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Tomato plants' growth observations obtained from multiple sources in a production-like setting

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Abstract: This dataset contains observations of tomato growth in a production-like setting, at research greenhouses. Two tomato plants in each of three growth cycles were continuously monitored: pictures were taken every other day from above and from a side view, while a weighting system was used to record changes in weight of the plant and of water in the substrate. Additionally, other plants in the environment were subjected to destructive analysis, in general every two weeks, to quantify aspects of growth that required destructive measurements, such as dry weight and plant leaf area. These records are also included in the dataset, including the scans of digitized leaves. Plant samples destined to destructive measurements also had their pictures taken before removal. In total, 618 photos of monitored and removed plants were annotated, and masks of leaf, fruit and mature fruit areas in pictures are also provided. The dataset also includes measurements of photosynthetically active radiation and air temperature recorded inside the greenhouses by two different sets of sensors during the growth cycles. The dataset allows for applications regarding growth monitoring, simulation modeling, and computer vision tasks.

Keywords: Protected growth, Computer vision, Image segmentation, Greenhouse, Digital agriculture

1 ORIGINAL PURPOSE: This dataset was obtained within a project aimed at performing data assimilation in a tomato growth model. A crop model was calibrated with the destructive observations from plants within the protected environment and simulations were performed with environmental data from inside the greenhouse. The estimates obtained for each state variable were compared to the estimates from the same crop model without calibration but that were updated using the non-destructive observations of two continuously monitored plants. To establish a relationship between the state variables simulated by the model and the monitored observations, observation models were obtained from the destructive observations of the plants that were also used in the calibration, along with non-destructive observations from the same plants. The environmental observations consisted in data obtained by low-cost sensors as well as by scientific-grade sensors, so that the quality of simulations performed with both set of sensors could be compared. All information related to the project can be found in its Zenodo versioned repository (Oliveira 2023). All data described in the paper is included in an online repository found at <https://doi.org/10.25824/redu/EP4NGO> (Oliveira et al. 2021).

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2 DATA DESCRIPTION: The experiments were conducted in research greenhouses at the School of Agricultural Engineering of the University of Campinas (22° 49' 06" S, 47° 03' 40" W, 635 m altitude). Four cycles of minitomatoes growth were performed (Table 1).

Table 1. Summary of growth cycles for data gathering.

Growth Cycle	Cultivar	Start date	End date
Cycle 0	Seminis – DRC 564	11/jan/2019	04/apr/2019
Cycle 1	Fercam – Milla	12/jul/2019	28/oct/2019
Cycle 2	Feltrin – Carolina	05/nov/2020	12/feb/2021
Cycle 3	Seminis – DRC 564	16/mar/2021	11/jun/2021

Environmental data includes measurements of relative humidity, air temperature, photosynthetically active radiation, and luminosity from inside the greenhouse environment. Growth data from destructive analysis comprises scans of leaf area and aboveground fresh and dry mass separated into leaves, stem, green fruits, and mature fruits. Non-destructive growth observations include pictures taken from top-down and lateral views of the two monitored plants and of plants subjected to destructive analysis, as well as continuous weight monitoring from the monitored plants. Manually annotated masks of the pictures taken highlighting leaves, green fruits, and mature fruits, and preprocessing scripts used for the studies are also provided. All observations are detailed in the following subsections and a summary table (Table 5) is provided at the end of the section.

2.1 Environmental observations: Sensors used for gathering environmental data were characterized as scientific grade (SG) and low-cost (LC) (Table 2). The scientific grade sensors for temperature and relative humidity corresponded to SHT75 transducers protected by porous capsules which, by their turn, were protected by polyvinylchloride (PVC) tubes, with downstream fans in the bottom, coated with aluminum foil. The sensors were installed in a hardware platform for wireless sensor networks (Raspberry BE900), with daily backup. For photosynthetically active radiation (PAR), the scientific grade sensors corresponded to quantum sensors Licor LI-190SA with a datalogger Licor LI-1400. Low-cost sensors were connected to Raspberry Pi model B computers. The computers were also protected by PVC tubes.

