Supporting information

Causes of variation among rice models in yield response to CO2 examined with Free-Air CO2 Enrichment and growth chamber experiments

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Table S1. Summary of the experimental conditions for the Japanese and Chinese FACE experiments

| Site description | Japan (1998-2000) | China (2001-2003) |
|------------------|------------------|------------------|
| Latitude/Longitude | 39°38’N/ 140°57’E | 31°37’N/120°28’E |
| Soil type and properties | Andosol | Stagnic anthrosol |
| Soil type | Sand 43.1%; Silt 31.4%; Clay 25.5% | Sand 9.2%; Silt 65.7%; Clay 25.1% |
| Bulk density cm$^{-3}$ | 0.73 | 1.2 |
| Plow layer cm | 12.3 | 13.0 |
| Total C g kg$^{-1}$ | 82.5 | 15.0 |
| Total N g kg$^{-1}$ | 18 | 1.59 |

Cultivar characteristics and growing conditions

| Cultivar | Akitakomachi | Wuxiangjing 14 |
|----------|--------------|----------------|
| Mean growth duration | 146 d | 158 d |
| Spikelets per panicle | 81 | 155 |

Daylight hour CO$_2$ concentrations (µmol mol$^{-1}$) at the center of the plot

| Year | 1998 | 1999 | 2000 | Mean | 2001 | 2002 | 2003 | Mean |
|------|------|------|------|------|------|------|------|------|
| FACE plots | 599 | 568 | 559 | 575 | 578 | 562 | 574 | 571 |
| Ambient plots | 368 | 369 | 365 | 367 | 354 | 364 | 375 | 364 |

N application rates (g N m$^{-2}$)

| Year | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | Mean |
|------|------|------|------|------|------|------|------|
| Low | 4 | 4 | 4 | 15 | 15 | 15 | |
| Standard | 8 | 9 | 9 | 25 | 25 | 25 | |
| High | 12 | 15 | 15 | - | 35 | 35 | |

Cultural practices

| Sowing dates | 1 May | 23 April | 23 April | 18 May |
| Transplanting dates | 21 May | 20 May | 22 May | 13 June |
| Planting density | 19 hills m$^{-2}$ | 24 hills m$^{-2}$ |

Mean daily temperatures (°C)

| Year | 1998 | 1999 | 2000 | Mean | 2001 | 2002 | 2003 | Mean |
|------|------|------|------|------|------|------|------|------|
| Transplanting to tillering | 15.4 | 17.2 | 17.7 | 16.8 | 26.7 | 24.9 | 25.8 | 25.8 |
| Tillering to panicle initiation | 19.9 | 20.6 | 21.3 | 20.6 | 29.1 | 28.6 | 29.4 | 29.0 |
| Panicle initiation to heading | 21.4 | 25.9 | 24.7 | 24.0 | 26.6 | 26.6 | 28.5 | 27.2 |
| Heading to mid-ripening | 21.3 | 22.5 | 23.6 | 22.5 | 24.1 | 25.7 | 26.0 | 25.3 |
| Mid-ripening to maturity | 20.3 | 19.8 | 20.9 | 20.3 | 20.9 | 20.3 | 18.8 | 20.0 |
| Season mean | 19.7 | 21.0 | 21.4 | 20.7 | 25.2 | 24.7 | 25.4 | 25.1 |
| Stage                                      | Mean daily solar radiation (MJ m\(^{-2}\) d\(^{-1}\)) |
|--------------------------------------------|------------------------------------------------------|
| Transplanting to tillering                 | 14.8, 20.3, 20.3, 17.5, 16.7, 14.9, 12.4, 14.7       |
| Tillering to panicle initiation            | 13.9, 15.1, 16.8, 14.4, 22.1, 19.4, 17.1, 19.5       |
| Panicle initiation to heading              | 14.7, 19.4, 17.3, 16.5, 17.1, 14.1, 15.0, 15.4       |
| Heading to mid-ripening                   | 12.3, 10.5, 18.2, 13.2, 17.2, 14.7, 12.5, 14.8       |
| Mid-ripening to maturity                  | 9.7, 11.4, 9.4, 9.1, 15.7, 13.0, 10.9, 13.2          |
| Season mean                                | 13.2, 16.2, 16.8, 14.6, 17.6, 14.9, 13.3, 15.2       |
Methods for uncertainty quantification

