

- This workbook is intended to load and prepare the key data for analysis for the archive incubation project.
- This is an updated version of RMD file "./src/arc_inc_data-wrangling_2020-04-20.Rmd" with the explanatory text removed
- all code chunk options are set to "echo = FALSE"; see raw .Rmd file for data wrangling code.

Methods and materials

Radiocarbon corrections

Although differences were small, radiocarbon data for archived samples were first corrected for decay since the year of collection before assessing treatment effects.

Decay correction formula:

$$1000 \cdot \left((FM \cdot e^{\frac{-year_{sampled}+1950}{8267}}) - 1 \right)$$

where FM is the fraction modern, and 8267 is the inverse of the product of the natural log of two and the true half life of ^{14}C (5730 y).

Results

Respiration rates

note that the text below was left because statistics were calculated on the fly

Experiment 1 (air-dry + storage treatment)

Among the air-dry + storage samples, respiration rates were more than twice as high in grassland soils than in forest soils, reaching a maximum of 3.8 mg CO_2 g soil C^{-1} d^{-1} after 92 h, followed by a sharp decline. Mean respiration rates in forest sites peaked at 1.5 mg CO_2 g soil C^{-1} d^{-1} after 166 h, followed by a much more gradual decline than in grassland sites. Control samples responded more weakly and more gradually to rewetting, although as in the treatment samples respiration was greater in grassland soils than in forest soils. Peak respiration rates for control incubations were 1.9 and 0.6 mg CO_2 g soil C^{-1} d^{-1} after 115 h for grassland and forest soils, respectively.

Experiment 2 (air-dry treatment, 2019 samples)

Peak respiration rates were not significantly different ($p > 0.05$) between forest and grassland soils in Experiment 2, peaking at 3.0 and 3.3 mg CO_2 g soil C^{-1} d^{-1} after 95 h for grassland and forest soils, respectively **(Fig. 1)**.

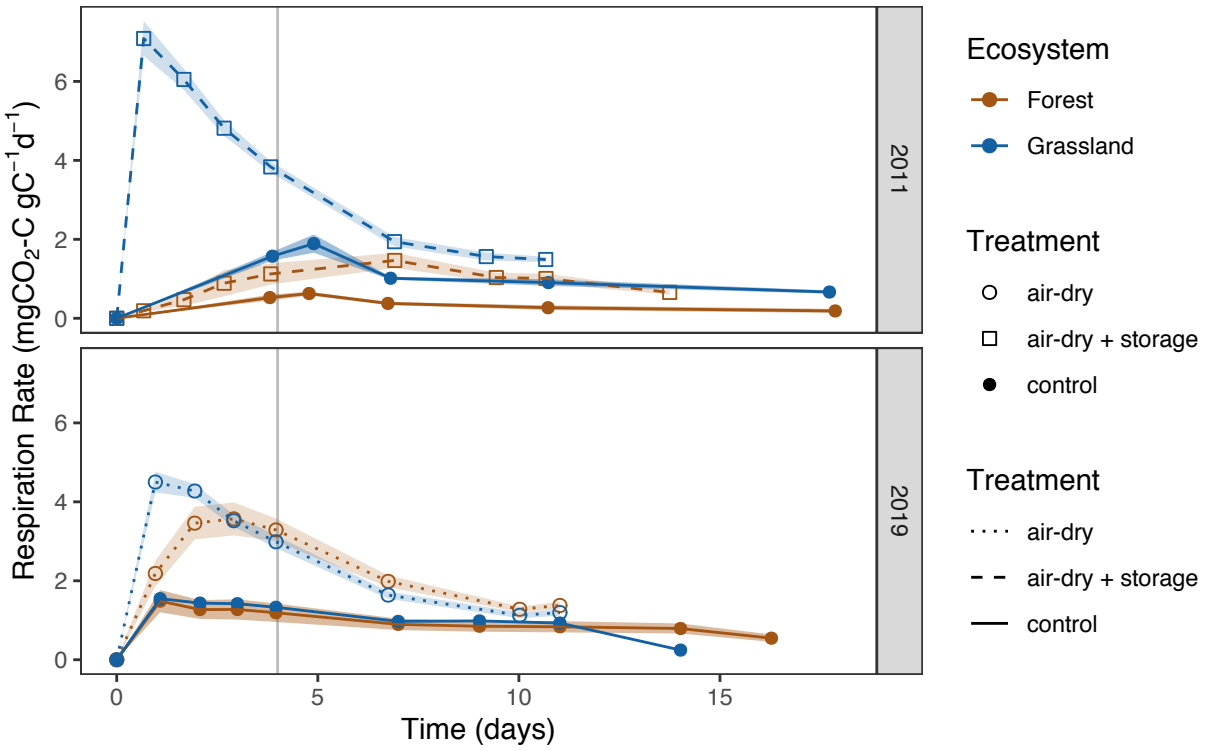


Fig. 1. Respiration rates for Experiment 1 (air-dry + storage treatment, 2011) and Experiment 2 (air-dry only treatment, 2019)