Table 2. Sensors used for monitoring the environment and frequency of data acquisition.

Variable	Type	Model	Frequency
Air temperature	SG	SHT75	5 minutes
Relative humidity	SG	SHT75	5 minutes
Air temperature	LC	DHT22	5 minutes
Relative humidity	LC	DHT22	5 minutes
Substrate moisture	SG	EC-05	10 minutes
Luminosity	LC	BH1750	5 minutes
Photosynthetically active radiation	SG	LI190SA	15 minutes

Each sensor node was positioned close to one of the monitored plants and each node included two sensors of the same type and for the same variable for redundancy, except for radiation and luminosity, which only include one of each type. As there were differences in the experimental set-ups, they are separately detailed as follows. Sensors were positioned as in Figure 1 for Cycles 0 to 2 and as in Figure 2 for Cycle 3. They are referred to as node 1 for sensors adjacent to Plant 1 and node 2, for those adjacent to Plant 2.

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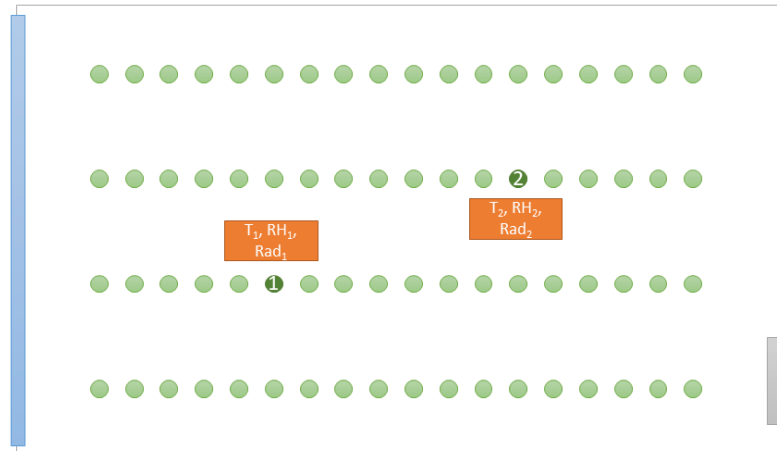


Figure 1. Positions of sensors of temperature (T), relative humidity (RH), and PAR and luminosity (Rad) during growth cycles 0 to 2. Gray rectangle refers to the door and blue rectangle refers to the wet pad. Green circles correspond to the vases. Monitored plants 1 and 2 are highlighted in dark green. Distances are at scale.

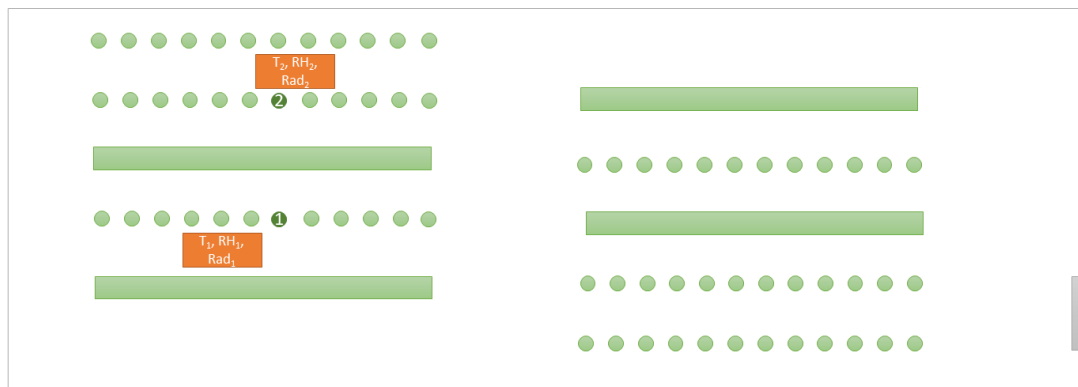


Figure 2. Positions of sensors of temperature (T), relative humidity (RH), and PAR and luminosity (Rad) during growth cycle 3. Gray rectangle refers to the door and green rectangles refer to tomatoes grown using different management practices. Green circles correspond to the vases. Monitored plants 1 and 2 are highlighted in dark green. Distances are at scale.

