Research article

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Analysis of the temperature behavior model for the optimization of sowing (TOMATO (*Solanum licopersicum*))

Análisis del modelo de comportamiento de las temperaturas para la optimización de la siembra (TOMATE) (*Solanum licopersicum*)

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ABSTRACT

Mathematics has continued to increase its presence in the sciences and in the economic sectors, in general. Along with information technologies, huge volumes of data are processed that facilitate analysis and serve for objective decision-making. The avoidance of agricultural risks is a task of the first order to safeguard food security and thus reducing the vegetative periods in crops is an effective strategy to achieve it. The work is carried out in the Babahoyo canton, Los Ríos province on obtaining behavior models of air temperatures that facilitate, through the application of Differential Calculation, obtaining the dates of maximum temperatures, which would allow obtaining the periods of higher temperatures. thermal supply to accelerate growth and development processes. The dates of maximum temperature were located around decade 7, between March 13 and 17, results of the sum of probabilities for 75%. The sums of temperatures obtained fluctuate in the range 2170 – 2266 Celsius Degrees that guarantee the acceleration of the vegetative period, since they have 100% of the sum of probabilities of being reached. Observe a management directed to the selection of the period of highest temperature will reduce the risks of pests and extreme events, in addition to reducing inputs in agricultural production, which will increase the sustainability of the system.

Keywords: Temperatures, Modeling, Optimization, Tomato.

RESUMEN

Las matemáticas han seguido elevando su presencia en las ciencias y en los sectores económicos, en general. Junto a las tecnologías de la información se procesan enormes volúmenes de datos que facilitan el análisis y sirven para la toma de decisiones de manera objetiva. La evasión de los riesgos agrícolas resulta una tarea de primer orden para la salvaguarda de la seguridad alimentaria y es así que la reducción de los períodos vegetativos en los cultivos, resulta una estrategia eficaz para lograrlo. El objetivo de este trabajo es determinar las fechas en que se producen las máximas de temperatura del aire para obtener los períodos probables en que se manifiestan los valores más altos y acelerar el crecimiento y desarrollo del cultivo del tomate en el cantón Babahoyo, provincia Los Ríos, Ecuador. Las fechas de máxima temperatura en el aire se ubicó alrededor de la decena 7, entre el 13 y el 17 de marzo, resultados de la suma de probabilidades para un 75%. Las sumas de temperaturas obtenidas fluctúan en el rango 2170 – 2266 Grados Celsius que garantizan la aceleración del período vegetativo, pues cuentan con el 100% de la suma de probabilidades de ser alcanzadas. Observar un manejo dirigido a la selección del período de mayor temperatura reducirá los riesgos de y eventos extremos, además de disminuir los insumos en la producción agrícola, lo que aumentará la sostenibilidad del sistema.
Palabras clave: Temperaturas, Modelación, Optimización, Tomate.

1. Introduction

The need to increase agricultural production worldwide has determined the introduction of modeling and advanced statistical-mathematical tools in research (Rodriguez, 2001). The adequate use and interpretation of these techniques allow optimal decision making, efficiency and the achievement of superior efforts in different spheres, especially in the agricultural sector, whose application favors the development of productive systems (Rodríguez & Bermúdez, 1995; Chávez et *al., 2013).* As reported (Chávez *et al*., 2013), in order to make medium and long-term decisions under similar experimental conditions, applied mathematics in agricultural sciences provides criteria and basic tools to better manage and interpret agricultural activity and meet the demands of new technologies to produce in highly competitive global markets while safeguarding natural resources.

Agricultural productivity is an important component of the global carbon cycle and a driver of the most essential ecosystem services for humanity (Vitousek *et al.,*1986; Costanza *et al.,*1998). Research on agricultural productivity has attracted much attention among the scientific community because it is an indicator of energy input to the biosphere and a measure of net assimilation of carbon dioxide ($_{CO2}$) providing a basis for assessing the status of a wide range of ecological processes (Pan *et al.,* 2014). The behavior of maximum temperature plays a very active role in this whole process.

Many authors have shown that there is a close relationship between changes in agricultural productivity and the behavior of climatic variables (Tiedemann, 2015; Deliree *et al.* , 2018; Pan *et al*., 2015). A higher correlation was found between agricultural productivity and temperature than that found with precipitation, concluding that these changes are closely related to climatic factors, landscape conditions and vegetation type (Yang *et al.,* 2020). Other authors have related it to the length of the growing season (Arora & Boer, 2005; Jönsson & Eklundh, 2004; Chandola et al. , *2010).*

The projected increase in global average temperature of 4.3 ± 0.7 degrees Celsius by 2100 will affect the geographic distribution, composition and productivity of tropical ecosystems (Elikana *et al*., 2020), a change that is currently taking place gradually. Therefore, management that guarantees the efficient use of ecosystem resources is necessary. Thus, crops depend on a certain amount of temperature sum for their growth and development, where the average must exceed a biological minimum (De Fina & Ravelo, 1979). Causing crops to pass through favorable climatic conditions that determine rapid growth and development reduces the risk of pest attack, in addition to increasing the productive efficiency of the system. On the other hand, there are cyclical phenomena (sequence of ordered states that are repeated without alteration of the order) such as the behavior of daily, monthly or annual temperature. These cyclical phenomena are mathematically associated with periodic functions (Plaza, 2011).

