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Effects of nutrient availability on intrinsic water-use efficiency of a grassland under rising CO_2

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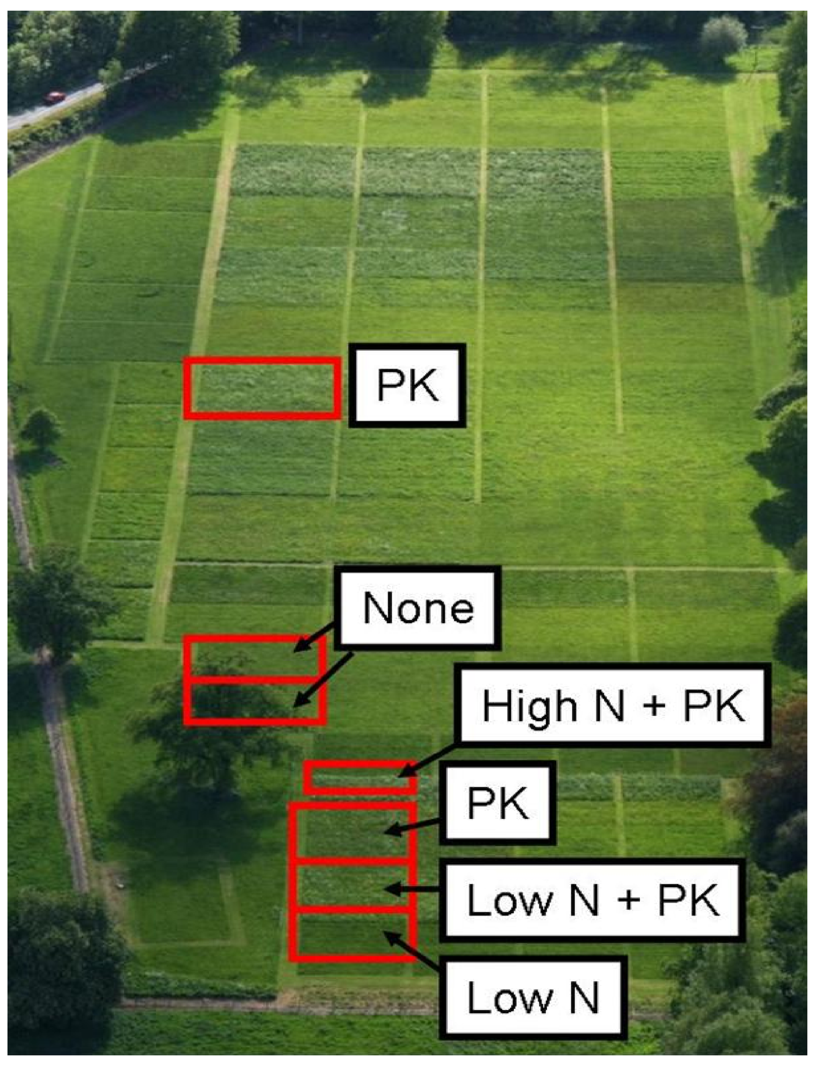
Introduction

Prediction of the effects of climate change on grassland requires an understanding of ecosystem responses to rising atmospheric CO_2. Our retrospective study of stable carbon isotopes ($\delta^{13}C$) in grassland plants investigates the responses of plant carbon and water relations to the recent history of CO_2 increase.

C_3 plants generally increase photosynthesis (*A*) and decrease stomatal conductance (g_s) under elevated CO_2 [1]. Nitrogen limitation has been shown to constrain the response of *A* to rising CO_2 [2] and could thus limit the increase of intrinsic water use efficiency (W_i, carbon gain per unit water lost under standard evaporative demand). $\delta^{13}C$ studies on tree rings have shown that W_i has increased during the last century in forest ecosystems. Recently we showed that W_i has also increased in nutrient limited grassland ecosystems [3, 4]. We now tested the hypothesis that the response to the recent increase in CO_2 was stronger in more fertile conditions, as *A* should increase with nutrient supply. Thus, we expected W_i to have increased more strongly on the well-fertilized plots of the studied Park Grass Experiment (or respectively that carbon isotope discrimination ($^{13}\Delta$) has increased less strongly).

