**Supplementary information**

**Table S1.** Specific parameter values of greenhouse and virtual canopy.

|  |  |  |  |
| --- | --- | --- | --- |
| **Description** | **Value range** | | **Unit** |
| Planting strategy | Single row | Double row |  |
| Furrow distance | - | 0.9 | m |
| Row distance | 1.0 | 0.45 | m |
| Plant spacing | 0.30 | 0.35 | m |
| Number of plants per row | 16 | 14 | - |
| Maximal leaf rank per plant | 15 | 13 | - |
| Planting density | 3.2 | 3.2 | Plants m-2 |
| LAI of the cucumber canopy | 0.57 | 0.89 | m2 m-2 |
| Averaged petiole length per rank | 0.142, 0.146, 0.152, 0.155, 0.134, 0.158, 0.139, 0.136, 0.126, 0.094, 0.099, 0.058, 0.040, 0.019, 0.010 | 0.162, 0.148, 0.156, 0.167, 0.130, 0.129, 0.128, 0.092, 0.072, 0.044, 0.032 | m |
| Averaged internode length per rank | 0.077, 0.065, 0.045, 0.065, 0.105, 0.120, 0105, 0.131, 0.135, 0.130, 0.117, 0.105, 0.066, 0.032 | 0.091, 0.082, 0.040, 0.062, 0.085, 0.122, 0.110,0.108 0.102, 0.083, 0.059 | m |
| Averaged leaf angle per rank | 53.1, 41.3, 48.0, 42.4, 40.4, 38.4, 60.4, 59.2, 55.5, 57.4, 106.9, 90.0, 91.0, 97.4, 164.0 | 59.2, 84.7, 53.6, 46.2, 46.3, 51.6, 127.3, 67.1,57.4, 72.4, 90.0, 87.6 | ° |
| Averaged petiole angle per rank | 74.3, 81.8, 34.1, 49.6, 49.2, 32.4, 55.7, 44.9, 39.8, 40.5, 65.4, 51.7, 61.7, 15.7, 15.0 | 52.3, 39.1, 74.2, 42.1, 46.3, 37.7, 35.2, 37.8, 49.5, 35.2,36.5, 21.0, 19.0 | ° |

**Table S2.** List of variables used in the photosynthesis model.

|  |  |  |
| --- | --- | --- |
| **Symbol** | **Description** | **Unit** |
| P | Net leaf assimilation rate | μmol m-2 s-1 |
| Ac | Net leaf assimilation rate limited by Rubisco activity | μmol m-2 s-1 |
| Aj | Net leaf assimilation rate limited by RuBP regeneration | μmol m-2 s-1 |
| Ap | Triose phosphate utilization-limited CO2 assimilation rate | μmol m-2 s-1 |
| Rd | Mitochondrial respiration in the light | μmol m-2 s-1 |
| Vcmax | Maximum carboxylation capacity | μmol m-2 s-1 |
| Cc | Chloroplastic CO2 concentration | μmol mol-1 |
|  | CO2 compensation point | μmol mol-1 |
| Ci | Intercellular CO2 concentration | μmol mol-1 |
| J | Electron transport rate | μmol m-2 s-1 |
| O | Oxygen concentration | μmol mol-1 |
| Kc | Michaelis–Menten constant of Rubisco for CO2 | μmol mol-1 |
| Ko | Michaelis–Menten constant of Rubisco for O2 | μmol mol-1 |
| Jmax | Maximum electron transport rate | μmol m-2 s-1 |
| Pu | Triose phosphate utilization rate | μmol m-2 s-1 |
| Tp | Leaf temperature | ℃ |
| Ea | Activation energy | kJ mol− 1 |
| H | Curvature parameter of the temperature dependence Jmax | 219.4 kJ mol− 1 |
| R | Universal gas constant | 8.314 J mol− 1 K − 1 |
| S | Electron transport temperature response parameter | 704.2 J mol− 1 K− 1 |
| θ | Curvature of response of electron transport to PAR | 0.7 |
| I | Photosynthetic photon flux density (PPFD) | μmol m-2∙s-1 |
| f | Spectral correction factor | 0.15 |
| δ | Leaf reflectance plus transmittance | 0.15 |

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**Figure S1.** The difference of PAR interception and photosynthetic rate for leaves at different canopy position of the left row under single-row planting strategy, (a) the plant near the wall, (b) the plant at the middle of the planting row, (c) the plant at the front of the planting row, (d-f) the photosynthetic rate for the corresponding plant.



**Figure S2.** The difference of PAR interception and photosynthetic rate for leaves at different canopy position of the right row under single-row planting strategy, (a) the plant near the wall, (b) the plant at the middle of planting row, (c) the plant at the front of planting row, (d-f) the photosynthetic rate for the corresponding plant.

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**Figure S3.** The difference of PAR interception and photosynthetic rate for leaves at different canopy position of the left row under double-row planting strategy, (a) the plant near the wall, (b) the plant at the middle of planting row, (c) the plant at the front of planting row, (d-f) the photosynthetic rate for the corresponding plant.



**Figure S4.** The difference of PAR interception and photosynthetic rate for leaves at different canopy position of the right row under double-row planting strategy, (a) the plant near the wall, (b) the plant at the middle of planting row, (c) the plant at the front of planting row, (d-f) the photosynthetic rate for the corresponding plant.

**Figure s6**

**Figure S5.** The point cloud of cucumber canopies within Chinese solar greenhouse. (a) the directly obtained point cloud, (b) false color point cloud at seedling stage under double-row planting strategy, (c) the directly obtained point cloud and (d) false color point cloud at flowering stage under single-row planting strategy. Note: Different colors represent different height information.

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**Figure S6.** Variations of canopy temperature in north-south direction within Chinese solar greenhouse.