Biomass Partitioning of Rice under Free-Air CO_2 Enrichment (FACE): Lessons for Crop Models

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Abstract

Changes in dry weight and grain yield of rice (*Oryza Sativa* L.) plants were analyzed to determine whether partitioning of biomass is affected by atmospheric CO_2 concentration ([CO_2]) and N supply. Plants were grown in local farmers fields at three levels of N and at ambient and elevated (ambient plus 200 ppm) [CO_2]. Oryza2000 model was also applied to compare with the observed patterns of biomass partitioning. Observed values showed that both CO_2 and N enrichment stimulated net dry matter production. [CO_2] did not affect partitioning of dry matter at FACE compared to ambient except lower leaf to total biomass ratio mainly at panicle initiation and around flowering stages across N levels and years. Oryza2000 model does not consider any effect of either [CO_2] or N on dry matter partitioning hence it overestimated leaf biomass, and LAI under elevated [CO_2]. We suggest that the formulation of LAI based on nitrogen rather than carbon allocation is more promising in simulating leaf area growth under elevated [CO_2].

Keywords

FACE CO_2, simulation model, partitioning, rice plant

Introduction

Increasing atmospheric [CO_2] has the potential to enhance the growth of C_3 species (Kimball et al., 2002). When N limits growth, root dry weight increases relatively more than shoot dry weight, perhaps maintaining a functional equilibrium that results in the balanced acquisition of carbon and N (Reynolds and Thornley, 1982). Atmospheric [CO_2] might also affect the allocation of dry matter between shoots and roots, although contrasting results have been reported for the shoot to root ratio, CO_2 enrichment may either increase, decrease or not affect R:S ratio (Hunt et al., 1991; Stulen and Den Hertog, 1993; Rogers et al., 1996). Although [CO_2] and N supply would be expected to interact regarding dry matter production and partitioning (i.e. the distribution of dry weight within the plant), the outcome cannot be predicted (Lloyd and Farquhar, 1996).

Partitioning dry matter between root and shoot, and the further separation of aboveground dry matter between the vegetative and reproductive organs is of crucial importance for crop yield under possible future global climate change. Prediction of crop performance and optimization of crop management under various N supply conditions consequently requires an accurate description of the partitioning processes and accordingly adaptation in the applied crop models. The influence of interactive effects of N and [CO_2] on partitioning dry matter of rice, however, is still not considered in any study. Here we examine the effects of elevated [CO_2] in interaction with N availability on growth, partitioning of dry weight of rice plant together to show how the Oryza2000 (Bouman et al., 2001) simulates them at similar conditions.

Methods

The experiment was conducted in 3 years in the Rice FACE facility located in Shizukushi, Iwate, Japan (Kim et al, 2003). The rice crops were grown under two levels of [CO_2] (ambient and ambient plus 200 $\mu mol\ mol^{-1}$ target level) for three seasons (1998 – 2000). The crops were supplied with three levels of fertilizer N: 4g (Low; LN), 8g (Medium; MN) and 12g Nm^{-2} (High; HN) in 1998, and 4 (LN), 9 (MN) and 15 (HN) g Nm^{-2}, for 1999 and 2000 respectively. Plant samples were taken at five different times from transplanting until grain maturity.

The model simulates the effect of leaf N content on photosynthesis and on the relative growth rate of leaves, and the effect of the amount of N in the crop on leaf death rate. The CO_2 assimilation light response of individual leaves follows a saturation type of function, characterized by an initial light use efficiency and an asymptote, both of which are increased by elevated [CO_2]. The simulated growth was compared with the observed ones using a method by Kobayashi and Salam (2000).

Results

Applying the Oryza2000 Model to evaluate the interactive effects of N x [CO_2] on Rice performance as our initial study (Bannayan et al., 2004) showed that the model is able closely to simulate the grain yield, slightly overestimates the biomass, but largely overestimated LAI especially at elevated [CO_2] (Fig. 1).

