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Simulation of the leaf area index from thermal units of the cauliflower (*Brassica oleracea var*. Botrytis) crop

Simulación del índice de área foliar a partir de unidades térmica del cultivo de coliflor (*Brassica oleracea var.* Botrytis)

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Abstract

In the present research, the leaf area index (LAI) of the cauliflower crop was modeled, applying the thermal time concept, which was obtained from the threshold and optimal temperatures using a beta function, and then correlating it with the LAI using a growth function. The experimental design was a divided plot design where the large plots corresponded to 4 fertilization doses and the small plots to three planting densities and 4 repetitions. The leaf area index (LAI) was measured on a flat surface, using photographs of the leaves taken by a mobile device and analyzing them with the software (Image J) each photograph was scaled with a 5 cm reference line. For calibration, data corresponding to a high density (30,000 plants/ha) were used, finding the following adjustment statistics: bias (0.0047), RMSE (0.1152 m^2 m^{-2}), and EF (0.994). In the validation, data collected at a low density (26,000 plants/ha) were used and the following adjustment statistics were found: BIAS (-0.3541), RMSE (0.6774 m^2 m^{-2}) and EF (0.8358).

Thermal time, heat units, Growing degree days

Resumen

En la presente investigación se modeló el índice de área foliar (IAF) del cultivo de la coliflor, aplicando el concepto tiempo térmico, que se obtuvo a partir de las temperaturas umbrales y óptimas mediante una función beta, para después correlacionarla con el IAF mediante una función de crecimiento. El diseño experimental fue un diseño en parcelas divididas donde las parcelas grandes correspondieron a 4 dosis de fertilización y las parcelas pequeñas a tres densidades de plantación y 4 repeticiones. El índice de área foliar (LAI) se midió sobre una superficie plana, mediante fotografías de las hojas tomadas por un dispositivo móvil y analizándolos con el software (Image J) cada fotografía se escaló con una línea de referencia de 5 cm. Para la calibración se emplearon datos correspondientes a una densidad alta (30,000 plantas/ha), encontrándose los siguientes estadísticos de ajustes: sesgo (0.0047), RMSE (0.1152 m^2 m^{-2}), y EF (0.994). En la validación se emplearon datos recabados en una densidad baja (26,000 plantas/ha) y se encontraron los siguientes estadísticos de ajuste: BIAS (-0.3541), RMSE (0.6774 m^2 m^{-2}) y EF (0.8358).

Tiempo térmico, Unidades calor, Grados días de desarrollo

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Introduction

Cauliflower is a biennial plant belonging to the Cruciferae family, genus *Brassica*, species *Brassica oleracea* L., var botrytis, from which the predominantly white inflorescence, called pella, which forms at the base of the stem of the plant, is used (Fernández de Sousa & García González de Lena, 2016). Nationally, about 2,500 ha are established per year with an average yield of 19 t/ha. The main producing states in Mexico are: Hidalgo, Guanajuato and Aguascalientes (Zamora, 2016).

Temperature is one of the main driving forces for crop growth and development and several phenological stages are manifested through its development (Salazar Gutierrez, 2006; Salazar-Gutierrez & Chaves Cordoba, 2013). Cauliflower plants require more specific environmental conditions than other types of cabbage; their cultivation in an unsuitable environment requires climate modifications to meet the requirements of the different growth stages of the plant (Elahi et al., 2015).

Considering that leaves are responsible for intercepting radiation, a relationship has been found between relative light intensity and cumulative leaf area index, with light being exponentially extinguished as a function of increasing leaf area (Alberto et al., 2008). One of the most widely used methods is the accumulation of mean daily temperature above a base temperature (Tb), known as thermal time, growth or development degree days (DDD), heat units (Ángel López et al., 2010; Ruiz Corral et al., 2002). or physiological time, and is defined as the number of degree days required to complete a given developmental process or phenological stage (Trudgill et al., 2005). Agroclimatic models have been developed that relate the different phenological phases to the thermal time or physiological time of the plant (Parra Coronado et al., 2015). The objective of the present work was to calibrate and validate a mathematical model that allows estimating the IAF dynamics based on thermal time for two cauliflower crop densities.