Simulations of growth and yield include two sources of uncertainty. One is the uncertainty caused by the difference between measured and simulated yield (Ubias) and the other is due to the variation among crop models (Umodel). In this study, we quantified both uncertainties by the following two methods:

1. To determine overall Ubias, a pairwise comparison between observed and simulated was made for datasets excluding those used for the model calibration. This was followed by further analysis on the deviations between simulations and observations to quantify the source of Ubias.

2. To determine sources of Umodel, the sum of squares (SS) from different sources was calculated for all simulation results.

FACE study

Simulations vs. observations

In step 1, we compared the measured and simulated yield and biomass under ambient [CO₂]. The bias for grain yield in Shizukuishi was significantly different from 0 (P<0.05), but only about 3.6 % of the measured yield. In Wuxi, simulated and measured yield did not differ significantly, but biomass was underestimated by 1.2 t/ha in Wuxi (P < 0.001), but about 6.7 % of the measured mean of 17.3 t/ha. The bias was consistent over the N treatments (Table S3, Figure S2). The mean bias in biomass of 0.4 t/ha in Shizukuishi was not significant.

The mean enhancement of grain yield in response to elevated [CO₂] was slightly but significantly overestimated in Shizukuishi, by 3 percentage point (P<0.05, Table S3, Figure S3). The bias was greater under low or high N conditions. In Wuxi, there was virtually no bias observed when averaged, but was slightly overestimated in medium N but underestimated in high N (Table S3, Figure S3). Overall, however, the mean biases were mostly not greater than the range of experimental errors (Table S3), suggesting that the mean of models was close to the measurements. We further analysed the sources of variation in the biases by means of analysis of variance, using differences between measured and simulated as a dependent variable and N and models as independent variables (Table S4). In general, more than half of the variation was due to models. These results suggest that Ubias is not large for the model ensemble means, but that for individual models is not negligible.

Variation among models (Umodel)

The simulated yield and biomass were further analysed for their sources of variation in a similar manner to the previous variance components (Table S5). Here we used all datasets including those used for calibration because the analyses targeted variation only among the simulated data. Variation in the experimental data is also shown in the table for reference, however.

For simulated yield and biomass, models are a large source of variation, but variation due to year and nitrogen levels were also large sources. The modelled variation follows that in observed yields and biomass. Model by N interactions were relatively small, suggesting that the models tend to behave similarly to different levels of N. The results were similar in both sites.

For yield and biomass enhancements to elevated [CO₂], 60% or more of the variation was due to the models. The main effect of year or N did not account for the variation (7 % or less).
A pairwise comparison between the simulated and observed was first made on the yield and biomass under ambient (330 µmol mol\(^{-1}\)) conditions, using Experiment 1, 2 and 3 under sufficient N conditions (Table S6). For the SPAR study, models were not calibrated except for phenology so all the data were used for this comparison. On average, grain yield was slightly but consistently overestimated by the models but no significant difference was observed for biomass. Models account for 65 % and 55 % of the total variation in the model bias for grain yield and biomass respectively.

Grain yield enhancement was significantly underestimated by the models (P < 0.05) by 4.5 percentage points and biomass was overestimated by 3.8%, but these differences were less than the standard error for the experiments (Table S6). The major source of the variation in the model simulations was models, accounting for more than 60 % of the total variations (Table S7). The model by CO\(_2\) interaction was relatively small ranging from 4 to 6 %, suggesting that relative model performance was similar under two [CO\(_2\)] conditions. These analyses highlight the importance of reducing uncertainties among the models.
Table S2  A paired T-test comparing measurements with simulated yield and aboveground biomass under ambient [CO₂] and enhancement by elevated [CO₂] in the FACE experiments with three N fertilizer levels. The datasets used for model calibration are not included.

