Effect of N fertiliser application strategy on nitrogen dynamics under elevated CO_2 concentration

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Abstract

The atmospheric carbon dioxide concentration is increasing and is predicted to reach ~550 µmol mol^{-1} by 2050. As an essential resource for plant metabolism, elevated [CO_2] (e[CO_2]) will impact plant performance. For example, when wheat (*Triticum aestivum* L.) grows under e[CO_2], biomass and yield are increased while grain nitrogen (N) concentration is decreased negatively affecting the nutritional quality of the grain. It has been suggested that N partitioning in plant organs and N remobilisation from vegetative plant parts to the grain is changed under e[CO_2], contributing to decreased grain N under e[CO_2]. The aim of this study was to investigate (1) whether targeted N fertilisation strategies can help to overcome grain N reductions under e[CO_2] and (2) to evaluate the N dynamics in different plant components in response to e[CO_2] conditions and contrasting N fertilisation strategies. The present study shows that biomass partitioning (leaf to stem ratio) was decreased in response to e[CO_2] and increased at anthesis due to fertilisation. The N accumulation and partitioning was affected by e[CO_2] in leaf and to a lesser extent in stem at anthesis but this effect was gone at maturity. The differences in N partitioning and reduced remobilisation to grain suggest a bottleneck in translocation of N that may not be solved by adding more N fertiliser to the crop under e[CO_2], at least under the environmental conditions present in 2015.

Keywords

Free Air CO_2 Enrichment (FACE), nitrogen partitioning.

Introduction

Increasing atmospheric carbon dioxide concentration [CO_2] (currently ~405 µmol mol^{-1}) has led to modifications of global processes that ultimately drive climate change. According to predictions [CO_2] is expected to continue to increasing (in A1B Emission Scenarios) and will reach ~550 µmol mol^{-1} by 2050 (IPCC 2013). This increase in [CO_2] will significantly impact plant performance and, consequently, global food production due to changes in the Earth's carbon budget aggravated by increasing human activities (Loladze 2002).

Wheat is an important staple food which supplies about 25% of the protein requirements for global human intake and other nutrients as well (Šramková et al. 2009). As a source of carbon, the rise in [CO_2] affects wheat crop in terms of physiology and yield (Wang et al. 2013). Such an effect is the decrease in concentration of nutrients in vegetative and reproductive plant parts. In grains, a reduction in protein of ~12% has been reported, while in leaf there is a decrease (~ 9%) in N concentration (Tausz-Posch et al. 2014; Fernando et al. 2012). Although the mechanism behind N concentration decrease under e[CO_2] is not clear, it has been proposed that changes in N dynamics (accumulation, partitioning and remobilisation), especially from flag leaf to grain during the grain filling period, might contribute significantly (Tausz-Posch 2014; Taub and Wang 2008).

In this study, we investigated the N dynamics in plant vegetative and reproductive components and whether the CO_2-driven decrease in grain N concentration can be ameliorated by adjusting N fertiliser management strategies. Specifically, we evaluated the N accumulation and partitioning between plant components and further N remobilisation to the grain. Preliminary results are presented.

Methods

This study was conducted on wheat cv. Yitpi grown during the 2015 season within the Australian Grains Free Air CO_2 Enrichment (AGFACE) facility (Mollah et al. 2009) The AGFACE facility is located in a 7.5 ha research farm in Horsham, Victoria, Australia (36°45'07"S, 142°06'52"E), within the Australian wheat belt. The AGFACE site is on a Murtoa clay (35% clay at the surface increasing to 60% at 1.4 m) and according to the Australian Soil Classification the soil is a Vertosol. The climate is Mediterranean with an average annual rainfall of 366 mm.

The experimental site was divided into 10 plots exposed to an ambient [CO_2] (a[CO_2], ≈ 400 µmol mol^{-1}) or to an elevated [CO_2] (e[CO_2], ≈ 550 µmol mol^{-1}), with sub-plots arranged as a randomised complete block design. At sowing, the total soil N concentration was 0.093% (top 10 cm). Experimental plants were grown at 0 kg N ha^{-1} as a control (data not yet available) and at a 50 kg N ha^{-1} application rate using four different fertilisation practices, as follows: broadcasted urea pre-sowing (N50 = 50 kg N ha^{-1}), foliar spray of urea (N50f = 25 kg N ha^{-1} pre-sowing + [4x] 6.25 kg N ha^{-1} from stem elongation to 8 days post-anthesis), urea top dressing (N50t = 25 kg N ha^{-1} pre-sowing + [4x] 6.25 kg N ha^{-1} from stem elongation to 8 days post-anthesis), polymer coated (slow release) urea (N50s = 50 kg N ha^{-1} at sowing). Sampling was conducted from stem elongation through maturity stage (Zadoks et al. 1974) with data collected derived from 2 whole plants from each subplot. There were 6 replicate subplots for a[CO_2] and 4 for e[CO_2]. The measured parameters that are presented here are: biomass accumulation, N accumulation (as a function of N concentration and dry mass), N partitioning index (proportion of N on each plant component in relation to total plant N). The data presented here represents only leaf, stem and grain from the main stem only. Data from the other plant parts is still undergoing analysis.

