Integrated Developmental Model of Life-Support Capabilities in Wheat

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The objective of this project was to develop a model for CO_2, O_2, H_2O , and nitrogen use during the life cycle of wheat. The following spreadsheets and accompanying graphs were developed to illustrate plant population reactions to environmental parameters established in the Controlled Ecological Life Support System (CELSS) program at Kennedy Space Center, Fl. The spreadsheets and graphs were produced using validated Biomass Production Chamber (BPC) data from BWT931.

Conditions of the BPC during the 83 day plant growth period were as follows: The BPC area is 27.8 m^2 , volume is 113 m^3. Temperatures during the 83 day plant growth period ranged from 16.3 °C to 24.8 °C during the light cycle (except for day 69, when the minimum and maximum temperatures were 7.7 °C and 7.9 °C ,respectively) and 14.5 °C and 23.6 °C during the dark cycle (except for day 49, when the minimum and maximum temperatures were 11.1 °C and 11.3 °C, respectively). Relative humidity was 85% for the first 7 days of plant growth, and 70% thereafter. The plant leaf canopy area was 10m^2 (and will be indicated as such in the formula descriptions that follow).

Following is a list and explanation of each spreadsheet and accompanying graph(s), conditions under which the data were collected, and formulas used to obtain each result. The format is: Spreadsheet Title, Filename (spreadsheet), Filename (graph(s)), conditions, formulas, and description of graphs. The Quattro Pro for DOS program, version 5.0 was used to generate the spreadsheets, the font used was Swiss SC 12 point Black. Sigmaplot for Windows, version 1.02 was used to generate the graphs.

Some of the spreadsheets include a supplementary data input area to the immediate right of the blocked (printed) spreadsheet area. The file names for these spreadsheets are CASSL, CEVOD, OEVOL, OEVOD, NUSET, TEMPLAT1, and TEMPLAT2. These areas are titled with a brief description of the type of data required to be inputted (ex: temperature data for average temperature calculations). The required data must be inputted into these areas as well as the blocked areas.

Spreadsheet files can be differentiated from graph files by the addition of the letter G at the end of the filename, which is followed by a number indicating graphs in numerical order. (ex: CASSLG1 would indicate the first graph file that was created with data from the spreadsheet file CASSL).

1. Whole plant net CO_2 assimilation for wheat (Triticum sp. cv. Yecora Rojo) in the light in the KSC BPC. (CASSL, CASSLG1, CASSLG2). CO_2 concentration in the BPC was set at 1000 umol/mol and automatically maintained by daily CO_2 additions, except for 18,36,71 and 72 DAP. CO_2 concentration was obtained at the beginning and end of the light period. The CO_2 minimum

was subtracted from the CO_2 maximum and this difference (in liters) was used in the following formula:
CO_2 assimilation (umol/m^2 /s) = liters/475 minutes[1] * 1mol/22.4L * 273/(273 + °C) * 1 min./60s * 1/10m^2 * 1,000,000 umol/mol.

Graphs

CASSLG1 - "Whole plant net CO_2 assimilation for wheat (Triticum sp. cv. Yecora Rojo) in the light in the KSC BPC". Net CO_2 assimilation (umol/m^2 /s) is plotted against days after planting (DAP).

CASSLG2 - "Whole plant net CO_2 assimilation for wheat (Triticum sp. cv. Yecora Rojo) in the light in the KSC BPC". Net CO_2 assimliation (mol/m^2 /20 h) is plotted against DAP.

2. Whole plant respiration for wheat (Triticum sp. cv. Yecora Rojo) in the dark in the KSC BPC. (CEVOD,CEVODG1,CEVODG2). CO_2 concentration was set at 1000 umol/mol and increases in CO_2 concentration in the closed system were monitored. The difference between maximum and minimum CO_2 levels was used in the following formula:

CO_2 evolution (umol/m^2 /s) = PPM/230 minutes * .0565 L/PPM * 1mol/22.4L * 273/(273 + °C) * 1min/60s * 1/10m^2 *1000,000 umol/mol.

Graphs

CEVODG1 - "Whole plant respiration for wheat (Triticum sp. cv. Yecora Rojo) in the dark in the KSC BPC." CO_2 evolution (umol/m^2 /s) is plotted against DAP.