| Site    | Mean difference (measured-simulated) | df | t     | P value | SE for the measurements\(^1\) | Difference (measured-simulated) in each N treatment |
|---------|--------------------------------------|----|-------|---------|-------------------------------|-----------------------------------------------------|
|         |                                      |    |       |         |                               | low N      | medium N            | high N       |
| Shizukuishi | Grain yield (t/ha) (ambient)          | 0.3| 82    | -2.39  | 0.019                         | 0.4        | 0.0                | 0.4          |
|         | Biomass (ambient) (t/ha)              | 0.4| 71    | -1.43  | 0.156                         | 1.0 a      | 0.5 ab              | 0.2 bc       |
|         | Grain yield enhancement (%)           | -3.0| 82    | 2.50   | 0.015                         | -5.3 a     | 1.0 b               | -4.5 a       |
|         | Biomass enhancement (%)               | -4.1| 71    | 3.04   | 0.003                         | -3.5       | -5.9               | -4.2         |
| Wuxi    | Grain yield (ambient) (t/ha)          | 0.2| 57    | -1.11  | 0.271                         | 0.8 a      | 0.4 ab              | -0.9 bc      |
|         | Biomass (ambient) (t/ha)              | 1.2| 57    | -4.30  | 0.000                         | 1.1        | 1.5                | 0.5          |
|         | Grain yield enhancement (%)           | -0.9| 57    | 0.83   | 0.408                         | -0.7 ab    | -3.4 a              | 2.6 c        |
|         | Biomass enhancement (%)               | 3.7| 57    | -2.97  | 0.004                         | 8.8        | 9.2 a               | -6.0 b       |

1) Standard error for the measurements was obtained from the residual mean square of the analysis of variance using year and N as main factors (see Table S3).

2) The same alphabetic letters followed by the values for each N treatment are not significantly different between the treatments.
Table S3. Sources of variation in the difference between measured and simulated values in the FACE experiments.

| Site  | Source          | df | SS  | MS  | %  | df | SS  | MS  | %  | df | SS  | MS  | %  |
|-------|-----------------|----|-----|-----|----|----|-----|-----|----|----|-----|-----|----|
|       |                 | df | SS  | MS  | %  | df | SS  | MS  | %  | df | SS  | MS  | %  |
|       |                 | df | SS  | MS  | %  | df | SS  | MS  | %  | df | SS  | MS  | %  |
|       |                 |    |     |     |    |    |     |     |    |    |     |     |    |
|       |                 | df | SS  | MS  | %  | df | SS  | MS  | %  | df | SS  | MS  | %  |
|       |                 | df | SS  | MS  | %  | df | SS  | MS  | %  | df | SS  | MS  | %  |
|       |                 |    |     |     |    |    |     |     |    |    |     |     |    |
|       |                 | df | SS  | MS  | %  | df | SS  | MS  | %  | df | SS  | MS  | %  |
|       |                 | df | SS  | MS  | %  | df | SS  | MS  | %  | df | SS  | MS  | %  |
|       |                 |    |     |     |    |    |     |     |    |    |     |     |    |
|       |                 | df | SS  | MS  | %  | df | SS  | MS  | %  | df | SS  | MS  | %  |
|       |                 | df | SS  | MS  | %  | df | SS  | MS  | %  | df | SS  | MS  | %  |
|       |                 |    |     |     |    |    |     |     |    |    |     |     |    |
|       |                 | df | SS  | MS  | %  | df | SS  | MS  | %  | df | SS  | MS  | %  |
|       |                 | df | SS  | MS  | %  | df | SS  | MS  | %  | df | SS  | MS  | %  |
|       |                 |    |     |     |    |    |     |     |    |    |     |     |    |
|       |                 | df | SS  | MS  | %  | df | SS  | MS  | %  | df | SS  | MS  | %  |
|       |                 | df | SS  | MS  | %  | df | SS  | MS  | %  | df | SS  | MS  | %  |
|       |                 |    |     |     |    |    |     |     |    |    |     |     |    |
|       |                 | df | SS  | MS  | %  | df | SS  | MS  | %  | df | SS  | MS  | %  |
|       |                 | df | SS  | MS  | %  | df | SS  | MS  | %  | df | SS  | MS  | %  |
|       |                 |    |     |     |    |    |     |     |    |    |     |     |    |
|       |                 | df | SS  | MS  | %  | df | SS  | MS  | %  | df | SS  | MS  | %  |
|       |                 | df | SS  | MS  | %  | df | SS  | MS  | %  | df | SS  | MS  | %  |
|       |                 |    |     |     |    |    |     |     |    |    |     |     |    |
|       |                 | df | SS  | MS  | %  | df | SS  | MS  | %  | df | SS  | MS  | %  |
|       |                 | df | SS  | MS  | %  | df | SS  | MS  | %  | df | SS  | MS  | %  |
|       |                 | df | SS  | MS  | %  | df | SS  | MS  | %  | df | SS  | MS  | %  |
|       |                 |    |     |     |    |    |     |     |    |    |     |     |    |