Material & Methods

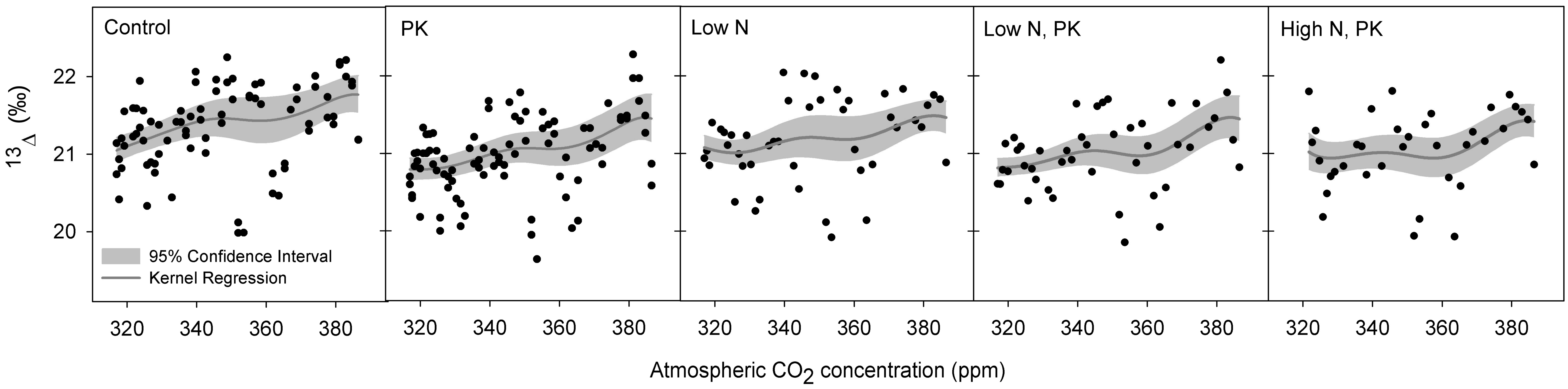


We analysed $\delta^{13}C$ of archived hay and herbage samples taken in late spring and autumn from 5 plots with different fertilizer treatments on the Park Grass Continuous Hay Experiment, where $\delta^{13}C = [(R_{sample}/R_{standard}) - 1]$, with *R* the $^{13}C/^{12}C$ ratio in the sample or standard. Carbon isotope discrimination $^{13}\Delta$ is calculated from $\delta^{13}C$ and is a proxy of the leaf-level coupling of CO_2 and transpiration fluxes, and a measure of W_i, with $W_i = A/g_s = c_a \cdot (1 - c_i\ /\ c_a)\ /\ 1.6$ and $c_i\ /\ c_a = (^{13}\Delta - a)\ /\ (b - a)$, ($a$=4.4‰, b=27‰).

Fig. 1: Aerial view of the Park Grass Experiment and sampled plots, low N = 48 kg ha^{-1} a^{-1}, high N = 96 kg ha^{-1} a^{-1}, P = 35 kg ha^{-1} a^{-1}, K = 225 kg ha^{-1} a^{-1}

Results

Fig. 2: Similar trends in carbon isotope discrimination ($^{13}\Delta$) were observed on all treatments from 1960 to 2009, (equivalent to an atmospheric CO_2 increase of 22% from 317 ppm to 387 ppm).



Linear regression showed significant $^{13}\Delta$ increases: 0.1‰ per 10 ppm CO_2 increase on the control ($P<0.05$), the PK treatment ($P<0.001$) and the low N, PK treatment ($P<0.05$). On the low N treatment, the increase was only significant at the 10% level. On the high N, PK treatment $^{13}\Delta$ increased by 0.04‰ per 10 ppm, but this was not significant ($P = 0.18$, data not shown). Smoothing the data with kernel regression revealed similar patterns for all plots (Fig 2). All 95% confidence intervals of the kernel regression overlapped. Intrinsic W_i was calculated from $^{13}\Delta$. Kernel regression showed increasing W_i on all treatments and a levelling off from about 360 ppm on. W_i of the control was significantly lower than W_i of the PK plots. All PK plots showed very similar trends regardless of N fertilization.