Samples were dried for 72 h at 70°C and biomass components measured. Dry components were ground and analysed for N concentration by combustion with an elemental analyser (CNS, LECO). Descriptive statistics were done using software Minitab 16. Analysis of variance with Residual Maximum Likelihood was performed (R Core Team 2014) for the effect of N content in response to CO_2 concentration, fertilisation strategy and their interaction.

Results

Plants grown under e[CO_2] and different N fertilisation strategy did not increased total biomass (g of dry mass) but rather changed the "leaf:stem ratio" at certain times (Figure 1). While there was a trend for leaf biomass to decrease (however not significant) and stem to increase in biomass (p=0.01 at anthesis, 0.006 at 8 days post-anthesis, data not shown); the effects on biomass are more evident when looking into the "leaf to stem ratio". For example, at anthesis (day 0 in Figure 1) the "leaf:stem ratio" was affected by N fertilisation strategy factor (p=0.03); also, at 8, 21 and 40 days post-anthesis (maturity) the leaf:stem ratio was significantly decreased by e[CO_2]. The leaf to stem ratio was not affected by an interaction of [CO_2] and N fertiliser application.

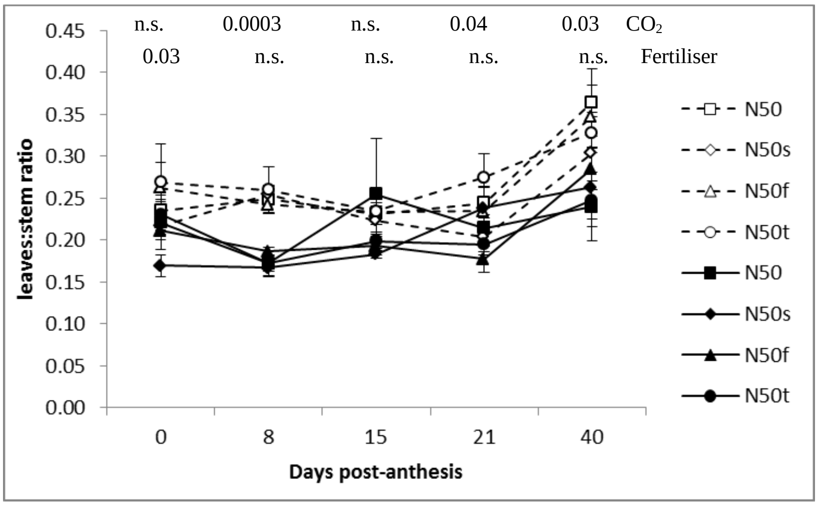

Figure 1. Time course plot for leaf to stem biomass ratio in wheat cv. Yitpi grown under 4 fertilisation strategies and a[CO_2] (open symbols, dashed lines) or e[CO_2](solid symbols, continuous lines) in AGFACE facilities during 2015 growth season. Fertilisation strategies are: (N50) urea pre-sowing; (N50s) urea slow release; (N50f) urea pre-sowing + urea foliar; (N50t) urea pre-sowing + 4 split top dressing. Time is indicated in days post anthesis (excepting stem elongation, s.e.). Anthesis occurs at 0 and maturity at 40 D.P.A. Bars represent standard error of the mean.

At anthesis, e[CO_2] had a strong effect on the N accumulated (mg N plant component^{-1}) in leaf but not in stem (Figure 2). The N accumulated in the leaf (from the main stem only) decreased (p=0.006) from about 4.4 to 2.5 mg of N regardless of the N fertilisation strategy. On the other hand, the N accumulated in the stem (at anthesis) was about 6.9 mg of N across all treatments regardless of [CO_2] or N fertilisation strategy utilised. At maturity, there were no significant effects of [CO_2] or N fertiliser application strategy to N accumulated in leaf or stem. There was no interaction of [CO_2] and N fertilisation strategy on N accumulated either at anthesis or maturity.