1) Sum of squares (SS) for the differences between measured and simulated values were calculated by the general liner model procedures (Type I sum of squares).
2) % of SS of the total (corrected by the overall mean).
Table S4  Sum of squares (SS) and mean squares (MS) of the simulated and measured yield and biomass under ambient [CO$_2$] and of enhancement due to elevated [CO$_2$] at two FACE sites.

| Site       | Source         | df | SS  | MS  | %     | df | SS  | MS  | %     | df | SS  | MS  | %     |
|------------|----------------|----|-----|-----|-------|----|-----|-----|-------|----|-----|-----|-------|
| Shizukuishi| Simulated      |    |     |     |       |    |     |     |       |    |     |     |       |
|            | Year           | 2  | 44.1| 22.03| 21.4 | 2  | 108 | 53.8| 15.9  | 2  | 904 | 452 | 6.7   |
|            | Nitrogen (N)   | 2  | 63.7| 31.84| 31.0 | 2  | 198 | 98.8| 29.2  | 2  | 821 | 410 | 6.1   |
|            | Year x N       | 4  | 3.23| 0.81 | 1.6  | 4  | 7.41| 1.9 | 1.1   | 4  | 177 | 44  | 1.3   |
|            | Model          | 13 | 64.1| 4.93 | 31.2 | 13 | 291 | 22.4| 42.9  | 13 | 8006| 616 | 59.6  |
|            | Model x Year   | 26 | 23.2| 0.89 | 11.3 | 26 | 47.1| 1.8 | 7.0   | 26 | 1362| 52  | 10.1  |
|            | Model x N      | 20 | 3.67| 0.18 | 1.8  | 20 | 17.1| 0.9 | 2.5   | 20 | 1126| 56  | 8.4   |
|            | Model x Year x N| 40 | 3.55| 0.09 | 1.7  | 40 | 9.23| 0.2 | 1.4   | 40 | 1034| 26  | 7.7   |
|            | Total          | 107| 205 | 1.92 |     | 107| 677 | 6.3 |     | 107| 13429| 126 | 117.3 |
|            | Measured       |    |     |     |       |    |     |     |       |    |     |     |       |
|            | Year           | 2  | 28.1| 14.03| 50.8 | 2  | 22.8| 11.4| 31.7 | 2  | 286 | 143 | 11.3  |
|            | Block$^2$      | 3  | 1.6 | 0.52 | 2.8  | 3  | 3.3 | 1.1 | 4.6   | 3  | 43  | 14  | 1.7   |
|            | Year x Block   | 6  | 1.5 | 0.26 | 2.8  | 6  | 5.9 | 1.0 | 8.3   | 6  | 258 | 43  | 10.2  |
|            | N              | 2  | 16.9| 8.45 | 30.6 | 2  | 24.8| 12.4| 34.6  | 2  | 414 | 207 | 16.4  |
|            | Year x N       | 4  | 0.1 | 0.01 | 0.1  | 4  | 3.1 | 1.0 | 4.3   | 4  | 67  | 17  | 2.7   |
|            | Sub plot error$^3$| 18 | 7.1 | 0.39 | 12.8 | 15 | 11.9| 0.8 | 16.6  | 18 | 1454| 81  | 57.7  |
|            | Total          | 35 | 55  | 1.58 |     | 31 | 71.9| 27.7|     | 35 | 2520.6| 504.4|       |
| Wuxi       | Simulated      |    |     |     |       |    |     |     |       |    |     |     |       |
|            | Year           | 2  | 50.6| 25.3 | 22.4 | 2  | 186 | 92.8| 34.4 | 2  | 256 | 128.1| 4.2  |
