How does ecosystem N and P partitioning, distribution, and correlation impact total C under different climate scenarios?

N and P constrain C in ecosystems under climate change: Role of nutrient redistribution, accumulation, and stoichiometry

Citation Rastetter, E.B., Kwiatkowski, B.L., Kicklighter, D.W., Plotkin, A.B., Genet, H., Nippert, J.B., O'Keefe, K.O., Perakis, S.S., Porder, S., Roley, S.S., Ruess, R.W., Thompson, J.R., Wieder, W.R., Wilcox, K., Yanai, R.D. (2022). N and P constrain C in ecosystems under climate change: Role of nutrient redistribution, accumulation, and stoichiometry. *Ecological Applications* e2684. https://doi.org/10.1002/eap.2684

Topic Summary

Cycling, distribution, and throughput of C, N, P, and water will influence how an ecosystem responds to symptoms of climate change, such as changing CO_2, temperature, and precipitation. The researchers used a multiple element limitation (MEL) model to assess differences in response among 12 ecosystems. This approach incorporates standardized perturbations and provides a framework to attribute model responses to ecosystem and climate differences rather than to climate perturbations.

How does the nutrient budget change under increased CO_2 conditions?

- Of the 12 ecosystems, 11 showed increased C in response to increased CO_2 with no other climate changes. Lowland boreal forest lost C over the course of the simulation while lowland boreal forest and tallgrass prairie both lost P.
- Increased CO_2 stimulates N fixation but in some ecosystems the loss of N through leaching and other processes results in a net loss of N in the system.

What is the impact of climate warming on ecosystem nutrient cycling and retention?

- In the warming only scenario 9 of the 12 ecosystems showed an increase in C over the course of the simulation. This resulted from increased photosynthesis and mineralization of N and P.
- The response of nutrients in the ecosystems promoted primary productivity and this increased the proportion of the nutrient stock in the ecosystem that was stored in vegetation.

How do changes in precipitation affect nutrient levels in ecosystems?

- In about half of the ecosystems, decreasing rainfall during the later part of the growing season led to large decreases in vegetative biomass. The associated loss of litter production led to decreased soil C.
- In all ecosystems, the amount of vegetative biomass left at the end of the 100 years of decreasing precipitation was related to the soil's water-holding capacity and the N cycle's openness.
- Increasing rainfall late in the growing season had less impact on vegetative biomass. Three ecosystems had small increases in C via increased vegetative biomass. The other nine systems had negligible change or small losses of nutrient through increased runoff and leaching.

How did ecosystems respond to scenarios with changes in multiple climate factors?

- When CO_2 and temperature increased and precipitation either increased or decreased, all ecosystems gained C. This gain was associated with the redistribution of N and P from soil to vegetation. The percent increase in C was positively correlated with the ratio of vegetation to soil C:N and with the ratio of vegetation to soil C:P.
- In the decreasing precipitation scenario, water use efficiency and fertility increased in response to higher CO_2 and higher mineralization. These changes compensated for lower water availability.
- For the scenario with increased precipitation, the response to the combined climate changes was approximately the same as the sum of the responses to each of the factors alone.

How do N and P interact under different climate scenarios?

- The response of N and P to different treatments showed a degree of desynchronization in response to climate change. The degree of similarity between changes in N and P cycling does not constrain gains and losses of C within a system.
- Correlations between N and P varied among ecosystems and was not related to change in vegetation, soil, or total C except in the combined scenario with increased rainfall. The N and P correlation decreased as the proportion of N taken up by plants as dissolved organic N or through fixation increased.

How do N and P interact within attribution factors, the general classes of nutrient processes that effect gain and loss of ecosystem C, across climate scenarios?