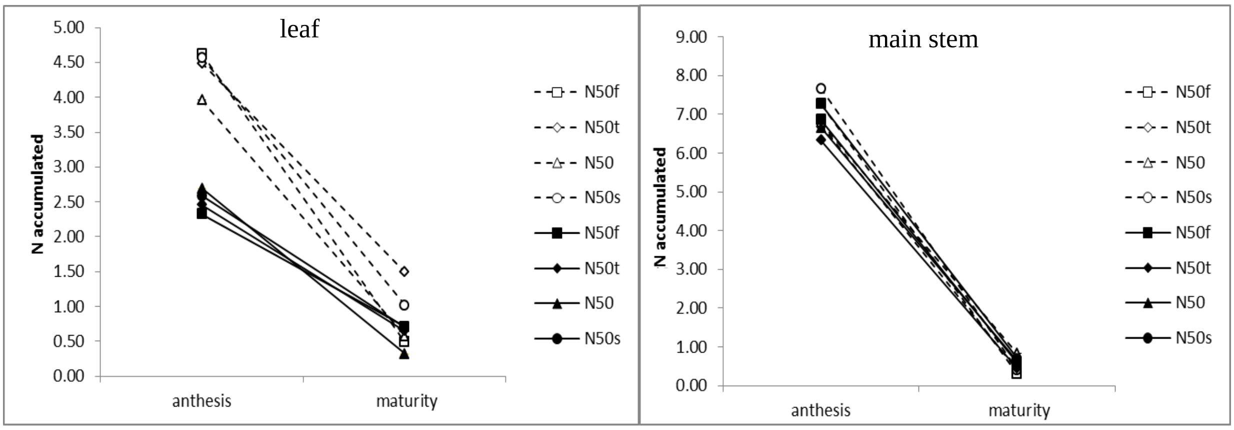

Figure 2. Time course plot N accumulated (mg N per leaf or stem) at anthesis and maturity in leaf and stem in wheat cv. Yitpi grown under 4 fertilisation strategies and a[CO_2] (open symbols, dashed lines) or e[CO_2](solid symbols, continuous lines) in AGFACE facilities during 2015 growth season. Fertilisation strategies are: (N50) urea pre-sowing; (N50s) urea slow release; (N50f) urea pre-sowing + urea foliar; (N50t) urea pre-sowing + 4 split top dressing. Bars represent standard error of the mean.

In regards to the N partitioning index across plant parts, there was a clear effect of e[CO_2] and N fertilisation strategy, but not from an interaction of both (Figure 3). At anthesis, the N partitioning index for leaf decreased from a mean of 0.18 to 0.13 in leaf in response to e[CO_2], a 27% decrease (*p*=0.0006). Meanwhile, also at anthesis, the N partitioning index in main stem increased from a mean of 0.31 to 0.36, a 16% increase (*p*=0.007). At maturity there were no significant differences either from [CO_2], fertilisation or an interaction of both.