2.2 Growth observations: In each growth cycle, two plants were continuously monitored through the weighting system and by two cameras, positioned above the plant and in an adjacent row. Continuous weight monitoring used force transducers HBM S2M with nominal force of 10 N (0.02 % accuracy) and stored in a data logger PMX WGX002, measure card PX455, and to the pictures taken from side (Figure 3, center panel) and top-down (Figure 4, center panel) views, with fixed Raspberry Pi Camera Modules v2, connected to Raspberry Pi Zero computers. The center panel of Figure 3 shows the camera above the plant (marked in magenta) and the load cell (marked in blue).

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Figure 3. Example of image captured by fixed camera in an adjacent row, along with respective annotation. Reference is marked in cyan.



Figure 4. Example of image captured by fixed camera above the plant, along with respective annotation. Reference is marked in cyan.

Every one to three weeks, three non-monitored plants were removed and used for destructive analysis. These plants are identified by an ID number included in the filename for pictures and in the spreadsheets for other types of data. Keeping guard plants of the destructed plants was not always possible. Before being removed, plants destined for analysis were first photographed from above (Figure 5, center panel) and laterally (Figure 6, center panel) with a smartphone camera. Plant material was weighted immediately after removal, to determine the fresh mass, and after drying for four days or until constant weight was reached, to determine the dry mass. Leaves, stem and green and mature fruits were separated for weighting. The number of nodes was also counted for Cycles 2 and 3. This data is recorded on spreadsheets separated by growth cycle. After being weighted, while fresh, leaves were digitized with a scanner (Figure 7). Digitization included a reference of known dimensions (Table 4).

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Figure 5. Example of image captured by a smartphone, from a plant destined to destructive analysis, from the top-down angle, along with respective annotation. Reference is marked in cyan.



Figure 6. Example of image captured by a smartphone, from a plant destined to destructive analysis, from a lateral angle, along with respective annotation. The reference is marked in cyan.



Figure 7. Example (resized) of leaf scans from Cycle 1 (left) and Cycle 3 (right), including the references of dimensions that were used to calculate the area corresponding to leaf in the picture.

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Figure 3 to Figure 6 are compositions that show, on the center, the photo as captured, on the left, the photo with overlaid annotated labels, and on the right, only the labels, with a dark background included merely to increase contrast, being transparent in original file. We stress that although the examples of annotations are showed along with the original images in the left panel, these are provided separately, in different files.

Labeling of the plant organs in the images was done manually, using the software GIMP. Leaves, green fruits, and mature fruits were colored differently, in green, yellow and red, respectively. Only areas in which there was confidence the organ corresponded to the correct plant were marked, which entailed that if there was uncertainty or occlusion, the area was not marked. It should be noted that even as a lot of care was taken in the annotation process, often with two persons responsible for each image, it cannot be guaranteed that annotation was perfect, especially for green areas. In total, 618 different pictures of tomato plants were annotated (Table 3).

Table 3. Number of pictures annotated in each growth cycle.

Growth cycle	Monitoring pictures	Calibration pictures
Cycle 01	170	53
Cycle 02	167	44
Cycle 03	148	36

Most images include references of size. For fixed cameras, when the reference was obstructed by the plant, reference values from previous pictures can be used, as the distance between camera and plant remains constant. Table 4 presents the references and their colors. For digitized leaves, the color refers to the reference itself, while for photos, to the color of the annotation. Area was used as a way of checking the conversion.

Table 4. Reference size information.