- In general, correlation between N and P attribution factors were strong across climate scenarios. The strongest relationships were for net redistribution of N and P between soil and vegetation and changes in C:N and C:P of vegetation.
- Net gain or loss of N was correlated with net gain or loss of P. The two are more strongly related when the N cycle was more open, but their correlation was not related to the openness of the P cycle.
- Changes in C:N and C:P are more strongly correlated when soil nutrient fractions are lower. A large stored amount of C, N, or P in the soil does not buffer soil chemistry processes, but allows N and P fractions to change independently.

Research Approach/Methods

- The MEL model uses daily inputs of atmospheric CO_2, minimum and maximum temperature, precipitation, shortwave radiation, and nutrient inputs to simulate soil water moisture and storage and movement of C, N, and P in plant biomass, Phase I and II soil organic matter, detritus, and inorganic nutrients.
- For the mass-balance portion of the model, vegetation and soil components are aggregated. However, vegetation is categorized as woody or active tissues using an allometric equation. The amount of active tissue increases with biomass toward a maximum.
- To calibrate the model, the researchers assumed most of the 12 study biomes to be in a steady state with mature vegetation and soil. For prairie ecosystems, they assumed steady-state with annual burning.

- They assumed that the amount of C, N, P, and water storage and fluxes fluctuated within a year, but overall values did not differ from year to year.
- After simulations were complete, the authors calculated changes in the amount of C, N, P, stocks and fluxes in each ecosystem over the 100 years.
- At each site, the authors ran 100-year simulations for six different possible climate change scenarios that alter temperature, precipitation, and CO_2 singly or in combination. Model drivers change through all years of the model, so no new steady state is reached.
- They use linearized correlations to ask whether N and P respond in parallel to a specific set of climate changes, termed attribution factors, among ecosystem types.
- Finally, they determine whether N and P respond in parallel within an attribution factor across all treatments. Specifically, whether total ecosystem C was associated with changes in: total N, fraction of total N in vegetation, vegetation C:N, soil C:N, and interactions of those four attributes.

Keywords carbon dioxide fertilization, carbon sequestration, carbon-nitrogen interactions, carbon-phosphorus interactions, climate change, long-term ecological research (LTER), nitrogen cycle, phosphorus cycle, terrestrial ecosystem stoichiometry

Images

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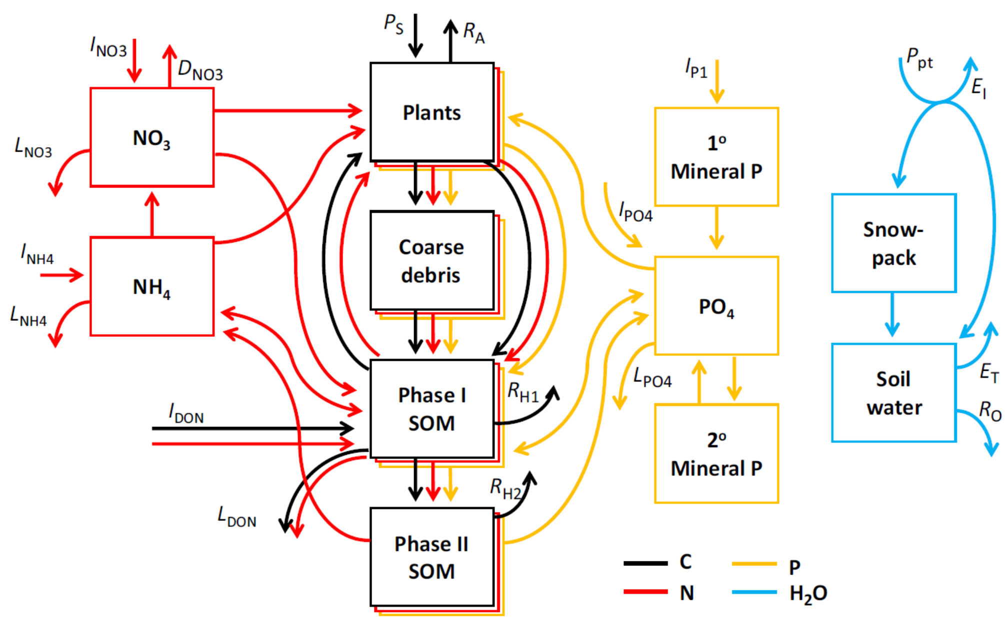