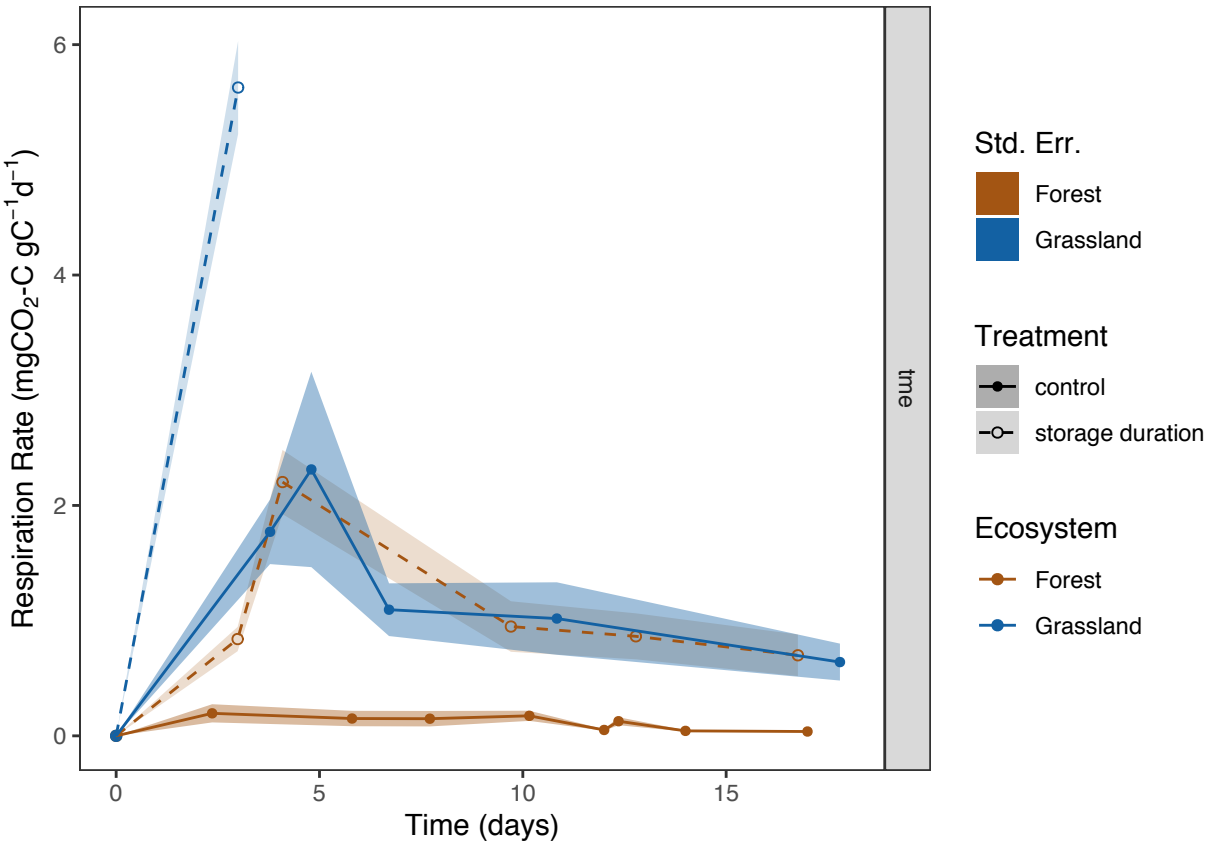
Caption: Top panel shows data from samples collected in 2011 for Experiment 1 (air-dry + storage treatment), bottom panel shows data from samples collected in 2019 for Experiment 2 (air-dry only treatment). Vertical gray line at day 4 demarcates the end of the pre-incubation period and the start of the equilibrium respiration period. Points show measurements and lines show trends in mean respiration rate. Shaded ribbons represent one standard error. The final measurement points for a few samples which took >18 days to reach CO_2 targets are excluded for display reasons; respiration rates for those samples remained flat. Note that headspace CO_2 concentrations for Experiment 1 control samples were only measured once during the pre-incubation period (day 4) in contrast to daily measurements for all other samples. Consequently the respiration rate for those samples is the cumulative average rate over the first 4 d.

Supplemental respiration rates figures:

Experiment 3 (storage duration)

Grassland soils from the storage duration treatment group responded rapidly to rewetting and reached target CO_2 levels after just 72 h of incubation. Only a single observation was made for the grassland treament samples due to the rapid respiration rates, which peaked at 5.6 mg CO_2 g soil C^{-1} d^{-1}. The mean peak respiration rate for forest treatment samples was lower and lagged in comparison to the grassland soils, reaching 2.2 mg CO_2 g soil C^{-1} d^{-1} after 97 h.

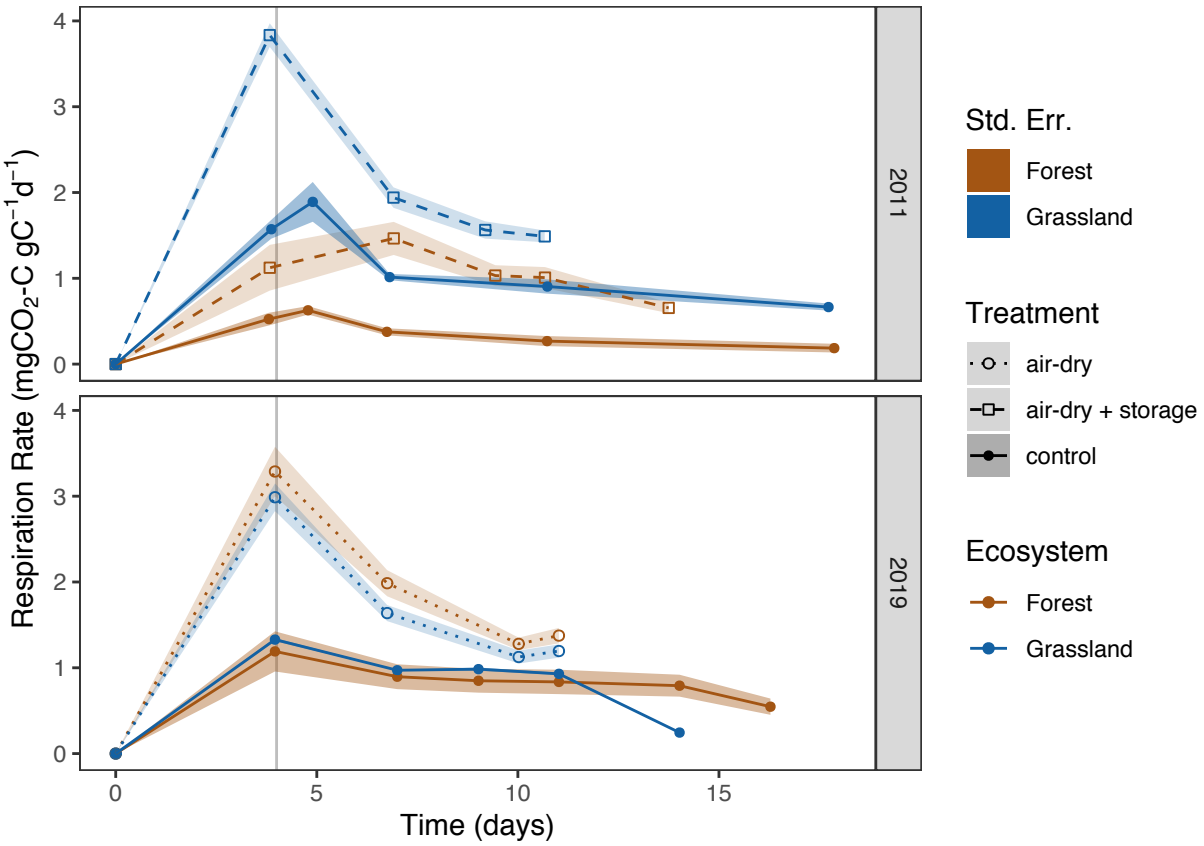
Control-3 respiration rates peaked after the pre-incubation period (115 h), at 2.3 mg CO_2 g soil C^{-1} d^{-1}. Forest control samples were pre-incubated under various conditions, but respiration rates were only measured during the pre-incubation period for two samples from the Sierra Nevada mountains (USA). In general, respiration rates for forest control samples in Experiment 3 were much lower than in the treatment incubations, peaking at 0.6 mg CO_2 g soil C^{-1} d^{-1} after 120 h.