|            | Block$^2$      | 3  | 1.7 | 0.87 | 2.8  | 3  | 1.7 | 0.8 | 1.7   | 3  | 152 | 43  | 7.2   |
|            | Year x Block   | 4  | 0.87| 0.2  | 0.4  | 4  | 3.79| 0.9 | 0.7   | 4  | 21.3| 3.3  | 0.7   |
|            | N              | 13 | 111 | 8.5  | 48.9 | 13 | 180 | 13.8| 33.3  | 13 | 3775| 290.4| 62.1 |
|            | Model          | 13 | 111 | 8.5  | 48.9 | 13 | 180 | 13.8| 33.3  | 13 | 3775| 290.4| 62.1 |
|            | Model x Year   | 26 | 32.2| 1.2  | 14.3 | 26 | 77.2| 3.0 | 14.3  | 26 | 862 | 331 | 14.2  |
|            | Model x N      | 20 | 12.3| 0.6  | 5.5  | 20 | 31.9| 1.6 | 5.9   | 20 | 649 | 32.4| 10.7  |
|            | Model x Year x N| 35 | 1.95| 0.1  | 0.9  | 35 | 3.92| 0.1 | 0.7   | 35 | 459 | 13.1| 7.6   |
|            | Total          | 102| 226 | 2.22 |     | 102| 540| 5.3 |     | 102| 6076| 59.6| 51.1  |
|            | Measured       |    |     |     |       |    |     |     |       |    |     |     |       |
|            | Year           | 2  | 12.33| 6.11| 66.3 | 2  | 5.71| 2.86| 20.8  | 2  | 9.7 | 4.8 | 0.9   |
|            | Block$^2$      | 2  | 0.06| 0.03 | 0.3  | 2  | 0.18| 0.09| 0.7   | 2  | 56.9| 28.5| 5.0   |
|            | Year x Block   | 4  | 1.28| 0.32 | 6.9  | 4  | 5.20| 1.30| 18.9  | 4  | 174.5| 43.6| 15.4  |
|            | N              | 2  | 3.04| 1.52 | 16.5 | 2  | 9.13| 4.56| 33.2  | 2  | 140.2| 70.1| 12.3  |
|            | Year x N       | 3  | 0.44| 0.15 | 2.4  | 3  | 2.70| 0.90| 9.8   | 3  | 198.7| 66.2| 17.5  |
|            | Sub plot error$^3$| 10 | 1.38| 0.14 | 7.5  | 10 | 4.59| 0.46| 16.7  | 10 | 555.9| 55.6| 48.9  |
|            | Total          | 23 | 18  | 0.80 |     | 23 | 28 | 1.20|     | 23 | 1136| 49.39| 94.69 |

1) % of SS of the total (corrected by the overall mean).
2) Randomized complete block design for the N treatments each year at each site.
3) Residual variance of the experiment.
Table S5. A paired comparison between measured and simulated yield and aboveground under 330 µmol mol\(^{-1}\) and between measured and simulated enhancements due to elevated CO\(_2\) (660 & 500 µmol mol\(^{-1}\)) in the SPAR experiment

| Variables compared | Mean difference (measured-simulated) | df | t    | P value | Standard error for the measurements |
|--------------------|---------------------------------------|----|------|---------|------------------------------------|
| Grain yield (t/ha) (330µmol mol\(^{-1}\)) | -1.28 | 41 | -3.41 | 0.001 | 1.29 |
| Biomass (t/ha) (330µmol mol\(^{-1}\)) | -0.21 | 41 | -0.33 | 0.742 | 1.79 |
| Grain yield enhancement (%) | 4.47 | 57 | 2.22  | 0.031 | 5.24 |
| Biomass enhancement (%) | -3.83 | 57 | -2.06 | 0.044 | 6.05 |