Figure 1 in Rastetter et al. 2022. Diagram depicting the stocks and fluxes of carbon (C), nitrogen (N), phosphorus (P), and water (H2O) represented in the Multiple Element Limitation (MEL) model. SOM is soil organic matter. For simplicity, only input and loss fluxes are labeled: PS, RA, RH1, and RH2 are photosynthesis, autotrophic respiration, heterotrophic respiration from Phase I SOM, and heterotrophic respiration from Phase II SOM. INH4, INO3, IDON, IPO4, and IP1 are inputs of ammonium (NH4), nitrate (NO3), dissolved organic N (DON), phosphate (PO4), and primary P minerals. LNH4, LNO3, LDON, LPO4, and DNO3 are leaching losses of NH4, NO3, DON, and PO4 and losses of NO3 through denitrification. Ppt is precipitation, EI is evaporation of intercepted precipitation, ET is transpiration, and RO is runoff. Not represented in this figure are the run-in of water, NH4, NO3, DON, and PO4, which are simulated only for arctic wet-sedge tundra (ARC-w). Values for all stocks and fluxes for all 12 ecosystems are presented in Table 1.

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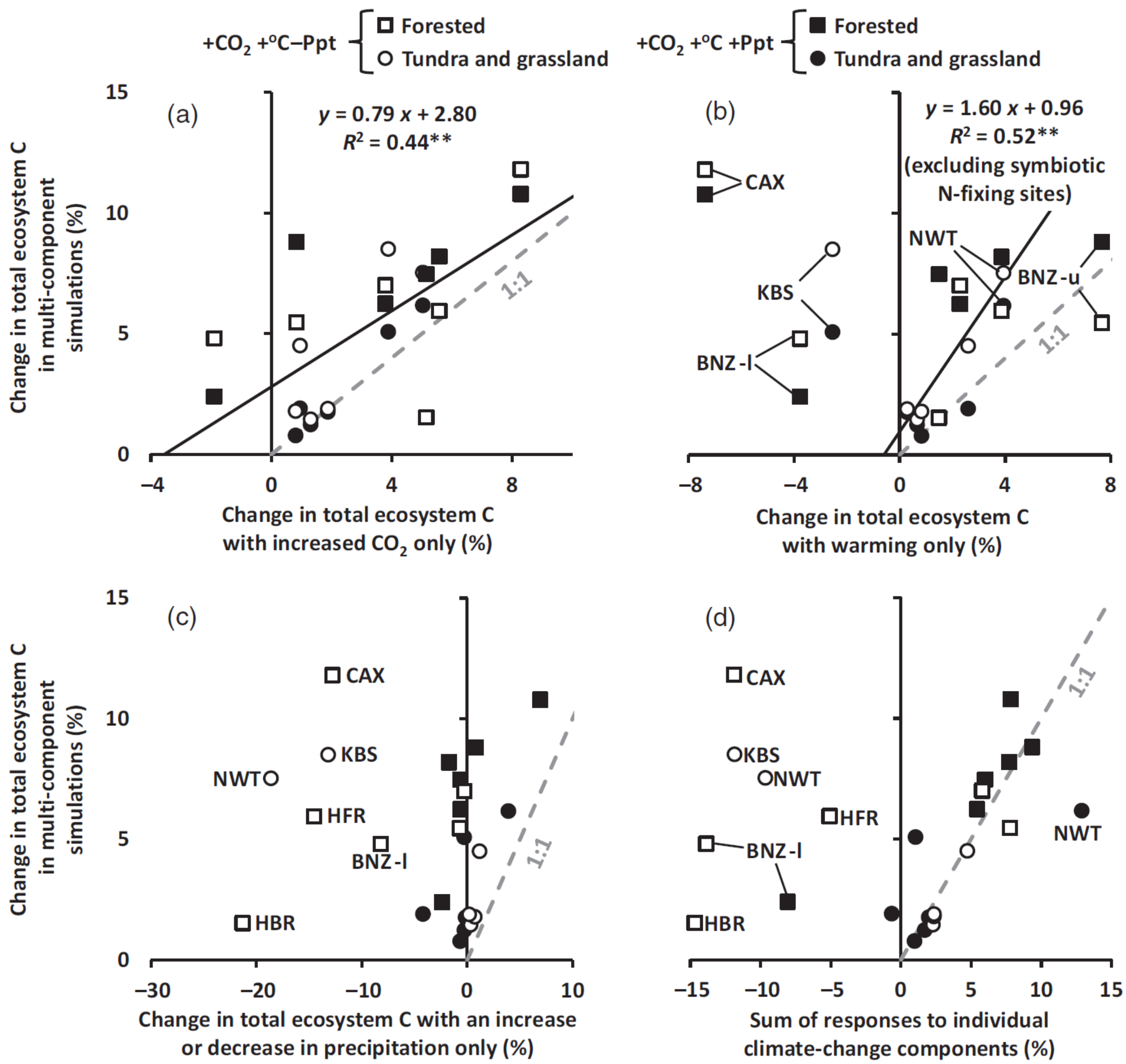