Supplemental Fig 1. Respiration rates for Experiment 3

Caption: Experiment 3 storage duration treatment samples were only incubated for a single enclosure period, as the results of Experiment 1 and Experiment 2 showed no significant difference in Δ^{14}C-CO_2 between the rewetting pulse CO_2 released during the pre-incubation period and the CO_2 respired during the equilibrium respiration period. The grassland storage duration treatment samples (blue dashed line) respired an equivalent amount of CO_2 in just 3 d as the corresponding control-3 samples respired during the pre-incubation period and the equilibrium respiration period combined. Consequently those incubations were stopped after the first CO_2 measurement point. Control-3 samples did undergo pre-incubation, but as the CO_2 release was not measured nor was Δ^{14}C-CO_2 for the majority of the samples, all data were averaged by day of measurement.

Preincubation headspace CO_2 concentations were only measured once for the control-1 samples, at the end of the four=day preincubation period. In order to compare the control-1 respiration rates more easily with the air-dry + storage treatment samples, Supplemental Figure 2 shows the air-dry + storage pre-incubation respiration rates plotted as a cumulative average for the preincubation period. However, as can be seen in Figure 1, headspace CO_2 concentration was measured daily for the air-dry + storage samples.



Supplemental Fig 2. Respiration rates for Experiment 1 and Experiment 2 shown with all pre-incubation data calculated as cumulative averages

Caption: CO_2 concentrations for Experiment 1 control samples were only measured once during the pre-incubation period, in contrast to daily measurements for all other samples. Pre-incubation respiration rates are shown here calculated as cumulative averages for the purpose of fair comparison across all treatments.

Radiocarbon data

Pre-incubation versus equilibrium respiration ^{14}C-CO_2

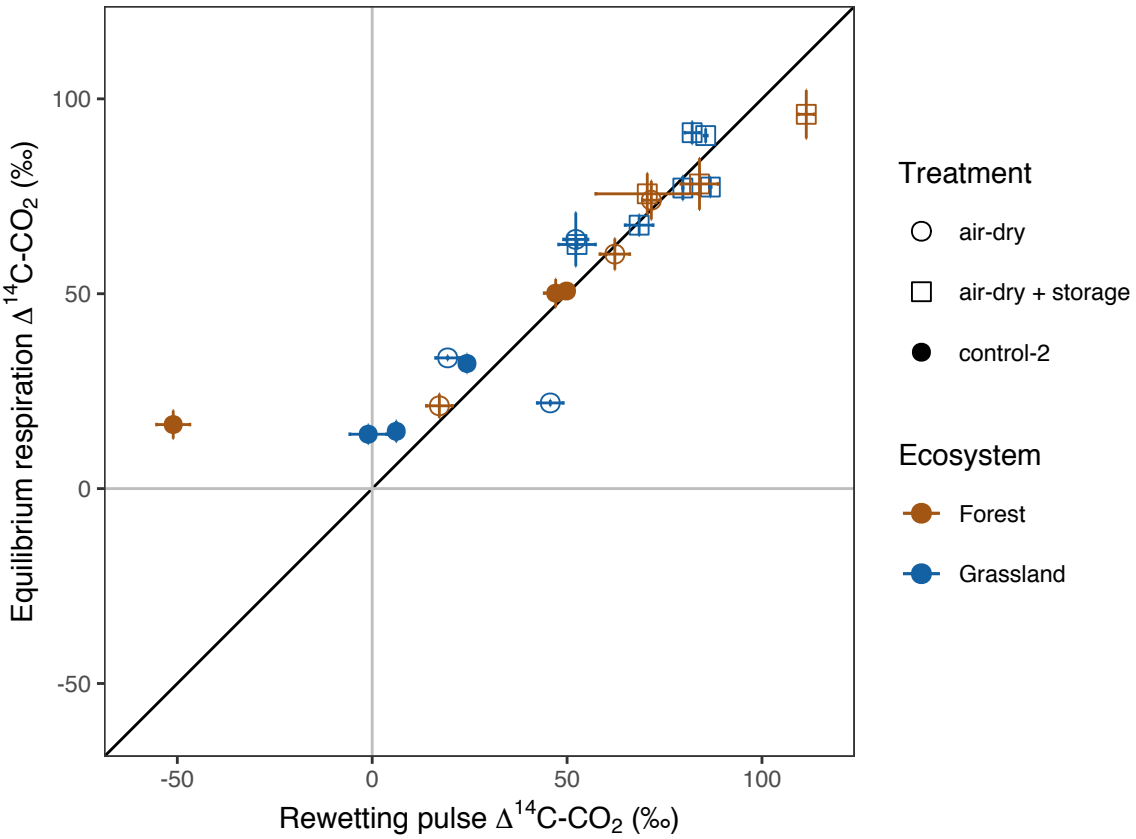


Fig. 2. Δ^{14}C-CO_2 of the rewetting pulse and the equilibrium respiration period

Caption: Points are means of laboratory duplicates and error bars are the min and max (except for Experiment 1 control samples, which were not replicated). Note that rewetting pulse Δ^{14}C was not measured for control-1 samples; additionally samples from three of the forest plots of the air-dry + storage samples from Experiment 1 failed to accumulate enough CO_2 during the pre-incubation period to measure Δ^{14}C. The outlier point with the substantially depleted pre-incubation Δ^{14}C is from Experiment 2 (control).

