Effects of nitrogen supply and nitrogen form on intrinsic water-use efficiency in temperate, seminatural grasslands under rising atmospheric CO2

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1 Introduction

Carbon uptake and water loss of plants are controlled by the regulation of carbon assimilation rate (A) and stomatal conductance (g_s). Any changes in these parameters under rising atmospheric CO_2 concentration (c_a) influence plant water-use efficiency and can affect carbon and water relations in grassland ecosystems. Time-series analyses of intrinsic water-use efficiency (W_i) of C_3 grassland vegetation during the 20th century have shown that carbon uptake relative to water loss generally increased ([4], [5], [1]). Short-term experiments suggest that nitrogen (N) supply [6] and N form [2] also play a role. We hypothesize that any increase in W_i should be stronger in swards with high N availability and with ammonium (NH_4)-N instead of nitrate (NO_3)-N fertilization.

2 Materials and Methods

W_i ($=A/g_s$) is a physiological efficiency reflecting the leaf-level relationship between CO_2 uptake and transpiration at standard humidity. It can be derived from stable carbon isotopes by using the Farquhar model of carbon isotope discrimination ($^{13}\Delta$) during C_3 photosynthesis [3] and measurements of carbon isotope composition ($\delta^{13}C$) in plant material and atmospheric CO_2. The Park Grass Experiment at Rothamsted (Hertfordshire, England) is a long-term fertilization experiment on grassland and has been running since 1856. $\delta^{13}C$ was measured in samples of grassland vegetation (available from the Rothamsted Sample Archive) from 16 plots with different nutrient supply, soil pH and botanical composition. The sample period covered 95 years (1915-2009), during which c_a increased by 86 ppm. Nutrient supply on the plots differed in the form and amount of applied N [nil, 48, 96 (NO_3 and NH_4 plots) or 144 (NH_4 plots only) kg/ha/year], and the amount of P (nil or 35 kg/ha/year) and K (nil or 225 kg/ha/year). Soil pH varied between 3.6 and 5.9 on the unlimed subplots and between 6.2 and 7.2 on the limed subplots (average values for 1995-2002). The $^{13}\Delta$ data were analysed using a multiple linear regression model with c_a and plant available soil water as explanatory variables. W_i was derived from the modelled $^{13}\Delta$ values, and the change in W_i from 1915 to 2009 (ΔW_i) was studied (pooled and separately for limed and unlimed subplots) in relation to N supply.

3 Results and Discussion

Changes in $^{13}\Delta$ per 100 ppm change in c_a varied between –1.0‰ and +0.9‰ on the 16 plots. Thus, the increase in W_i from 1915 to 2009 varied between 6.9 and 25.5 µmol/mol. When all 16 treatments were analysed together, no significant relationship was found between the change in W_i and the amount of applied N plus N from biological N-fixation (Fig. 1, p = 0.1). A significant relationship was found for the limed NO_3-N plots ($p < 0.05$), but not for the unlimed ones (p = 0.6) (Fig. 1b). No significant relationship was found for the NH_4-N plots (limed: p = 0.5, unlimed: p = 0.1) (Fig. 1). A significant relationship between the increase in W_i and N supply was only found for the limed NO_3-N plots as reported in [5]. The highest increases in W_i were observed on the unlimed NH_4-N plots, but no significant relationship with N supply could be found. In contrast to our hypothesis the increases in W_i on the limed NH_4-N plots were lower than on the limed NO_3-N plots. The difference between NO_3-N and NH_4-N plots and limed and unlimed subplots indicates that other factors may play a role. A recent study suggests that botanical composition may affect the response of W_i [5]. This may be due to the greater responsiveness of grasses and will be investigated in future work: The average %-contribution of grasses to sward biomass varied between 49% and 99% and increased significantly ($p < 0.01$) with decreasing soil pH.

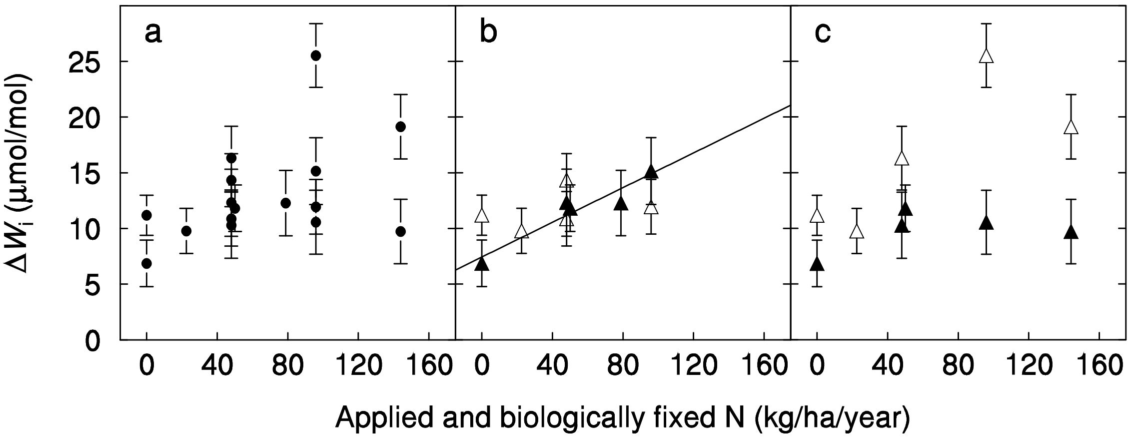

Fig. 1: Relationship between the absolute change in W_i from 1915 to 2009 (ΔW_i, µmol/mol) and the amount of applied plus biologically fixed N (kg/ha/year), presented for (a) all plots, (b) NO_3-N and (c) NH_4-N plots and their limed (▲) and unlimed (Δ) subplots. The same data from the controls and the PK-only plots are used in all three graphs. The black line is the linear regression for the limed NO_3-N plots ($y = 7.43 + 0.08\,x$, $p < 0.05$, $R^2 = 0.9$). Error bars represent the standard error.

4 Conclusion

Besides N supply and N form, multiple factors may influence the response of W_i to rising c_a in terrestrial ecosystems directly or indirectly, e.g. through changes in botanical composition. Our understanding of these factors and their interactions needs to be improved to better predict future responses of grassland ecosystems to rising atmospheric CO_2.

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6 Literature

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