Table S6. Sum of squares (SS) and mean square (MS) of yield and biomass under ambient [CO\(_2\)] (330µmol mol-1) and of enhancement due to elevated CO\(_2\) (660 & 500 µmol mol-1) in SPAR experiment

| Source                  | Grain yield (330 µmol mol\(^{-1}\)) (t/ha\(^2\)) | Biomass (330 µmol mol\(^{-1}\)) (t/ha\(^2\)) | Yield Enhancement (%)\(^2\) | Biomass Enhancement (%)\(^2\) |
|-------------------------|-----------------------------------------------|-----------------------------------------------|----------------------------|-------------------------------|
|                         | df               | SS   | MS | % | df               | SS   | MS | % | df               | SS   | MS | % | df               | SS   | MS | % | df               | SS   | MS | % |
| CO\(_2\)                | 2              | 26.5 | 13.3 | 11.9 | 2               | 125 | 62.4 | 19.5 | 1               | 1051 | 1051 | 11.4 | 1               | 1402 | 1402 | 14.0 |
| Experiment              | 14             | 158 | 11.3 | 71.1 | 14              | 366 | 26.1 | 57.1 | 1               | 5915 | 422  | 64.1 | 1               | 6756 | 483  | 67.6 |
| CO2×Experiment          | 1              | 0.554 | 0.554 | 0.006 | 1               | 3.33 | 3.33 | 0.03 | 1               | 3.33 | 3.33 | 0.03 | 1               | 3.33 | 3.33 | 0.03 |
| Model                   | 14             | 158 | 11.3 | 71.1 | 14              | 366 | 26.1 | 57.1 | 1               | 5915 | 422  | 64.1 | 1               | 6756 | 483  | 67.6 |
| Model × CO\(_2\)        | 1              | 0.554 | 0.554 | 0.006 | 1               | 3.33 | 3.33 | 0.03 | 1               | 3.33 | 3.33 | 0.03 | 1               | 3.33 | 3.33 | 0.03 |
| Error                   | 25             | 37.8 | 1.51 | 17.0 | 25              | 151 | 6.02 | 23.5 | 39              | 1129 | 28.9 | 12.2 | 39              | 803  | 20.6 | 8.04 |
| Corrected Total         | 41             | 222 | 12010 | | 71              | 9231 | | 9992 | | 71              | 9992 | | | | | | |
Figure S1. Responses of leaf photosynthesis or radiation use efficiency used in 16 rice models. Values expressed as % increase with a [CO$_2$] elevation by 200 µmol mol$^{-1}$ from 367 µmol mol$^{-1}$ to Red, LRC (light response curve-type photosynthesis model); Yellow, FvCB (Farquhar, von Caemmerer & Berry photosynthesis model); Green, RUE (Radiation use efficiency). Analysis of variance testing the difference among model types showed no significant differences.
Figure S2. Simulated and observed yield (a) and biomass (b) under ambient [CO₂].
Box-whiskers represent the variation among simulated values by 14 rice models and red dots and bars represent the measured mean ±80% confidence intervals. The 80% confidence intervals are to compare the whiskers of the simulated values ranging from 10 to 90 percentiles. Datasets not used for the calibration are shown. Measurements for biomass in LN at Shizukuishi in 1998 and for yield and biomass in HN in 2001 were not available.
Figure S3. Simulated and observed yield (a) and biomass (b) enhancement by elevated [CO₂]
Box-whiskers represent the range of simulated values by 14 rice models and red dots and bars represent the measured mean ±80% confidence intervals. The 80% confidence intervals are to compare the whiskers of the simulated values ranging from 10 to 90 percentiles. Datasets not used for the calibration are shown. Measurements for biomass in LN at Shizukuishi in 1998 and for yield and biomass in HN in 2001 were not available.
Figure S4. Simulated yield enhancements due to elevated [CO\(_2\)] for individual models at Shizukuishi (a) and Wuxi (b).
Variation within each model derives from differences in simulated yields under different N or years. Values expressed as % increase with a [CO\(_2\)] elevation by 200 µmol mol\(^{-1}\) from 367 µmol mol\(^{-1}\) to 567 µmol mol\(^{-1}\). LRC, light response curve-type photosynthesis model; FvCB, Farquhar, von Caemmerer & Berry photosynthesis model; RUE, radiation use efficiency.