Treatment effects on observed equilibrium period ^{14}C-CO_2

Treatment effect on $\Delta^{14}C$-CO_2 for all samples (Experiments 1, 2, and 3)

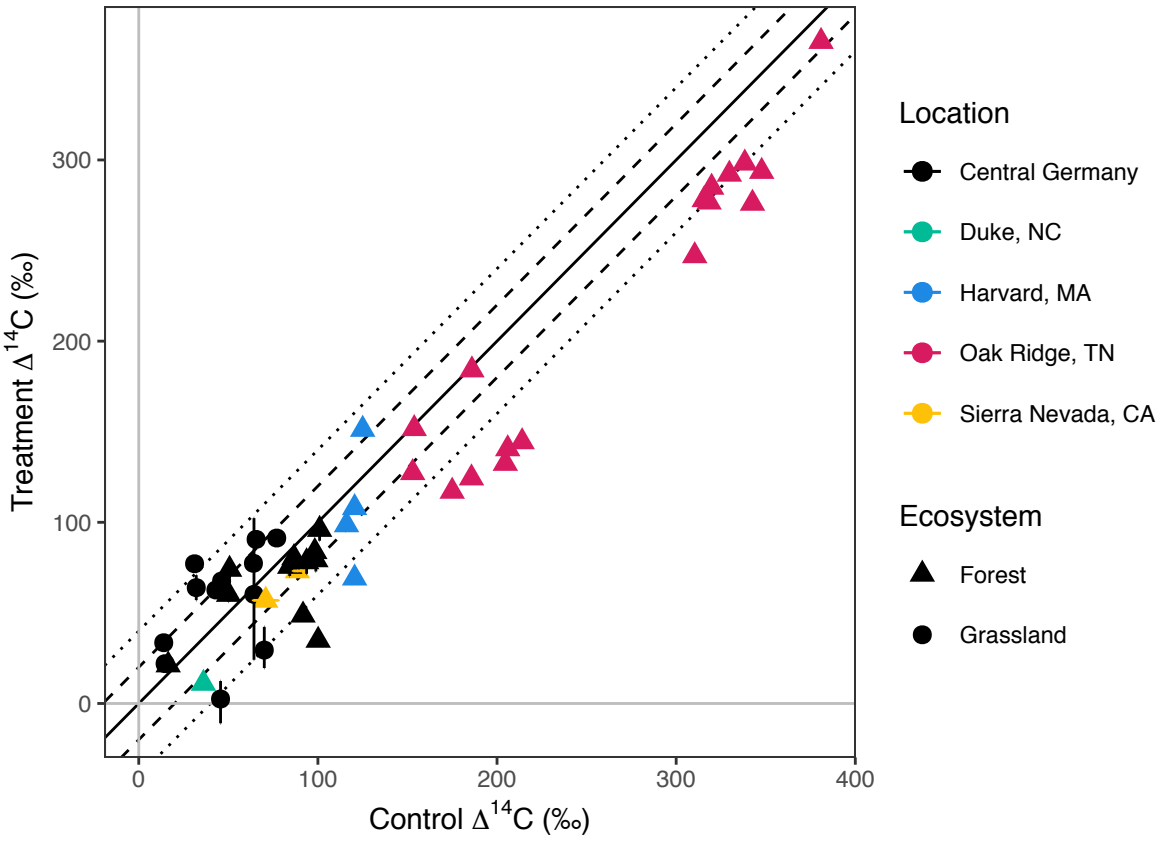


Fig. 3. Overall treatment effect on $\Delta^{14}C$-CO_2

Caption: Points show data from Experiments 1 and 3 (air-dry + storage treatment) and Experiment 2 (air-dry only treatment). Points are the mean of laboratory replicates (for replicated samples); error bars are 2x standard error. Solid line is 1:1. For context, the dashed and dotted lines show differences of ±20‰ and ±$40‰, equivalent to the decline in $\Delta^{14}C$ in atmospheric CO_2 over 4 and 8 y respectively, during the period of 2000 to 2020 (Graven et al. 2017).

Storage duration effect on ^{14}C-CO_2 (Experiment 3)