CEVODG2 - "Whole plant respiration for wheat (Triticum sp. cv. Yecora Rojo) in the dark in the KSC BPC". CO_2 evolution (mol/m^2 /4 h) is plotted against DAP.

3. Whole plant CO_2 fixed per twenty hour light and four hour dark cycle for wheat (Triticum sp. cv. Yecora Rojo) in the KSC BPC. (CUSET, CUSETG1, CUSETG2). These values were derived from CO_2 assimilation in the light (spreadsheet 1) and CO_2 evolution in the dark (spreadsheet 2) through linking. CO_2 evolution in the dark was subtracted from CO_2 assimliation in the light. From this, net CO_2 fixed for 24 hours (mol/m^2 /24 h) was obtained. Cumulative CO_2 fixed (mol/m^2) over the 83 day period was also calculated.

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[1]The time between maximum CO_2 and minimum CO_2 measurements was 475 min. In other spreadsheets the measurement times may be different, but this does not affect the information obtained, as all of the measurements are extrapolated to umol/m^2 /s.

Graphs

CUSETG1 - "Whole plant CO_2 fixed per twenty hour light and four hour dark cycle for wheat (Triticum sp. cv. Yecora Rojo) in the KSC BPC". Net CO_2 fixed per twenty four hour cycle (mol/m^2 /24 h) is plotted against DAP.

CUSETG2 - "Whole plant net CO_2 assimilation per twenty hour light and four hour dark cycle for wheat (Triticum sp. cv. Yecora Rojo) in the KSC BPC. Cumulative CO_2 assimilation (mol/m^2) is plotted against DAP.

4. Whole plant net O_2 production for wheat (Triticum sp. cv. Yecora Rojo) in the light in the KSC BPC. (OEVOL,OEVOLG1,OEVOLG2). The minimum O_2 concentration in the light was subtracted from the maximum O_2 concentration in the light and the difference was used in the following formula: Net O_2 production (umol/m^2 /s) = % oxygen/475 minutes * 530 L/% * 1 mol/22.4L * 273/(273 + °C) * 1min/60s * 1/10m^2 * 1,000,000 umol/mol.
Note: O_2 measurements did not begin until 41 DAP.

Graphs

OEVOLG1 - " Whole plant net oxygen production for wheat (Triticum sp. cv. Yecora Rojo) in the light in the KSC BPC". Net O_2 production (umol/m^2 /s) is plotted against DAP.

OEVOLG2 - " Whole plant net oxygen production for wheat (Triticum sp. cv. Yecora Rojo) in the light in the KSC BPC". Net CO_2 production (umol/m^2 /20 h) is plotted against DAP.

5. Whole plant O_2 consumption for wheat (Triticum sp. cv. Yecora Rojo) in the dark in the KSC BPC. (OUSED, OUSEDG1,OUSEDG2). The minimum O_2 concentration in the dark was subtracted from the maximum O_2 oxygen concentration in the dark, and the difference was used in the following formula:
O_2 consumption (umol/m^2 /4 h) = % oxygen/235 min. * 530 L/% * 1 mol/22.4L * 273/(273 + °C) * 1 min./60s * 1/10m^2 * 1,000,000 umol/mol.
Note: O_2 measurements did not begin until 41 DAP.

Graphs

OUSEDG1 - "Whole plant net O_2 consumption for wheat (Triticum sp. cv. Yecora Rojo) in the dark in the KSC BPC". O_2 consumption (umol/m^2 /s) is plotted against DAP.

OUSEDG2 - "Whole plant net O_2 consumption for wheat (Triticum sp. cv. Yecora Rojo) in the dark in the KSC BPC". O_2 consumption (mol/m^2 /4 h) is plotted against DAP.

6. Whole plant O_2 production for wheat for a twenty hour light and four hour dark cycle for wheat (Triticum sp. cv. Yecora Rojo) in the KSC BPC. (OEVOT, OEVOTG1,OEVOTG2). These values

were derived from O_2 production in the light (spreadsheet 4) and O_2 consumption in the dark (spreadsheet 5) through linking. O_2 consumption during the dark cycle was subtracted from O_2 production during the light cycle to determine O_2 production per twenty four hour cycle (in mol/m^2 /24 h). Cumulative oxygen production (mol/m^2) was also calculated.
Note: O_2 measurements did not begin until 41 DAP.