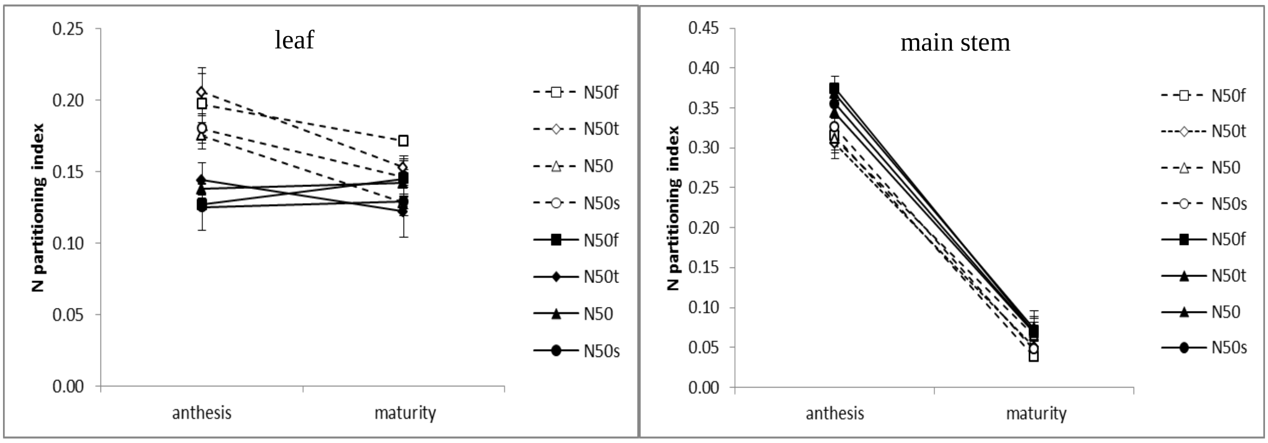

Figure 3. Time course plot N partitioning index at anthesis and maturity in leaf and stem in wheat cv. Yitpi grown under 4 fertilisation strategies and a[CO_2] (open symbols, dashed lines) or e[CO_2] (solid symbols, continuous lines) in AGFACE facilities during 2015 growth season. Fertilisation strategies are: (N50) urea pre-sowing; (N50s) urea slow release; (N50f) urea pre-sowing + urea foliar; (N50t) urea pre-sowing + 4 split top dressing. Bars represent standard error of the mean.

At maturity, the grain N partitioning index and grain protein concentration did not show significant effects in response to e[CO_2], N fertilisation strategy or an interaction (Figure 4a and b). This may have been due to the higher standard error of the N50t treatment.

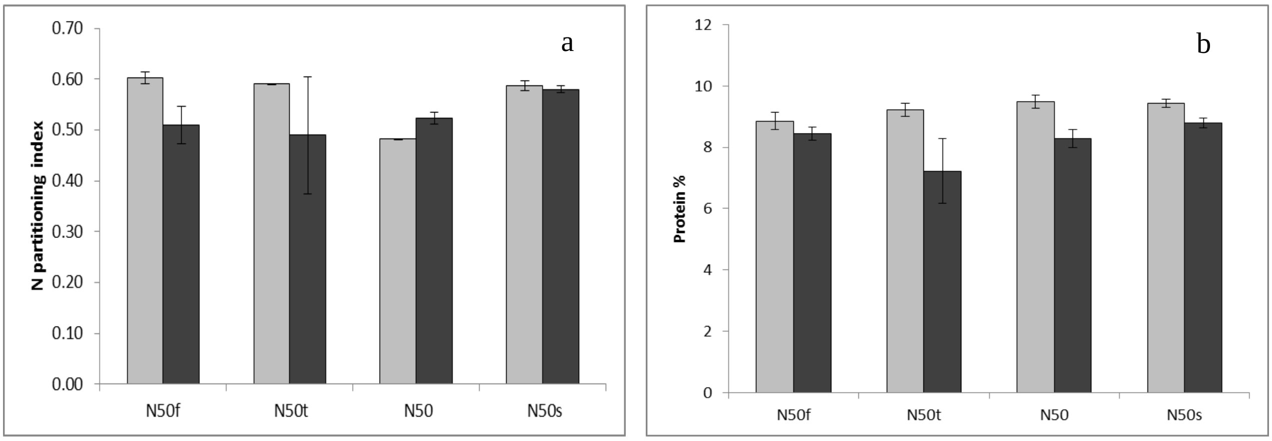

Figure 4. Nitrogen partitioning to the grain at maturity (a) and grain protein concentration (b) in wheat cv. Yitpi grown under 4 fertilisation strategies and a[CO_2] (light gray bars) or e[CO_2](dark gray bars) in AGFACE facilities during 2015 growth season. Fertilisation strategies are: (N50) urea pre-sowing; (N50s) urea slow release; (N50f) urea pre-sowing + urea foliar; (N50t) urea pre-sowing + 4 split top dressing. Bars represent standard error of the mean.

Conclusion

The N accumulated in leaf at anthesis was decreased due the effect of e[CO_2] on N concentration and there was no significant effect of N fertiliser strategy on leaf biomass. There was a greater proportion of N in main stems under e[CO_2] than a[CO_2] at anthesis but this effect was gone at maturity when the amount of N accumulated in leaf and stem was not affected by e[CO_2]. Any differences due to e[CO_2], however, did not affect the N partitioning index in grain nor the grain protein concentration. From these results and a lack of any [CO_2] x N interactions, there does not appear to be any differences in grain N response to N fertiliser under e[CO_2] compared to current a[CO_2] conditions. The differences in proportions of plant component N and lack of transfer to grain suggest a bottleneck in translocation of N that may not be solved by adding more N fertiliser to the crop under e[CO_2], at least under the environmental conditions present in 2015. A complete N budget will illuminate these details as analysis proceeds.

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