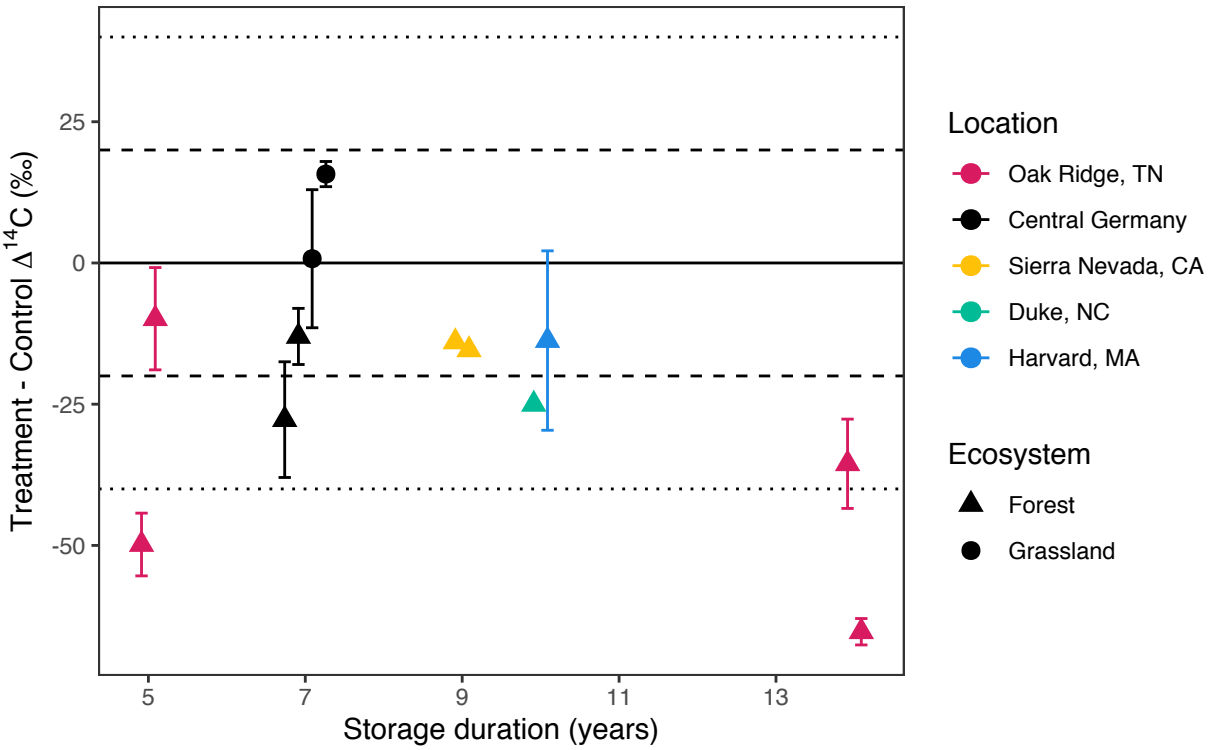


Fig. 4. Change in ^{14}C-CO_2 in relation to storage duration

Caption: Data are from both Experiment 1 (in black) and Experiment 3 (all other points), averaged by site and ecosystem type. Points are the mean, error bars are 2x standard error. For context, the dashed and dotted lines are the same is in Fig. 4 and show a difference of 20‰ and 40‰, equivalent to the decline in $\Delta^{14}C$ in atmospheric CO_2 over 4 and 8 y respectively, during the period of 2000 to 2020 (Graven et al. 2017). Position of points jittered to avoid overplotting; storage duration has been rounded down to the nearest whole year.

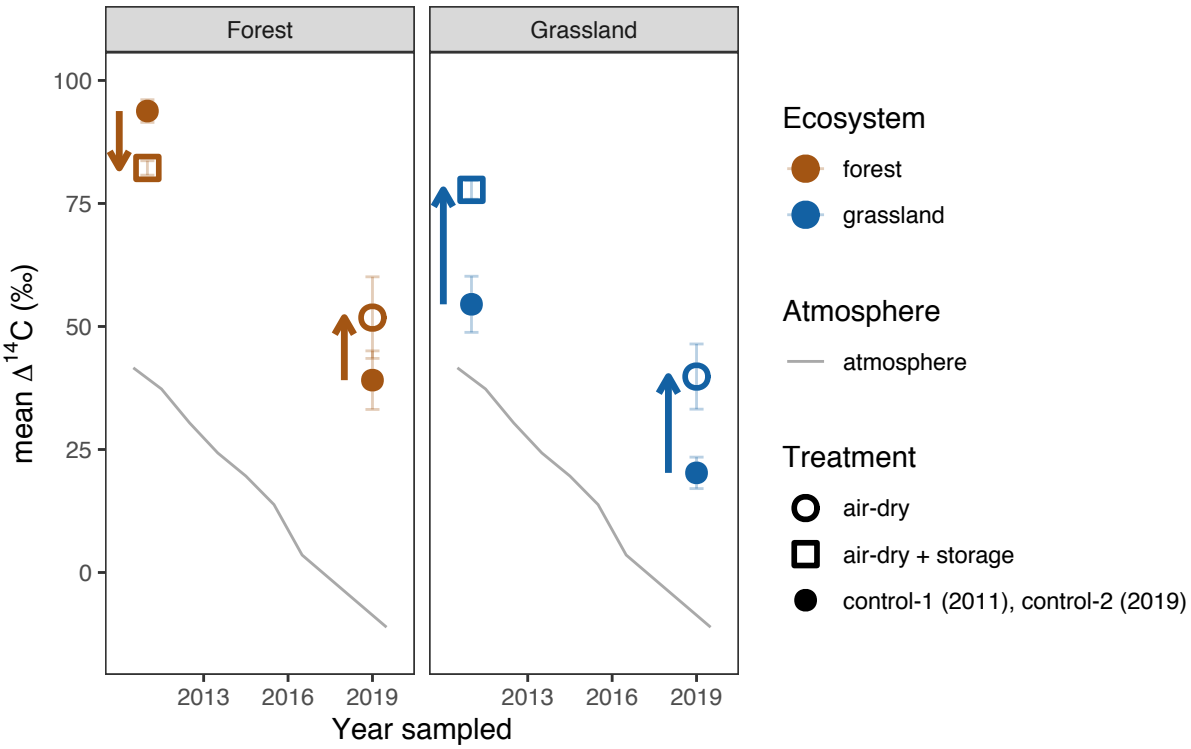
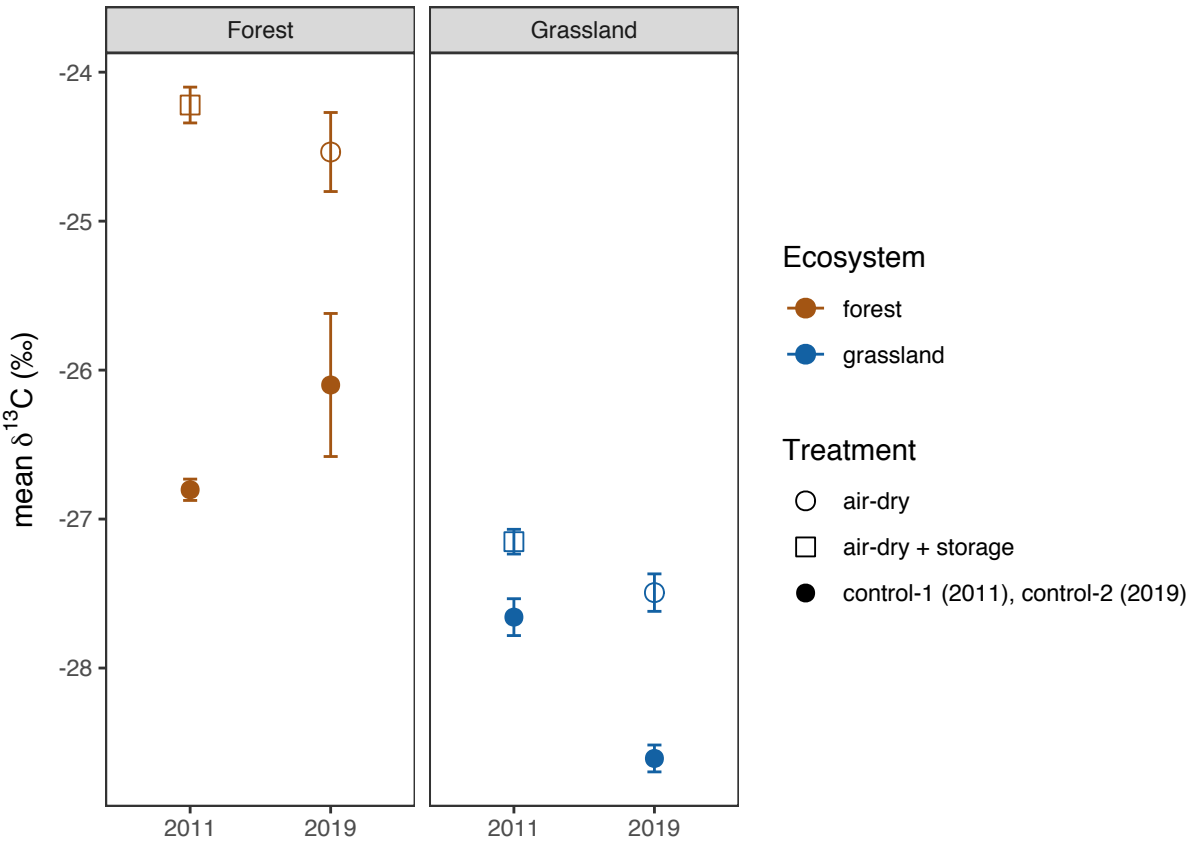