Graphs

OEVOTG1 - "Whole plant net O_2 production per twenty hour light and four hour dark cycle for wheat (Triticum sp. cv. Yecora Rojo) in the KSC BPC". Cumulative O_2 production (mol/m^2) is plotted against DAP.

OEVOTG2 - "Whole plant oxygen production per twenty hour light and four hour dark cycle for wheat (Triticum sp. cv. Yecora Rojo) in the KSC BPC". O_2 production per twenty four hour cycle (mol/m^2 /24 h) is plotted against DAP.

7. Whole plant transpiration for wheat (Triticum sp. cv. Yecora Rojo) in the light in the KSC BPC. (WUSEL, WUSELG1,WUSELG2). Water from evapotranspiration was collected and measurements were obtained. The minimum amount of condensate in the light from the maximum amount of condensate in the light was used in the following formula:
Transpiration (umol/m^2 /s) = Liter water/1200 minutes * 1000g/L * 1 mol/18.0 g water * 1 min/60s * 1/10m^2 * 1,000,000 umol/mol.

Graphs

WUSELG1 - "Whole plant transpiration for wheat (Triticum sp. c.v. Yecora Rojo) in the light in the KSC BPC". Transpiration (umol/m^2 /s) is plotted against DAP.

WUSELG2 - "Whole plant transpiration for wheat (Triticum sp. cv. Yecora Rojo) in the light in the KSC BPC". Transpiration (mol/m^2 /20 h) is plotted against DAP.

8. Whole plant transpiration for wheat (Triticum sp. cv. Yecora Rojo) in the dark in the KSC BPC. (WUSED, WUSEDG1, WUSEDG2). The minimum amount of condensate in the dark (in liters) was subtracted from the maximum amount of condensate in the dark and the difference was used in the following formula:
Transpiration (umol/m^2 /s) = Liter water/240 minutes * 1000g/L * 1 mol/18.0 g water * 1 min./60s * 1/10m^2 *1,000,000 umol/mol.

Graphs

WUSEDG1 - "Whole plant transpiration for wheat (Triticum sp. cv. Yecora Rojo) in the dark in the KSC BPC". Transpiration (umol/m^2 /s) is plotted against DAP.

WUSEDG2 - "Whole plant transpiration for wheat (Triticum sp. cv. Yecora Rojo) in the dark in the KSC BPC". Transpiration (mol/m^2 /4 h) is plotted against DAP.

9. Whole plant transpiration per twenty hour light and four hour dark cycle for wheat (Triticum sp. cv. Yecora Rojo) in the KSC BPC. (WUSET, WUSETG1,WUSETG2). These values were derived from transpiration in the light (spreadsheet 7) and transpiration in the dark (spreadsheet 8) through linkage. Values from the transpiration in the light (mol/m^2 /20 h) and transpiration in the dark (mol/m^2 /4 h) were summed to determine transpiration per twenty four hour cycle (mol/ m^2 /24 h). Cumulative transpiration (mol/m^2) value was also calculated.

Graphs

WUSETG1 - "Whole plant transpiration per twenty hour light and four hour dark cycle for wheat (Triticum sp. cv. Yecora Rojo) in the KSC BPC". Cumulative transpiration (mol/m^2) is plotted against DAP.

WUSETG2 - "Whole plant transpiration per twenty hour light and four hour dark cycle for wheat (Triticum sp. cv. Yecora Rojo) in the KSC BPC". Transpiration per twenty four hour cycle (mol/m^2 /24 h) is plotted against DAP.

10. Whole plant nitrogen uptake for wheat (Triticum sp. cv. Yecora Rojo) in the KSC BPC. (NUSET, NUSETG1, NUSETG2, NUSETG3, NUSETG4, NUESTG5,NUSETG6, NUSETG7). Nitrogen was added to the system in nitrate form through daily nutrient and nitric acid additions. Nitrate concentration in the nutrient solution was .063 M and nitric acid was .39 M. The amount of solution added (either nutrient solution or nitric acid) was obtained and used in one of the following two formulas:
For nutrient solution - 0.39 M N * liters added * 1/1440 mins. * 1 min/60s * 1/10m^2 * 1,000,000 umol/mol = NO_3^- from nutrient solution (umol/m^2 /s).
For nitric acid - 0.063 M N * liters added * 1/1440 mins. * 1min/60s * 1/10m^2 * 1,000,000 umol/mol = NO_3^- from nitric acid (umol/m^2 /s).
The results of the previous two calculations were summed to obtain the total nitrogen uptake (umol/m^2 /s and mol/m^2 /24 h) for a twenty four hour cycle. Cumulative nitrogen uptake (mol/m^2) was also calculated for an 83 day cycle.