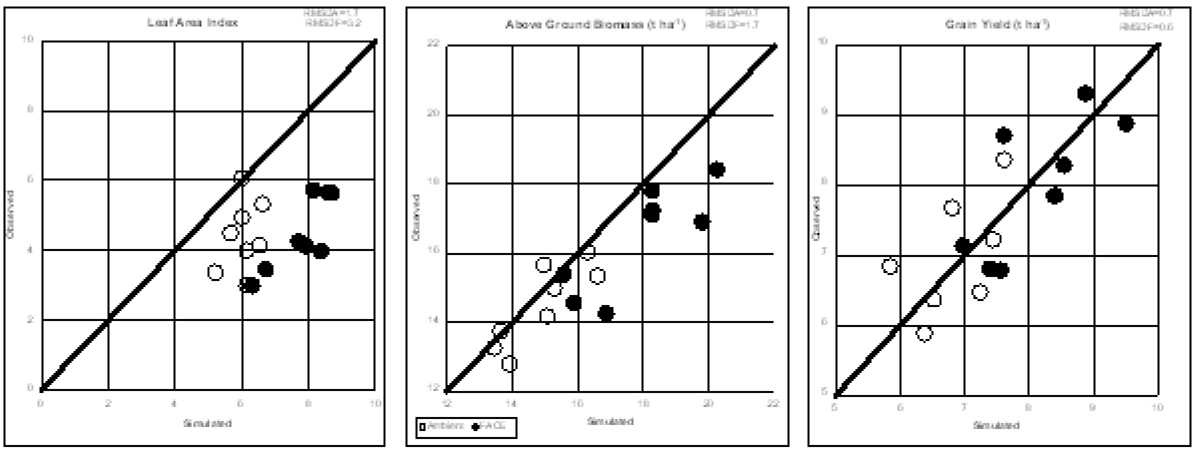

Figure 1. Comparison of observed and simulated LAI, above ground biomass and grain yield across N x CO_2 x Year.

Further analysis, using Kobayashi and Salam (2000) approach, showed that the squared bias (SB) is the major fraction of the mean squared deviation (MSD) for LAI and above-ground biomass, but not for grain yield (Table 1). This was more pronounced in elevated [CO_2]. In other words, the overestimation of LAI and above-ground biomass was the major contributor to the model-observation difference, and this was more so for elevated [CO_2].

Table 1. Goodness of fit of simulated LAI around anthesis, biomass (above ground) and grain yield, across N x [CO_2] x Year.

		SB/MSD Ratio
LAI	Ambient	0.55
	FACE	0.83
Biomass	Ambient	0.29
	FACE	0.72
Grain Yield	Ambient	0.01
	FACE	0.05

The result of the comparison between simulation and observation indicates the requirement of revising the model approach of elevated [CO_2] effects on growth characters especially LAI simulation.

In order to realize the inaccurate simulation of LAI while closely simulating both biomass and grain yield, the same time, the partitioning dry matter of all plant components were analyzed. The model highly overestimated partitioning of dry matter to plant components were analyzed. The model highly overestimated partitioning of biomass to root (Fig. 2) but due to underestimation of partitioning to stem (Fig. 3) simulation of above ground biomass was more accurate than the individual plant biomass components. However the above ground biomass still slightly was overestimated. Figure 4 shows that this might be due to overestimation of partitioning to leaf biomass and LAI.