Fig 5. Time series of control and treatment Δ^{14}C-CO_2 (Experiments 1 and 2)

Caption: Filled circles show Δ^{14}C-CO_2 observed for both control-1 and control-2 samples (2011 and 2019 points, respectively). Open symbols show Δ^{14}C-CO_2 observed for treament samples: open squares = air-dry + storage treatment, Experiment 1; open circles = air-dry only treatment, Experiment 2. Arrows show the direction of change in Δ^{14}C-CO_2 relative to the controls. Points are means and error bars show 2x standard error. The gray line shows Δ^{14}C of the atmosphere.

The absolute mean difference in ^{14}C-CO_2 between control and treatment samples was greater in grassland samples (21.4‰) than in forest samples (12.1‰) for both Experiment 1 and Experiment 2.

δ^{13}C

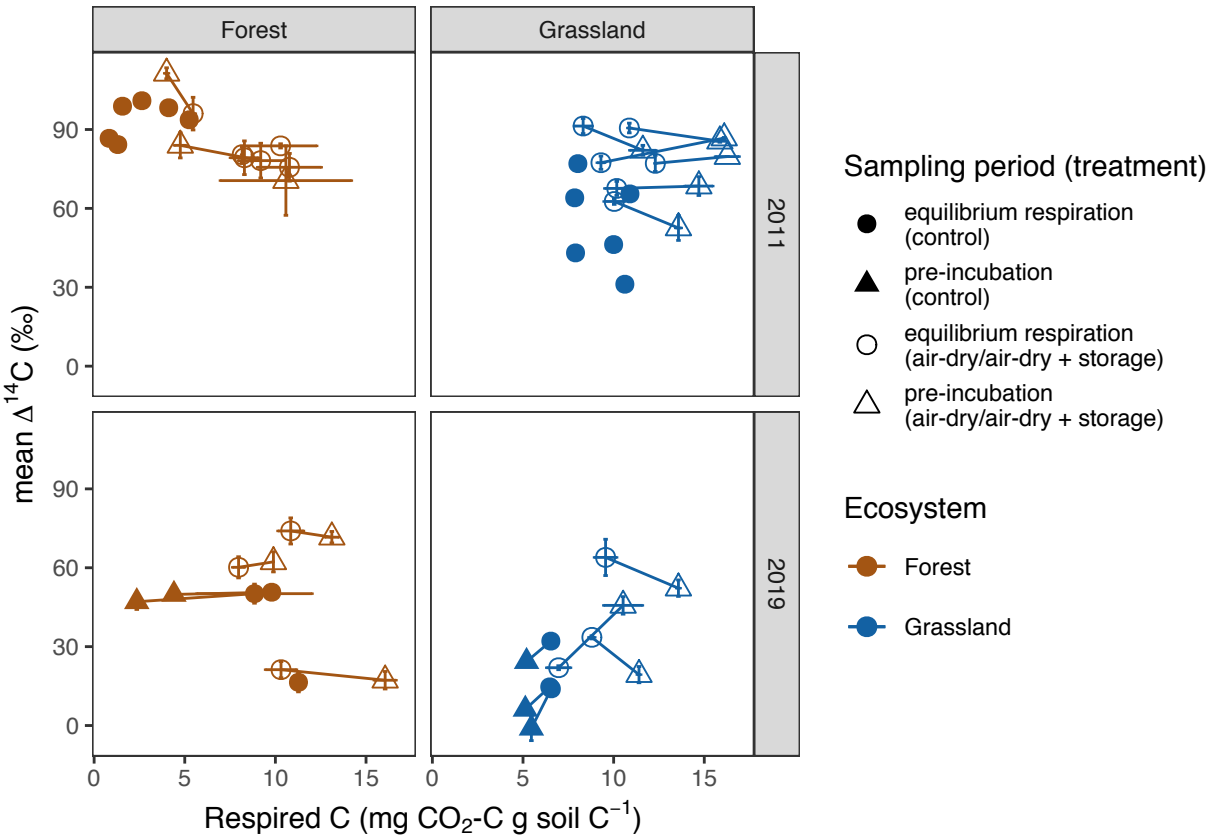


Supplemental Fig 3. Time series of control and treatment δ^{13}C-CO_2 (Experiments 1 and 2)

Caption: Filled circles show δ^{13}C-CO_2 observed for control samples, while open symbols show δ^{13}C-CO_2 observed for treament samples (open squares = air-dry + storage treatment, Experiment 1, 2011; open circles = air-dry only treatment, Experiment 2, 2019). Points are means and error bars show 2x standard error.