Figure 8 in Rastetter et al. 2022. Change in total ecosystem C plotted against the responses to the individual climate-change components: (a) increased CO2, (b) warming, (c) changes in precipitation, and (d) the sum of responses to the individual climate-change components. Squares are for the forested ecosystems (BNZ-l, BNZ-u, HBR, HFR, AND, and CAX). Circles are for tundra and grassland ecosystems (ARC-t, ARC-w, ARC-s, NWT, KBS, and KNZ). Ecosystems are identified in Table 1. The combined-component climate simulations with decreased precipitation are in open symbols and the combined-component climate simulations with increased precipitation are in filled symbols. **Regression p < 0.01.

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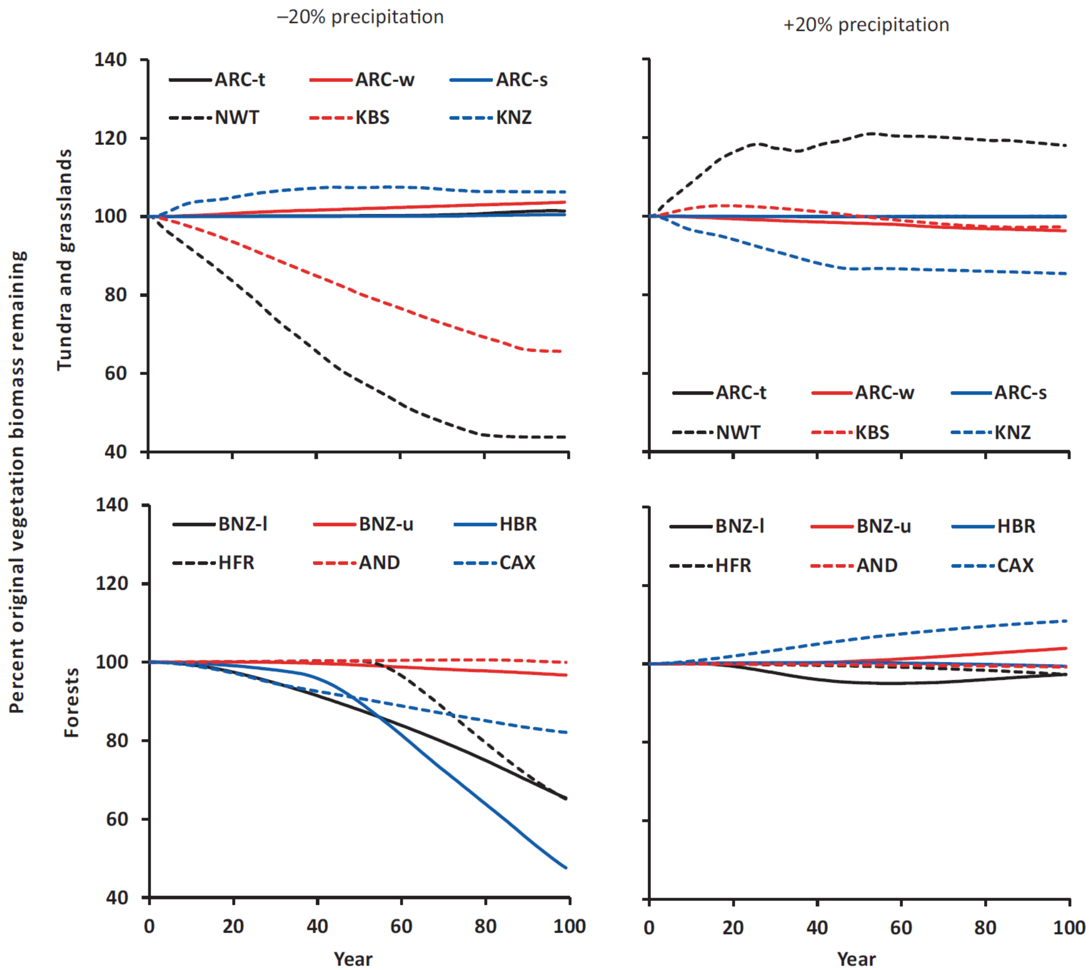