Source	Growth cycle	Color of annotation or of reference	Type of reference (line/rectangle)	Value of the reference
Scan	1	Black	Rectangle	Length: 5.7 cm; Area: 50.73 cm ²
Scan	2, 3	Pink	Rectangle	Length: 5 cm; Area: 19 cm ²
Photo – fixed camera – above view	1	Magenta	Line	Length: 31 cm
Photo – fixed camera – above view	2, 3	Cyan	Rectangle	Length: 29.7 cm; Area: 623.7 cm ²
Photo – fixed camera – above view	2, 3	Magenta	Rectangle	Length: 3,0 cm; Area: 9 cm ²
Photo – fixed camera – lateral view	1	Magenta	Line	Length: 27 cm
Photo – fixed camera – lateral view	2, 3	Cyan	Rectangle	Length: 29.7 cm; Area: 623.7 cm ²
Photo – smartphone – above view	1	Red	Line	Length: 4 cm
Photo – smartphone – above view	2, 3	Cyan	Rectangle	Length: 29.7 cm; Area: 623.7 cm ²
Photo – smartphone – above view	2, 3	Magenta	Rectangle	Length: 3,0 cm; Area: 9 cm ²
Photo – smartphone – lateral view	1	Magenta	Rectangle	Length: 8.9 cm; Area: 50.73 cm ²
Photo – smartphone – lateral view	2, 3	Cyan	Rectangle	Length: 29.7 cm; Area: 623.7 cm ²

Data is provided as raw as possible and the data repository includes the scripts used to process the observations to obtain time-series without missing data, for environmental observations, and of quantified areas in images, for pictures and masks. Scripts include comments to aid in processing the

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data accounting for particularities in gathering. Table 5 summarizes data as provided in the repository, including formats and specific organization details. Each group of files is provided in the repository as ".zip", but they had their extension renamed to ".zipfile" because of restrictions of the repository. To access the content, the extension must be rename to ".zip".

Table 5. Summary of dataset files.

File group	File description	File format	Number of files
Destructive biomass	Records of weight (fresh and dry) from tomato plants, separated in leaf, stem, and green and mature fruits for all growth cycles. Cycle 02 includes number of nodes and Cycle 03, number of nodes and plant height. Files separated by growth cycle. Different variables are presented in different tabs.	.xlsx	3 .xlsx files
Leaf area index (LAI) data	Leaf scans. The ID of each plant is indicated in the name of the file, as is the date of the analysis. For Cycle 01, size reference is a black rectangle (length 5.7 cm and area 50.73 cm ²). For Cycle 02 and Cycle 03, size reference is a pink post-it (length 5 cm and area 19 cm ²).	.png	6 .zip files
PAR	Photosynthetically active radiation obtained by quantum sensors Licor LI-190SA with a datalogger Licor LI-1400, using range from 400 to 700 nm.	.txt	1 .zip file
Pixel-level plant organs masks	Annotations of leaves and fruits in pictures taken of plants used in destructive analyses and of monitored plants. Size references are detailed in a text file inside the zip.	.png	1 .zip file
Plants' photos	Photos taken of plants used in destructive analyses and continuously monitored. Size references are described on a text file within the masks' .zip file. Most photos from monitoring cameras are .png files, but some are .jpg. Photos of plants used in destructive analyses are .jpg files.	.jpg, .png	1 .zip file
Scripts	Scripts used in the processing of raw data.	.py, .R	1 .zip file
Substrate moisture	Substrate moisture measured in mV with EC-05 sensors.	.csv	1 .zip file
Temperature, Relative Humidity - Transdutors	Air temperature and relative humidity obtained with SHT75 transducers protected by porous capsules.	.csv	1 .zip file
Temperature, Relative Humidity, Luminosity - Pi	Air temperature and relative humidity obtained with DHT22 sensors and luminosity obtained with BH1750 sensors. All sensors were connected to Raspberry Pi model B computers.	.csv	1 .zip file
Weight	Weight data for each minute during growth cycles for each of the two monitored plants. Retrieved using used force transducers HBM S2M with nominal force of 10 N (0.02 % accuracy) and stored in a data logger PMX WG002, measure card PX455 Measurements in Newton [N].	.csv	1 .zip file

3 GROWTH INFRASTRUCTURE:

3.1 Cycle 0: This growth cycle was conducted in the same setting of Cycles 1 and 2 described below, but as monitoring was not completely established from the beginning, it was treated as a pilot to test the installation of sensors, the irrigation system and to obtain experience in growing the plants.