Effect of cumulative respired carbon on ^{14}C-CO_2

We looked at the possible effect of the difference in the amount of carbon respired (mg CO_2-C g soil C^{-1}) on the differences between control and treatment ^{14}C-CO_2 using a linear regression model, but it was not significant overall. When data from Experiment 1 and Experiment 2 were considered separately, we observed a slight positive trend between the difference in respired carbon and the difference in ^{14}C-CO_2 within Experiment 2, but it was only marginally significant ($p = 0.063$).



Supplementary Fig. 4. Change in ^{14}C-CO_2 in relation to cumulative soil carbon respired

Caption: Note that pre-incubation $\Delta^{14}C$ was not measured for the control-1 samples in 2011. Limits exclude outlier point (HEW22 control-2, pre-incubation) for improved legibility. Points are means, error bars show min and max of duplicate samples.

Discussion

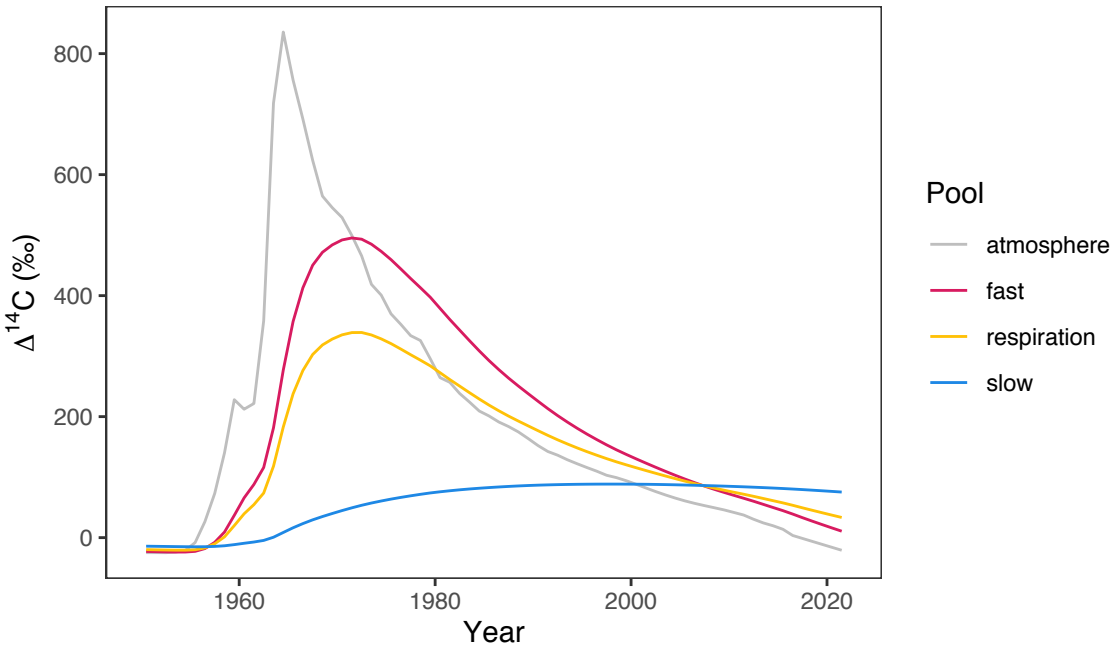


Fig 6a. Modeled trajectories of $\Delta^{14}C$ over time for a hypothetical 2-pool soil carbon model in relationship to observed atmospheric $\Delta^{14}C$

Caption: Modeled curves derived from a hypothetical two-pool parallel model system in which inputs are partitioned between a fast cycling soil carbon pool ($k = 1/6$) and a more slowly cycling pool ($k = 1/100$) without any tranfers between the pools. Carbon stocks and pool sizes are based on density fraction data for the Hainich-Dün forest site (Schrumpf et al. 2013); decomposition rates are chosen to be realistic but are arbitrary. Atmospheric $\Delta^{14}C$ data up to the year 2015 are from Graven et al. (2017), while data points beyond 2015 use the extrapolation method from Sierra (2018). All atmospheric radiocarbon data is for the northern hemisphere (zone 2).