Materials and Methods

Location of the experiment

The experimental site was located in Xochimilco, municipality of Tecamachalco in the state of Puebla, with coordinates 18º 50' 34.7" North latitude and 97º 44' 40.4" West longitude. A cauliflower (Brassica Oleracea L.) open field crop was established on the land of a cooperating farmer in the aforementioned locality. With the help of agricultural machinery and implements, the fallow was carried out, and the land was furrowed twice, followed by the formation of the cultivation beds, which were 0.9 m apart and approximately 100 m long. The characteristics of the irrigation tape used were as follows: 16 mm ID, 6 mil gauge, 10 cm spacing, 1 lph @ 0.55 BAR, 3,050 m length, Rivulis® brand. The tape was placed only in a single row and fastened with wooden stakes at the end of each planting bed.

Experimental design

The experimental plot consisted of a length of one hundred metres long by twenty-five metres wide, the experiment dealt with four treatments, with different doses of fertilisation (F1, F2, F3, F4). The experimental unit was then divided into four parts, each of these parts was called a "replicate", so there were four replicates (R1, R2, R3, R4). Each repetition in the same way will be divided into twelve parts, which were called "densities" these had a length of 8 meters long by 5. 4 metres wide, three densities were considered: D1= 25,000 plants/ha (43 cm separation between plants), D2= 28,000 plants/ha (40 cm), D3= 30,000 plants/ha (37 cm), in a horizontal way the densities were represented, and in a vertical way the treatments (F1,F2,F3,F4), obtaining the following combinations: (F1xD1, F1xD2, F1xD3), (F2xD1, F2xD2, F2xD3), (F3xD1,F3xD2, F3xD3) and (F4xD1,F4xD2, F4xD3), with 4 replications, each experimental unit had a width of 5. 4 m wide and 8 m long (area of 43.2 m^2). Of these combinations, only the combinations (F3xD1 and F3D3), consisting of a medium-high fertilisation rate and low and high densities, were considered for modelling the leaf area index. Fertilisation was applied in three split applications: bottom application (33.3%), one month after transplanting (33.3%) and one and a half months after transplanting (33.3%).

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Crop variables

The leaf area index (LAI) was measured in the laboratory using a flat surface on which a five centimetre reference line was marked and then used to support the scaling of the images, which was applied to each photograph of the leaves using the software (Image J). Each plant had to be carefully detached. These leaves were placed on a flat surface, in a strategic manner, in such a way as to cover the exposed area of each leaf for each photograph taken, as well as with their respective identification label. For this purpose, a vertical base (tripod) was installed to support the camera for the capture of the images.

Temperature measurement

During the cultivation cycle, a HOBO climatic station (HOBO Onset Bourne, Massachusetts, USA) was installed in which the air temperature was recorded, using a sensor model STM-B-M008 (HOBO, Onset), which was measured every minute and averaged on an hourly basis.

Simulation of leaf area index (LAI)

To simulate this variable, a modification was made to the functions originally used by the HORTSYST model (Martinez-Ruiz 2019 and 2021), so that it could be extended to open field crops, as in the case of the crop under analysis. This variable was obtained by multiplying the (ºC d), obtained with a Gompertz equation, by the planting density (d). For this, the thermal time (, °C) was calculated, applying the beta function (Zhou & Wang, 2018), defined as the relationship between the growth rate and the conditions of the actual, optimum and base temperature. As described below.

$$LAI_{j+1} = LA_j * d \tag{1}$$

$$LA_j = p5 * \exp\left(-\exp\left(p6 - \left(p7 * TT_{j+1}\right)\right)\right) \tag{2}$$

$$TT_{i+1} = \begin{cases} 0; & T_{a,i+1} < T_b \\ \frac{(T_{a,i+1} - T_b)}{(T_o - T_b)} \frac{(T_u - T_{a,i+1})}{(T_u - T_o)}^{\frac{(T_u - T_o)}{(T_u - T_b)}} (T_o - T_b); & T_b \leq T_{a,i+1} \leq T_u \\ 0; & T_u < T_{a,i+1} \end{cases} \tag{3}$$

$$TT_{j+1} = \left[\sum_{i=1}^{24} TT_{i+1}\right]/24 \tag{4}$$

Where, LA_j is the leaf area on the -th day, TT_{i+1}y TT_{j+1} represents thermal time in the hour $i+1$ y of day $j+1$ next, LAI_{j+1} is the leaf area index of the following day, is the planting density, $T_{a,i+1}$, T_b, T_o, T_u is the air temperature in the next hour, base temperature (T_b=10 ºC), lower optimum temperature and upper optimum temperature, respectively. The parameters $p5$, $p6$ y $p7$ se were estimated during calibration, applying the non-linear least squares method.