Figure 6 in Rastetter et al. 2022. Changes in vegetation biomass in response to a gradual 20% decrease (left) and a 20% increase (right) in precipitation among tundra and grassland ecosystems (upper) and forests (lower). The decrease and increase are imposed by decreasing or increasing the intensity of rainfall events in the latter part of the growing season by successively larger amounts each year until the annual precipitation is decreased or increased by 20% by year 100. Ecosystems are identified in Table 1.

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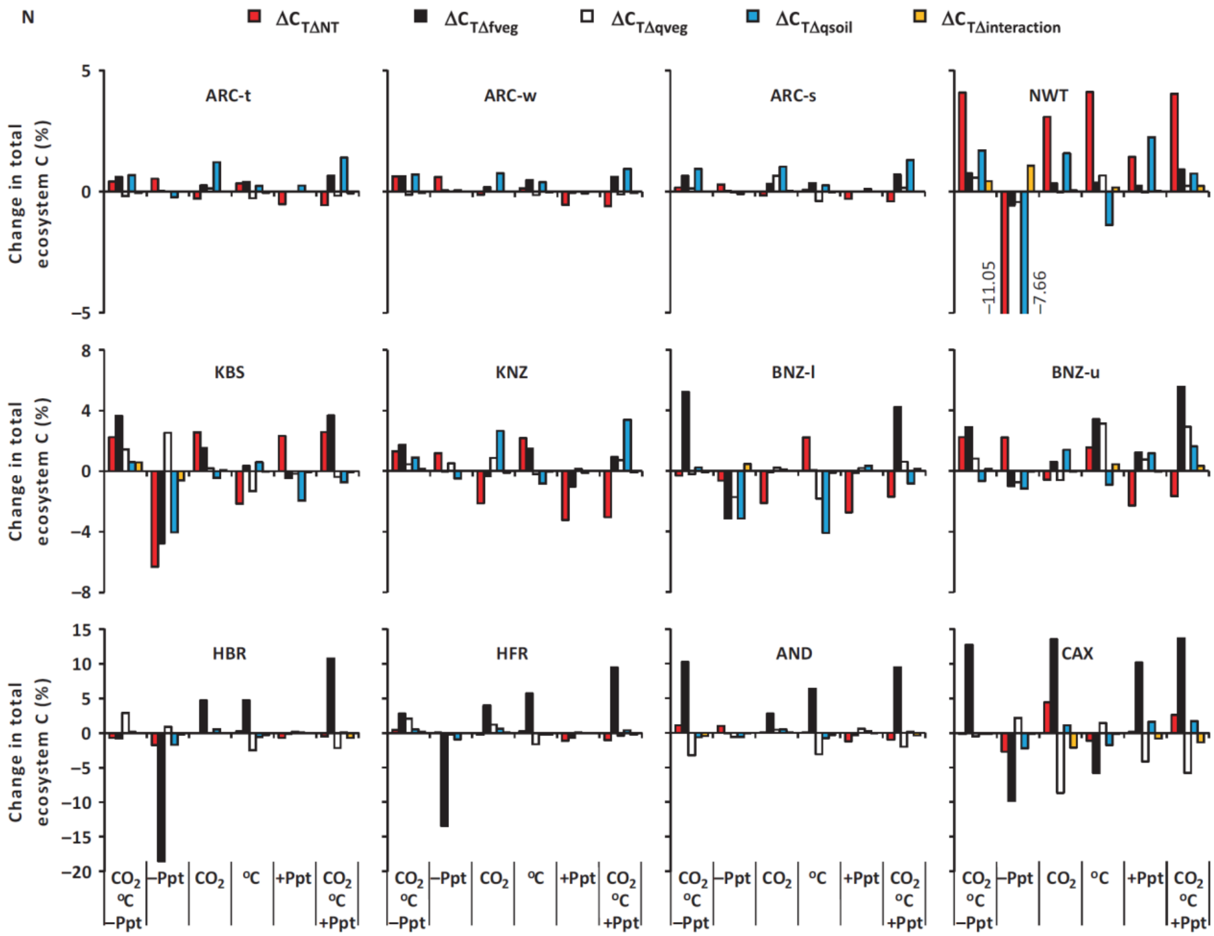

Figure 4 in Rastetter et al. 2022. N-attribution of the percent change in total ecosystem C between initial and year-100 in response to doubled CO2 (CO2), 3.5_C warming (_C), and 20% decrease or increase in precipitation (_Ppt, +Ppt), alone or in combination. The changes in CO2, temperature, and precipitation are imposed gradually as linear changes over 100 years. The five N-attribution factors (Equations 1–5) are the changes in total ecosystem C associated with (1) the changes in total ecosystem N (ΔCTΔNT), (2) changes in the fraction of total ecosystem N in vegetation (ΔCTΔfveg), (3) changes in vegetation C:N (ΔCTΔqveg), (4) changes in soil C:N (ΔCTΔqsoil), and (5) the interactions among 1–4 (ΔCTΔinteraction). The sum of these five attribution factors for each treatment equals the total percent change in ecosystem C over the 100 years. These total percent changes are presented in Table 2. Ecosystems are identified in Table 1.