Graphs

NUSETG1 - "Whole plant nitrogen uptake for wheat (Triticum sp. cv. Yecora Rojo) in the KSC BPC". Total nitrogen uptake (umol/m^2 /s) is plotted against DAP.

NUSETG2 - "Whole plant nitrogen uptake for wheat (Triticum sp. cv. Yecora Rojo) in the KSC BPC". Total nitrogen uptake (mol/m^2 /24 h) is plotted against DAP.

NUSETG3 - "Whole plant nitrogen uptake for wheat (Triticum sp. cv. Yecora Rojo) in the KSC BPC". Cumulative nitrogen uptake (mol/m^2) is plotted against DAP.

NUSETG4 - "Whole plant nitrogen uptake for wheat (Triticum sp. cv. Yecora Rojo) in the KSC BPC". Nitrogen uptake by nutrient solution addition (umol/m^2 /s) is plotted against DAP.

NUSETG5 - "Whole plant nitrogen uptake for wheat (Triticum sp. cv. Yecora Rojo) in the KSC BPC". Nitrogen uptake by nutrient solution addition (mol/m^2 /24 h) is plotted against DAP.

NUSETG6 - "Whole plant nitrogen uptake for wheat (Triticum sp. cv. Yecora Rojo) in the KSC BPC". Nitrogen uptake by nitric acid addition (umol/m^2 /s) is plotted against DAP.

NUSETG7 - "Whole plant nitrogen uptake for wheat (Triticum sp. cv. Yecora Rojo) in the KSC BPC". Nitrogen uptake by nitric acid addition (mol/m^2 /24 h) is plotted against DAP .

11. Whole plant nitrogen uptake for wheat (Triticum sp. cv. Yecora Rojo) during the light cycle in the KSC BPC. (TEMPLAT1). Template for input of data from nitrogen uptake studies; will calculate instantaneous (umol/m^2/s) and light (mol/m^2/20 h) cycle information for plant nitrogen uptake.

12. Whole plant nitrogen uptake for wheat (Triticum sp. cv. Yecora Rojo) during the dark cycle in the KSC BPC. (TEMPLAT2). Template for input of data from nitrogen uptake studies; will calculate instantaneous (umol/m2/s) and dark (mol/m2/4 h) cycle information for plant nitrogen uptake.

13. Whole plant water use efficiency for wheat (Triticum sp. cv. Yecora Rojo) in the KSC BPC. (WUE, WUEG1, WUEG2). These values were derived from CO_2 fixed per twenty hour light and four hour dark cycle (spreadsheet 3) and transpiration per twenty hour light and four hour dark cycle (spreadsheet 9) through linking. Values from net CO_2 assimilation in the light (mol/m^2 /20 h) were divided by values from the transpiration in the light (mol/m^2 /20 h), to obtain water use efficiency (WUE) for a twenty hour light cycle. Similarly, values from net CO_2 fixed per twenty four hour cycle (mol/m^2 /24 h) were divided by values from the transpiration per twenty four hour cycle (mol/m^2 /24 h) to determine WUE for a twenty hour light and four hour dark cycle.

Graphs

WUEG1 - "Whole plant water use efficiency for wheat (Triticum sp. cv. Yecora Rojo) in the KSC BPC". WUE for a twenty hour light cycle (mmol CO_2 fixed/mol H_2O transpired) is plotted against DAP.

WUEG2 - "Whole plant water use efficiency for wheat (Triticum sp. cv. Yecora Rojo) in the KSC BPC". WUE for a twenty hour light and four hour dark cycle (mmol CO_2 fixed / mol H_2O

transpired) is plotted against DAP.