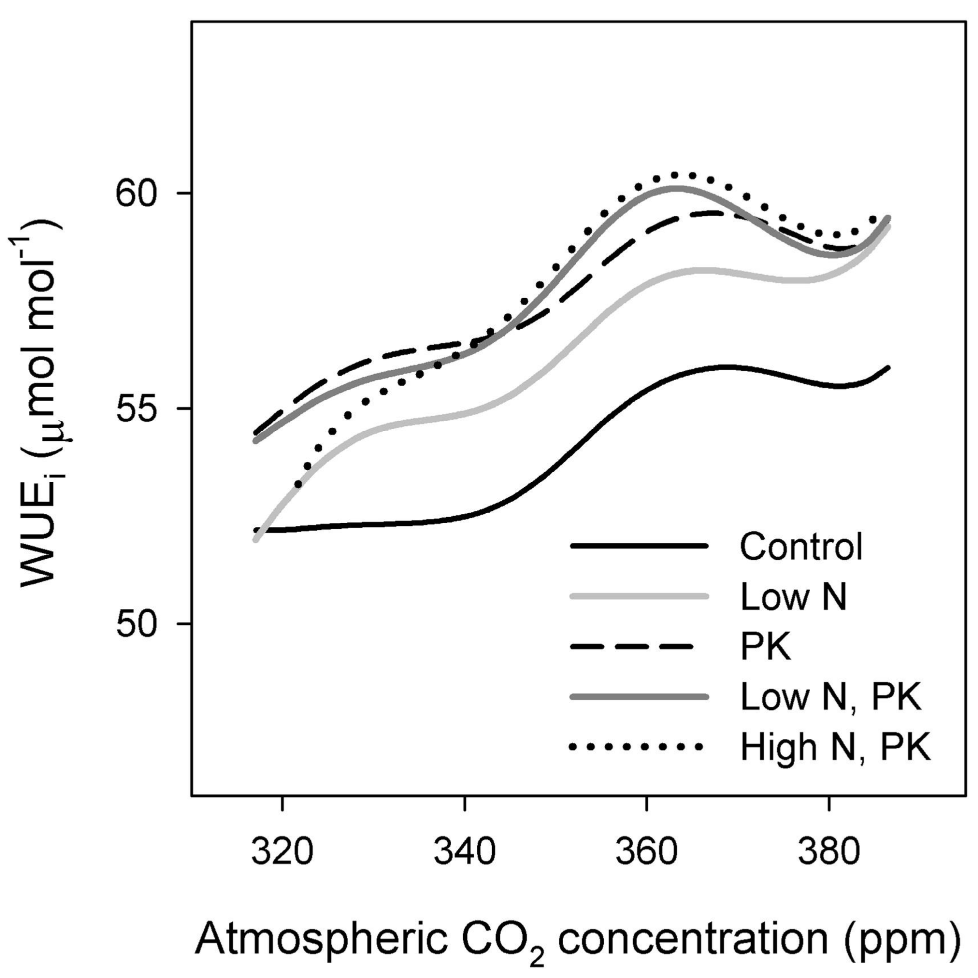


Fig. 3: Kernel regression of intrinsic water-use efficiency W_i for the 1960 to 2009 period (equivalent to an atmospheric CO_2 increase from 317 ppm to 387 ppm) showed similar increases of W_i for all treatments, regardless of nutrient application.

Conclusion

We found no significant differences between the responses of W_i to rising CO_2 on the differently fertilized treatments. This indicates that the regulation of *A* and g_s under the recent CO_2 increase did not differ between the treatments. No increase in yields was observed on the studied plots (data not shown). Thus, if an increase in *A* occurred, it did not transform into an increase in above ground biomass, even on the well fertilized plot. We suggest that the increase in W_i was mainly achieved by a decrease in stomatal conductance. This could lead to decreased transpiration of water and increased surface run-off or drainage from this grassland.

Literature

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