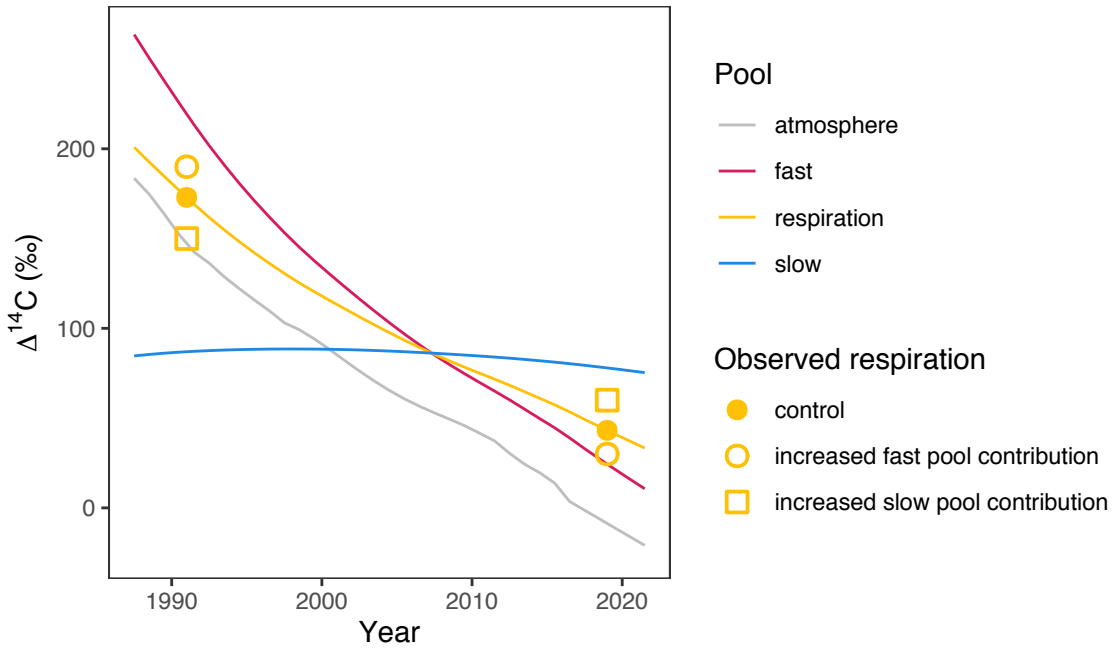
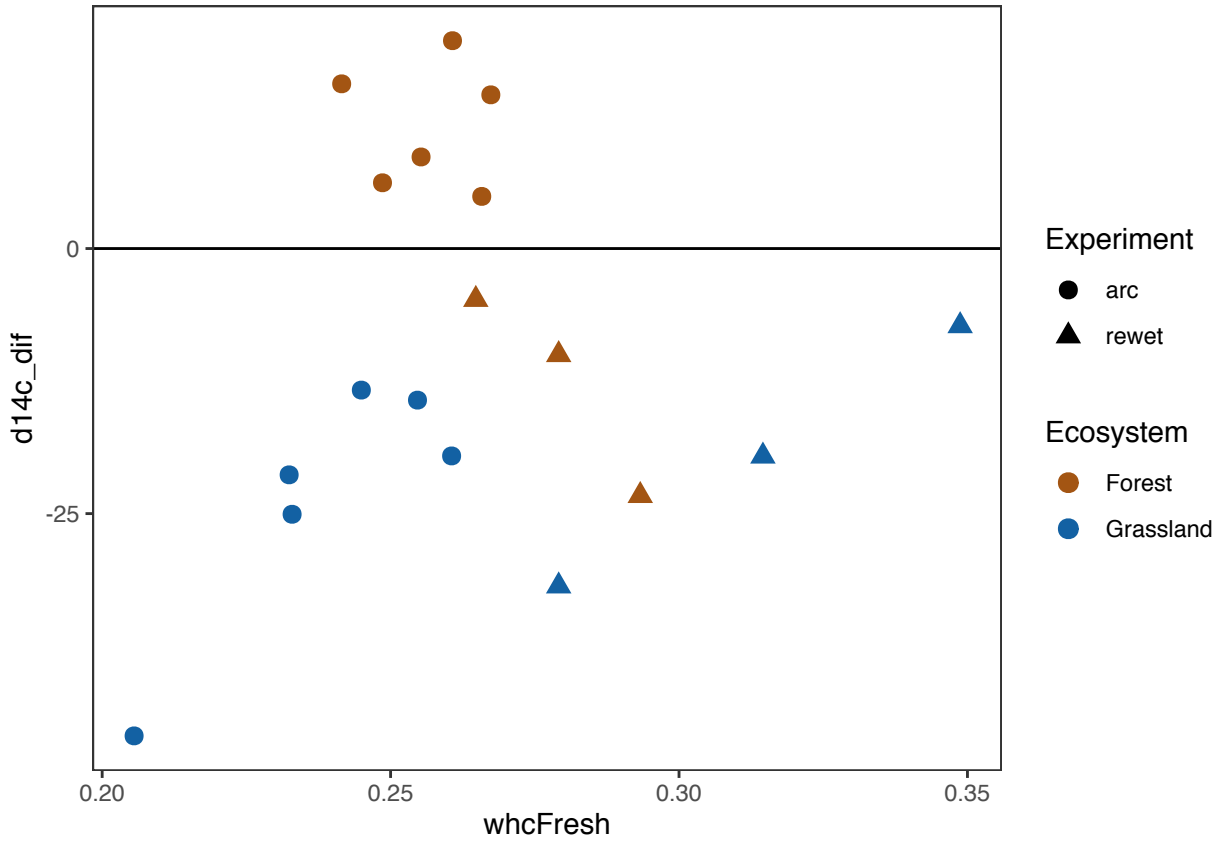


Fig 6b. Potential shifts in $\Delta^{14}C$ of respired CO_2 in response to treatment

Caption: Blue and magenta lines show modeled trajectories of $\Delta^{14}C$ in fast and slow cycling soil carbon pools (same model as Fig 6a), while $\Delta^{14}C$ of respired CO_2 is shown in yellow. Filled circles show hypothetical observations of $\Delta^{14}C$-CO_2 from control incubations, while the open symbols represent two possible scenarios in which an air-drying and rewetting treatment leads to a shift in $\Delta^{14}C$-CO_2. In the first scenario (open squares), an increased contribution from the slow pool shifts $\Delta^{14}C$-CO_2 toward the slow pool curve (blue line), while in the second scenario (open circles), an increased contribution from the fast pool shifts $\Delta^{14}C$-CO_2 toward the fast pool curve (magenta line). Due to the crossing of the slow and fast pool curves in 2009, an increased contribution of the slow pool to respiration following treatment leads to relative depletion of $\Delta^{14}C$-CO_2 in 1991, but relative enrichment of $\Delta^{14}C$-CO_2 in 2019, while the opposite is observed for the increased fast pool contribution scenario.

Change in soil moisture content with moisture adjustment



Supplemental Fig 5. Change in $\Delta^{14}C$-CO_2 (control - treatment) relative to field moisture

Caption: Data are from Experiment 1 ("arc") and Experiment 2 ("rewet"). All samples were moisture-adjusted prior to incubation, but control samples were adjusted from field moisture, "whcFresh" (percent of WHC), whereas treatment samples were moisture adjusted after air-drying, i.e. at approximately 0% of WHC.