This model to predict leaf area index was calibrated at a high density of 30,000 plants/ha and validated for a density of 26,000 plants/ha.

Results and Discussion

Figure 1 shows the average daily air temperature during the cauliflower growing cycle, with a minimum temperature of 12 °C 5 days after transplanting, corresponding to February, a maximum temperature of 25 °C for May and an average temperature of 18 °C. The temperature drop of 12 °C during the growing cycle of cauliflower was observed for the month of May. The temperature drop of 12 °C that was recorded is due to the fact that the month of February belongs to the winter season, therefore, the days are susceptible to sudden changes in temperature, in fact, winter ends 40 days after transplanting and after those days the temperature increase was observed with the onset of spring.

Figure 2 shows the calibration of the simulated LAI with respect to the measured LAI, it can be seen that the simulated curve has an accurate trend with respect to the measured values. On the other hand, Figure 2B shows the 45° line (1:1 line) where the simulated data points are on this line due to the accuracy of the calibration process.

For the validation of the model it can be seen in Figure 2C that the simulated LAI curve with respect to the measured LAI points there is a bias approximately at 70 DAT and 85 DAT, this anomaly can be clearly identified by the 45° line. In Figure 2D the simulated LAI given by the model tends to overestimate with respect to the measured ones. The observed systematic error of the measured LAI may be a cause of a sampling error at the time of plant selection.

For the model studied, the following model fit statistics were found: In the calibration, a value for BIAS of 0.0047, RMSE (0.1152) and EF (0.994) were found, and in the validation of: BIAS (-0.3541), RMSE (0.6774) and EF (0.8358). in the calibration the result close to zero for the BIAS indicator shows that there is no considerable bias and the predicted values are accurate, contrary to the validation in which a negative result was obtained, which indicates that the LAI is being overestimated by the model. For the RMSE indicator in the calibration it resulted in a small value, not so for the validation, however, the value of this statistic is statistically acceptable as it is above 80%. On the other hand, the EF indicator in both calibration and validation both resulted in acceptable values, which indicates that the estimation of the parameters was performed with excellent computational efficiency. This fact is in agreement with what Zhou & Wang, (2018) mentioned that accurate estimates of degree development days (DDD) are important in models that simulate crop growth and for field crop management. Where they found that the use of DDD greatly improved the description and prediction of phenological events compared to other approaches, such as time of year or number of days, especially for describing crop phenology and developmental stage, they found that the use of DDD greatly improved the description and prediction of phenological events compared to other approaches, such as time of year or number of days, especially for describing crop phenology and developmental stage.

On the other hand, Ángel López et al. (2010) mention that phenological models are tools designed to know and predict plant development and they used the Euler method for the simulation of nodes and phenological development of the plant through thermal time. They found a value of RSME = 0.28. Trudgill et al. (2005) proposed a phenological model for feijoa cv. Quimba, in which the base temperature (Tb) is estimated for four different reproductive phenological periods and its duration in terms of DDD, to predict the dates of anthesis, fruit set and harvest. Besides relating leaf area to thermal time, other authors such as Kresnatita et al. (2020) found that leaf area is strongly related to dry weight of cauliflower plants (R2 = 96 and 97 %). The parameter values found during the calibration process were: p5 = 3, p6 = 2.2112 and p7 = 0.0025.

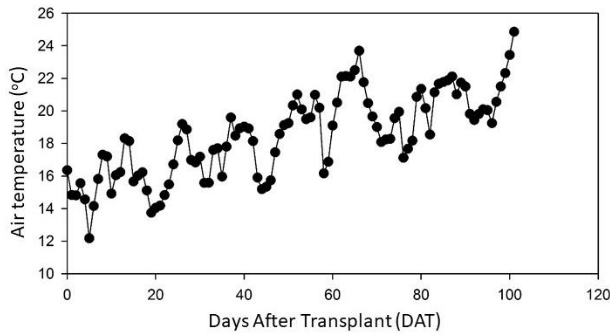

Figure 1 Average air temperature of the experimental site Xochimilco, Puebla

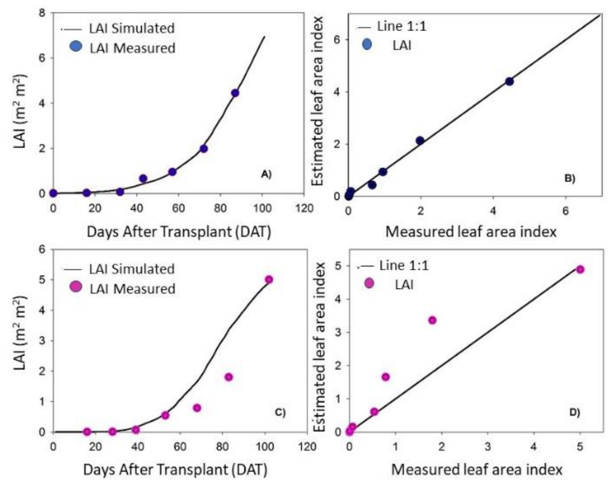

Figure 2 Simulation of leaf area index of cauliflower crop A) calibration, C) validation, B and D) line 1:1