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3.2 Cycle 1 and Cycle 2: These growth cycles were conducted in a research greenhouse with 6.4 m of width, 10.98 m of length, 3.0 m of height from the floor to the gutter and 4.5 m of total height. The greenhouse has a gable roof covered with low density polyethylene of 150 μm width with light diffuser and anti-UV treatment. The ridge of the greenhouse section was oriented North-South. The section was only bounded to the East, by another greenhouse of the same dimensions. Its cooling system consisted of a pad-fan system, activated by a scheduling device. The South-facing side wall was covered with an evaporative cooling pad and an insect screen. Other walls were covered with the same plastic as the cover. Seedlings provided by commercial units were transplanted to polyethylene pots (8 L) filled with coconut fiber approximately 30 days after seeding. They were distanced 1.5 m x 0.5 m (density of 1.33 plants m^{-2}). Figure 8 shows the overall disposition of pots.



Figure 8. Disposition of the pots in the first research greenhouse, used for cycles one and two.

3.3 Cycle 3: The experiment was conducted in a research greenhouse with dimensions 6.4 m of width, 18 m of length and 3.0 m of height from the floor to the gutter. It has a gable roof covered with low density polyethylene, light diffuser with 150 μm width and anti-UV treatment. The ridge of the greenhouse section was oriented North-South. The section was not bounded in any directions. All walls were covered by an insect screen. Locally cultivated seedlings were transplanted to polyethylene pots (8 L), filled with coconut fiber, distanced 0.9 m x 0.5 m (2.22 plants m^{-2}) approximately 30 days after seeding. Lines of pots were intercalated with lines of nutrient film hydroponic growth (Nutrient Film Technique – NFT), which were not used in this project. Figure 9 shows the environment. Cycle 3 also included application of neem oil, Bordeaux mixture and lime-sulfur prevent the occurrence of pests and an abamectin-based pesticide (Syngenta's VERTIMEC® 18 EC) after appearance of rust mite.

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Figure 9. Disposition of the pots in the second research greenhouse used, for cycle three.

4 MANAGEMENT PRACTICES: All cycles consisted of approximately 100 days and in all of them plants had reached the highest wire, when the growth was stopped. Management practices (thinning, staking, pruning, pest management and diseases) overall followed the recommendations for hydroponic growth in (Alvarenga 2013). Only one stem was grown per pot. Removal of side shoots happened once to three times a week. Leaves were pruned only when their senescence was dominant. Harvest happened when the whole truss was mature. Irrigation consisted of fertigation through a drip irrigation system and while the nutritive solution mainly followed the recommendations in (Pires et al. 2011), concentrations were changed according to plants' responses. In Cycles 0 and 1, irrigation length used fixed time through the cycle, but in Cycle 1 the duration proved insufficient by the end of the cycle. In Cycles 2 and 3, total irrigation time was defined as that which would not allow for deficit by the end of the day, to minimize mass fluctuations from one day to the following caused by variation in irrigations. Cycle 1 showed water deficits throughout growth. Cycle 2 suffered with excessive nitrogen fertilization followed by rust mite while Cycle 3 more closely resembled full irrigation and fertilization.

5 AUTHORS' CONTRIBUTIONS **Monique Oliveira:** Conceptualization, Methodology, Software, Investigation, Data Curation, Writing - Original Draft; **Rafaela Amaro:** Investigation, Writing - Review & Editing; **Henrique Pescarini:** Investigation; Writing - Review & Editing; **Luiz Rodrigues:** Writing - Review & Editing, Supervision, Funding acquisition

6 CONFLICT OF INTEREST STATEMENT The authors declare that there is no conflict of interest.

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