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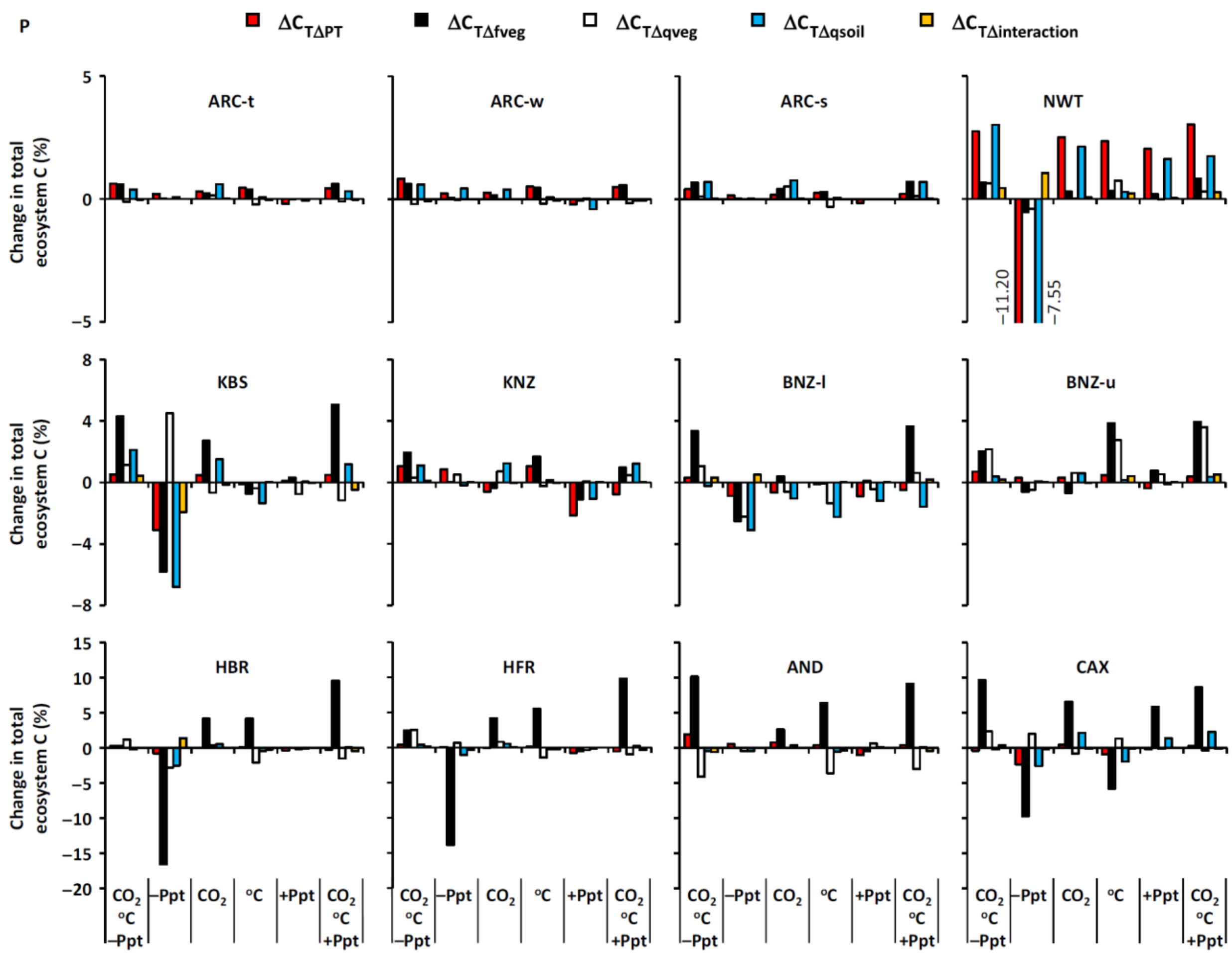

Figure 5 in Rastetter et al. 2022. P-attribution of the percent change in total ecosystem C between initial and year-100 in response to doubled CO2 (CO2), 3.5_C warming (_C), and 20% decreased or increased in precipitation (_Ppt, +Ppt), alone or in combination. The changes in CO2, temperature, and precipitation are imposed gradually as linear changes over 100 years. The five P-attribution factors (analogous to Equations 1–5, but for P) are the changes in total ecosystem C associated with (1) the changes in total ecosystem P (ΔCTΔPT), (2) changes in the fraction of total ecosystem P in vegetation (ΔCTΔfveg), (3) changes in vegetation C:P ratio (ΔCTΔqveg), (4) changes in soil C:P ratio (ΔCTΔqsoil), and (5) the interactions among 1–4 (ΔCTΔinteraction). The sum of these five attribution factors for each treatment equals the total percent change in ecosystem C over the 100 years. These total percent changes are presented in Table 2. The results presented here are for the same simulations as in Figure 4. Ecosystems are identified in Table 1.