14. Whole plant NUE for wheat, (Triticum sp. cv. Yecora Rojo) for a twenty hour light and four hour dark cycle in the KSC BPC. (NUE, NUEG1) These values were derived from CO_2 fixed per twenty hour light and four hour dark cycle (spreadsheet 3) and nitrogen uptake (spreadsheet 10) through linking. Values from net CO_2 fixed per twenty four hour cycle (mol/m^2/24 h) were divided by values from the total nitrogen uptake (mol/m^2/24 h) to obtain nitrogen use efficiency (NUE).

NUEG1 - "Whole plant NUE for wheat (Triticum sp. cv. Yecora Rojo) for a twenty hour light and four hour dark cycle." Nitrogen use efficiency (mol CO_2 fixed/mol NO_3^- taken up) was plotted against DAP.

15. Whole plant respiratory quotient for wheat (Triticum sp. cv. Yecora Rojo) in the KSC BPC. (RQ, RQG1) These values were derived from CO_2 fixed per twenty hour light and four hour dark cycle (spreadsheet 3) and O_2 production for a twenty hour light and four hour dark cycle (spreadsheet 6). Values from CO_2 evolution per 4 hour dark cycle (mol/m^2/4 h) were divided by O_2 consumption per four hour dark cycle (mol/m^2/4 h) to obtain the respiratory quotient (RQ) during the dark cycle.
Note: O_2 measurements did not begin until 41 DAP.
Graphs
RQG1 - "Whole plant RQ for wheat (Triticum sp. cv. Yecora Rojo) in the KSC BPC." RQ per four hour dark cycle (mol CO_2 evolved/mol O_2 consumed) was plotted against DAP.

16. Whole plant photosynthetic quotient (PSQ) per twenty hour light cycle for wheat (Triticum sp. cv. Yecora Rojo) in the KSC BPC. (PSQ, PSQG1) These values were derived from CO_2 fixed per twenty hour light and four hour dark cycle (spreadsheet 3) and O_2 production for a twenty hour light and four hour dark cycle (spreadsheet 6). Values from CO_2 assimilated per twenty hour light cycle (mol/m^2/20 h) were divided by O_2 evolved per twenty hour light cycle (mol/m^2/20 h) to obtain the photosynthetic quotient during the light cycle.
Note: O_2 measurements did not begin until 41 DAP.
Graphs
PSQG1 - "Whole plant photosynthetic quotient (PSQ) per twenty hour light cycle for wheat (Triticum sp. cv. Yecora Rojo) in the KSC BPC." PSQ per 20 h light cycle (CO_2 assim./O_2 evolved) was plotted against DAP.

The spreadsheets are set up on a two tier linked system.

The following example will illustrate how to utilize a spreadsheet. It will include where to put the input data on the spreadsheet, what type of results to expect, and how a linked spreadsheet will react. The spreadsheets used for this example are "Whole plant net CO_2 assimilation for wheat (Triticum sp. cv. Yecora Rojo) in the light in the KSC BPC" (spreadsheet 1), "Whole plant CO_2 fixed per twenty hour light and four hour dark cycle for wheat (Triticum sp. cv. Yecora Rojo) in the KSC BPC" (spreadsheet 3), and "Whole plant water use efficiency for wheat (Triticum sp. cv. Yecora Rojo) in the KSC BPC" (spreadsheet 11).

Maximum CO_2 concentration (in liters) (spreadsheet 1) is entered into column B12. CO_2 minimum is entered into column D12. Temperature maximum and minimum values are entered into the temperature columns on the far right of the spreadsheet. (Temperature data will only have to be entered for those spreadsheets concerned with gas exchange characteristics.) After the data are entered, CO_2 assimilation in umol/m^2/s, mol/m^2/20 h and cumulative CO_2 assimilation results will be calculated automatically. Also the linked spreadsheets will be updated with the information just created. In this example, the linked spreadsheets are "Whole plant CO_2 fixed per twenty hour light and four hour dark cycle for wheat (Triticum sp. cv. Yecora Rojo) in the KSC BPC" (spreadsheet 3), and "Whole plant water use efficiency for wheat (Triticum sp. cv. Yecora Rojo) in the KSC BPC" (spreadsheet 11). When a linked spreadsheet is opened, the message "Link options: Load Supporting, Update Refs, and None will appear. Choose Update Refs to properly update the linked cell references.