Conclusion

The calibration and validation of the mathematical model presents a good fit for the study conditions, although its evaluation in other locations with different environmental conditions is recommended. Finally, it is important to make sure in each sampling that the selected plants are representative of the whole field, otherwise, the model fit may not be as expected for its application for more general conditions. The thermal time to track phenological stage changes is a fairly accurate and acceptably robust concept.

References

Alberto, C., Alfaro, T., Ramírez Fonseca, A., Farías, E. V., & Corral, A. R. (2008). Arreglo espacial de híbridos de maíz, índice de área foliar y rendimiento * stand arrangement of maize hybrids, leaf area index and seed yield. In *Agricultura Técnica en México* (Vol. 34).

Ángel López, M. M., Chaves, B., Julio Flórez, V. R., & Ruth Salazar, M. (2010). Modelo de aparición de nudos en clavel (Dianthus caryophyllus L.) cv. Delphi cultivado en sustratos. *Agronomía Colombiana*, *28*(1), 47–54.

Elahi, E., Wali, A., Ayub, G., Ahmed, S., Huma, Z., Ahmed, N., & Ehsan Elahi, C. (2015). Response of cauliflower (Brassica oleracea L. botrytis) cultivars to phosphorus levels. *Pure Appl. Biol*, *4*(2), 187–194.

Fernández de Sousa, M., & García González de Lena, G. (2016). *Cultivo de la coliflor*.

Kresnatita, S., Ariffin, Hariyono, D., & Sitawati. (2020). A cauliflower-sweet corn intercropping system in high-temperature conditions. *Revista Chapingo, Serie Horticultura*, *26*(1), 15–27. https://doi.org/10.5154/r.rchsh.2019.09.014

Martínez-Ruiz, A., López-Cruz, I. L., Ruiz-García, A., Pineda-Pineda, J., & Prado-Hernández, J. V. (2019). HortSyst: A dynamic model to predict growth, nitrogen uptake, and transpiration of greenhouse tomatoes. Chilean journal of agricultural research, 79(1), 89-102.

Martínez-Ruiz, A., Ruiz-García, A., Prado-Hernández, J. V., López-Cruz, I. L., Valencia-Islas, J. O., & Pineda-Pineda, J. (2021). Global sensitivity analysis and calibration by differential evolution algorithm of HORTSYST crop model for fertigation management. Water, 13(5), 610.

Parra Coronado, A., Fischer, G., & Chaves Cordoba, B. (2015). Tiempo térmico para estados fenológicos reproductivos de la feijoa (Acca sellowiana (O. Berg) Burret). *Acta Biologica Colombiana*, *20*(1), 153–162. https://doi.org/10.15446/abc.v20n1.42756

Ruiz Corral, M., López, F., Díaz, R., & Eguiarte, G. (2002). Temperaturas cardinales y duración del ciclo de madurez del híbrido de maíz h-311 en condiciones de temporal. *Agrociencia*, *36*, 569–577. http://www.redalyc.org/articulo.oa?id=30236508

Salazar Gutierrez, M. R. (2006). *Un modelo simple de producción potencial de uchuva (Physalis peruviana L.)*. Universidad Nacional de Colombia.

Salazar-Gutierrez, M. R., & Chaves Cordoba, B. (2013). Relationship of base temperature to development of winter wheat. In *Article in International Journal of Plant Production*. https://www.researchgate.net/publication/256252017

Trudgill, D., Honek, A., Li, D., & van Straalen, N. (2005). Thermal time - concepts and utility. Annals of Applied Biology. *Ann Appl Biol*, *146*(1), 1–14.

Zamora, E. (2016). *El cultivo de la coliflor*.
Zhou, G., & Wang, Q. (2018). A new nonlinear method for calculating growing degree days. *Scientific Reports*, *8*(1). https://doi.org/10.1038/s41598-018-28392-z.