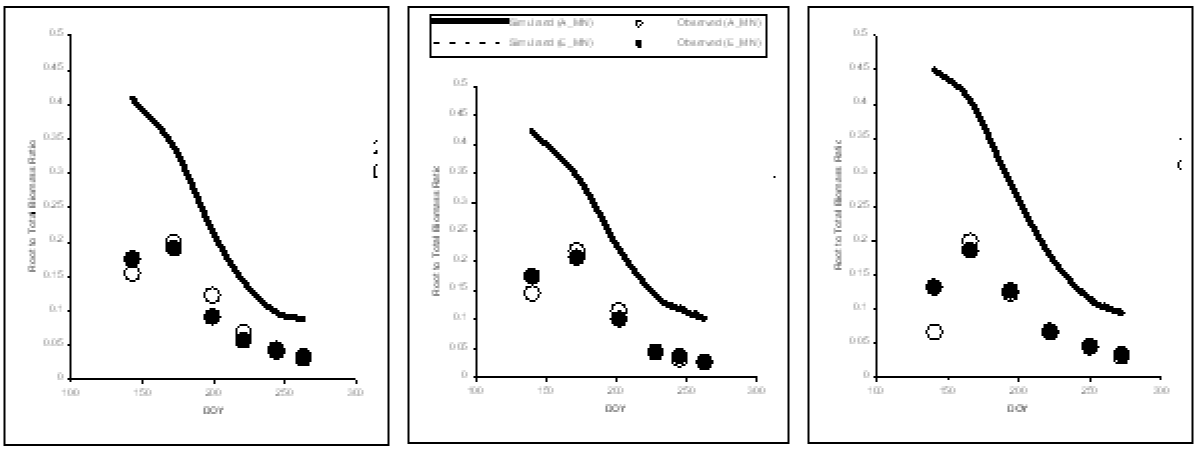

Figure 2. The time course of root to total biomass ratio across all years and [CO_2] levels.

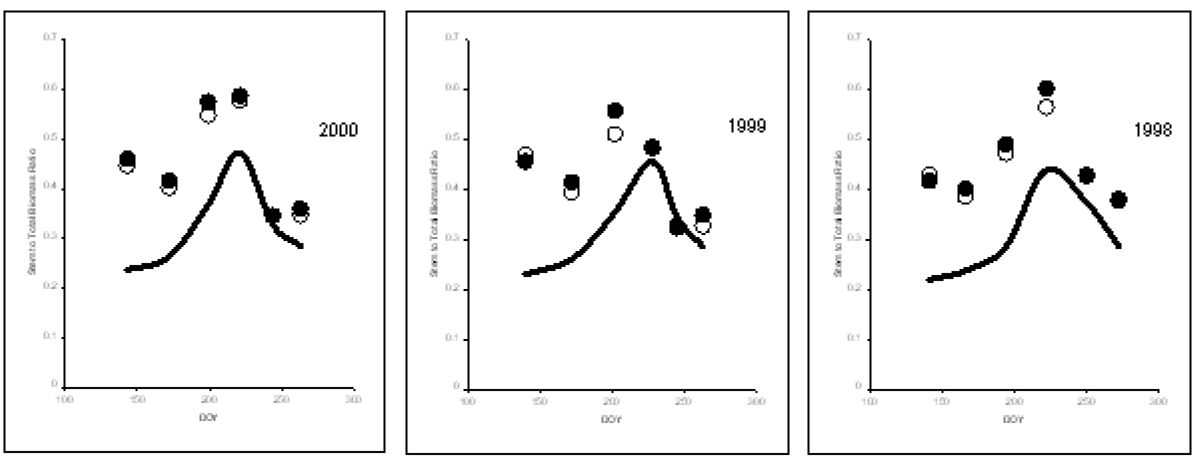

Figure 3. Time course of observed and simulated stem to total biomass ratio across all years and [CO_2] levels.