Figure S5. Grain yield response to changes in [CO\(_2\)] under three N levels in SPAR experiment (Exp. 3).
Pink, LRC (light response curve-type photosynthesis model); Yellow, FvCB (Farquhar, von Caemmerer & Berry photosynthesis model); Green, RUE (Radiation use efficiency). Numbers above or below the bars correspond to the individual models listed in Table S1.
Figure S6. Factors affecting the simulated enhancements of grain yield due to E-[CO2] in high N treatment in the FACE experiments at two sites. (a) grain yield enhancement versus biomass enhancement, (b) grain yield enhancement versus harvest index enhancement, (c) biomass enhancement versus primary [CO2] enhancement (leaf CO2 assimilation rate, CAR, or radiation use efficiency, RUE), and (d) biomass enhancement versus maximum LAI enhancement. The data from all N treatments at two sites are included. Symbols with a single color are for Shizukuishi and those that are half-filled in black are for Wuxi. LRC, light response curve-type photosynthesis model; FvCB, Farquhar, von Caemmerer & Berry photosynthesis model; RUE, radiation use efficiency.
Figure S7. Relationship between grain yield and biomass responses to various levels of [CO$_2$] ((a) 900 µmol mol$^{-1}$, (b) 660 µmol mol$^{-1}$, (c) 500 µmol mol$^{-1}$, (d) 660 µmol mol$^{-1}$, (e) 160 µmol mol$^{-1}$) in the SPAR chamber experiments (Ex.1 & 2).

% changes are relative to the value at 367 µmol mol$^{-1}$. LRC, light response curve-type photosynthesis model; FvCB, Farquhar, von Caemmerer & Berry photosynthesis model; RUE, radiation use efficiency.
Figure S8. Relationship between grain yield and harvest index responses to various levels of [CO₂] ((a) 900 µmol mol⁻¹, (b) 660 µmol mol⁻¹, (c) 500 µmol mol⁻¹, (d) 660 µmol mol⁻¹, (e) 160 µmol mol⁻¹) in the SPAR chamber experiments (Ex.1 & 2).

% changes are relative to the value at 367 µmol mol⁻¹. LRC, light response curve-type photosynthesis model; FvCB, Farquhar, von Caemmerer & Berry photosynthesis model; RUE, radiation use efficiency.
Figure S9. Relationship between primary $[\text{CO}_2]$ of each model and biomass response to various levels of $[\text{CO}_2]$ (a) 900 µmol mol$^{-1}$, (b) 660 µmol mol$^{-1}$, (c) 500 µmol mol$^{-1}$, (d) 660 µmol mol$^{-1}$, (e) 160 µmol mol$^{-1}$) in the SPAR chamber experiments (Ex 1 & 2).

% changes are relative to the value at 367 µmol mol$^{-1}$. LRC, light response curve-type photosynthesis model; FvCB, Farquhar, von Caemmerer & Berry photosynthesis model; RUE, radiation use efficiency.
Figure S10. Relationship between maximum LAI response and biomass response to various levels of $[\text{CO}_2]$ (a) 900 µmol mol$^{-1}$, (b) 660 µmol mol$^{-1}$, (c) 500 µmol mol$^{-1}$, (d) 660 µmol mol$^{-1}$, (e) 160 µmol mol$^{-1}$) in the SPAR chamber experiments (Ex 1 & 2).

% changes are relative to the value at 367 µmol mol$^{-1}$. LRC, light response curve-type photosynthesis model; FvCB, Farquhar, von Caemmerer & Berry photosynthesis model; RUE, radiation use efficiency.