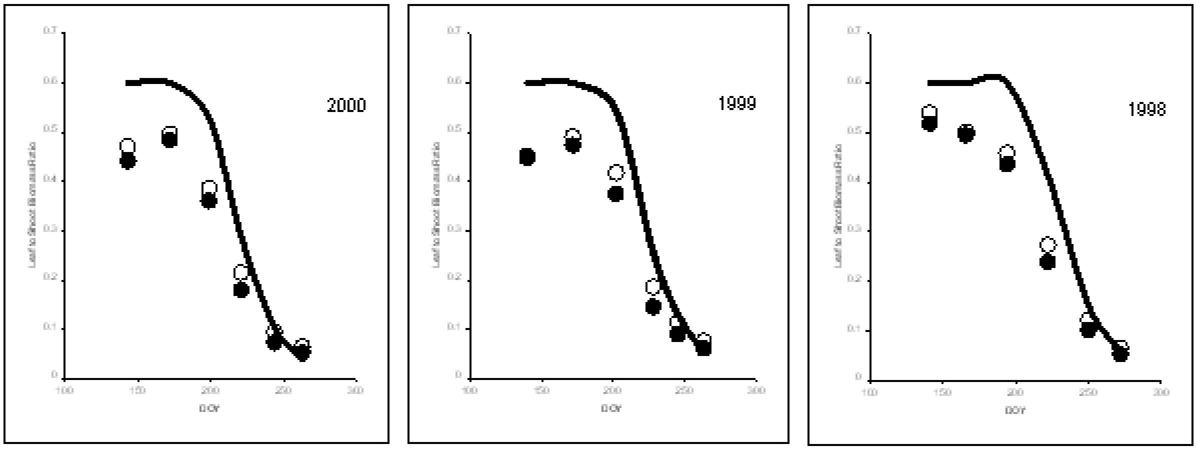

Figure 4. Time course of observed and simulated leaf to shoot biomass ratio across all years and [CO_2] levels.

Discussion

As it is shown in the Fig. 2, [CO_2] did not affect observed root to total dry matter ratio across all years of experiment. The model at all stages overestimated the root to shoot dry matter ratio. N showed a slight effect on this ratio, however the difference of partitioning coefficients showed its highest value around flowering, where higher applied N increased the partition to roots. It would be possible that increasing applied N delays the root death.

The nutrient status of a plant has been recognized as an important factor in the determination of dry weight partitioning. Due to its role in regulating plant growth and partitioning, N has been included in most attempts to model dry weight allocation (e.g. Reynolds and Chen, 1996). In simulation LAI, carbon based approach of Oryza2000 overestimated leaf weight and LAI, and finally resulted in overestimation of final biomass under elevated [CO_2]. The observation (Fig. 5) indicates that LAI simulation based on N than carbon might be a better approach not just for elevated [CO_2] effects but for its interaction with other management resources like N.

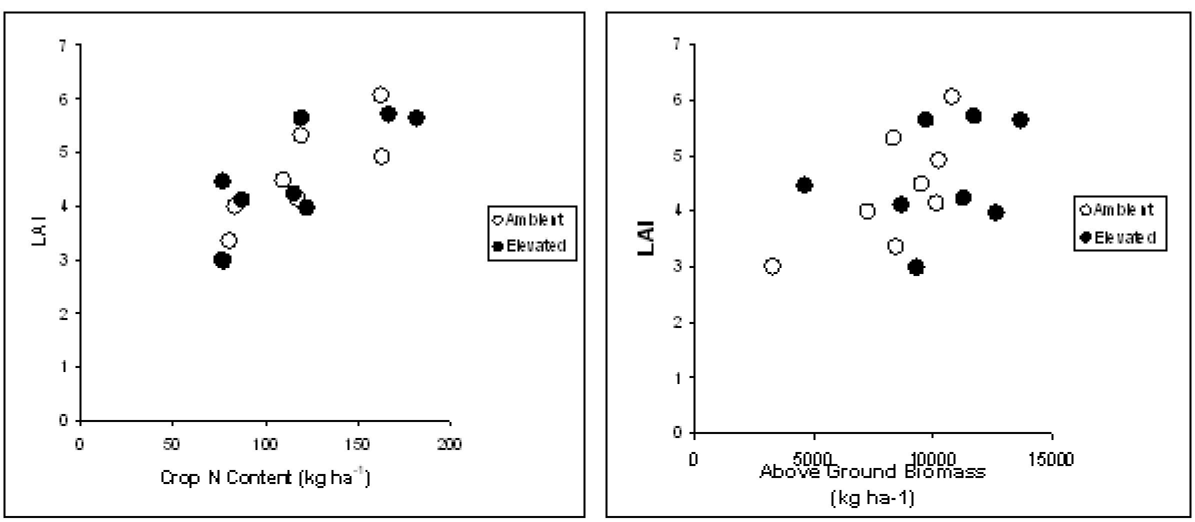

Figure 5. The relation between LAI with crop N content and above ground biomass at flowering.

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