Materials and methods

The present work was developed in the Babahoyo canton, Los Ríos province, to determine the period in which the highest temperature values are reached through its behavioral model. Thirty years of decennial mean temperature data for the period 1981 - 2010 were used and in each of the years the behavioral model and the value of the existing correlations were determined through the application of SPSS software, the Curve Expert, an important element for the selection of the model that best explained the results. The tomato variety selected has a vegetative cycle equivalent to 180 days and a minimum biological temperature equal to 13 degrees Celsius.

Once the functions were obtained for each curve in each year, the function was optimized to obtain the maximum temperature through differential calculus: derivative of the function equal to zero, to obtain the extreme values, from which the absolute maximum is acquired. For the development of this section, the methodology proposed by (Morales, 1993) was used, which is based on the use of differential calculus for the optimization of the functions in question. Once the absolute maximum was obtained, it was possible to determine the periods of greatest accumulation of heat summation, taking as the midpoint the date on which the absolute maximum occurred and extending to the right and left the same period of time, until it coincided with the length of the growth period of the crop in question (Figure 1).

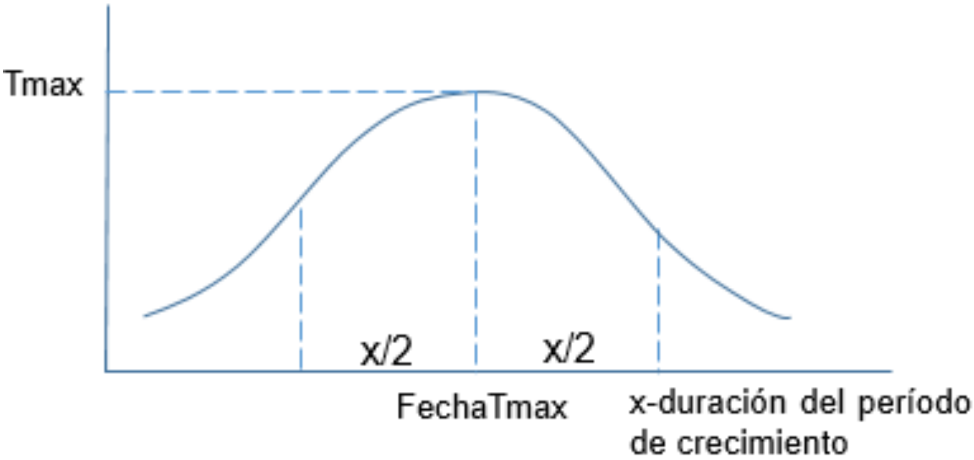

Figure 1. Temperature behavior during the growing period of the crop.
Source: Authors' own elaboration.

Once the optimum periods for each of the years and the average temperatures corresponding to each of the tens involved in the growing period of the tomato crop have been obtained, the cumulative probability in dates of maximum temperature manifestation is evaluated for a 75% probability. The 75% guarantees that out of every 10 years, the phenomenon occurs in 7.5 years, which represents a lower risk for the farmer (Eldin & Rojas, 1983).

The sum of accumulated temperatures in each of the years was calculated. The sum of probabilities of the sums of effective temperatures was evaluated.

$$ST_e = n(T_m - T_{mb})$$

STe - sum of effective temperatures
n - number of days
Tm - average temperature
Tmb - minimum biological temperature

3. Results

Among the models analyzed, the best fit models were the sinusoidal and the polynomial, in that order. The best fitting model has the form of a cosine wave:

$$T = A.\cos(Bt + C) + D$$

The above results coincide with those obtained by (Plaza, 2011) in his work on daily temperature modeling in Valle del Cauca, Colombia.

From the annual temperature behavior models and with the application of the differential calculation, the maximums for each year were obtained. In general, the behavior of the temperature is cyclical, with a maximum that fluctuated around the 7th decade and a minimum that fluctuated around the 21st and 22nd decades. If the decades are taken to a decimal scale, then the maximum fluctuated in the range 6.76 - 7.88, which converted to exact dates would be 8/March - 19/March. This method ensures that the periods when the highest temperatures occur in each year are evaluated.

Table 1 presents for each year the equations of the behavior models of the decennial temperature, correlation coefficients (Coef. Correl.), standard error (SE), the tens of manifestation of the maximums and their corresponding dates, which also presents the dates 90 days before (F.BEFORE) and 90 days after (F.AFTER) the date of maximum, so as to include the tomato growth period, which has a duration of 180 days. The characteristic of these functions is that their values are repeated at regular intervals and their periodicity, as asserted by (San Martín, 2005).

Table 1. *Models of annual temperature behavior, statisticians, dates of manifestation of maximums and optimum development period for tomato cultivation.*

YEAR	ECUATION	Coef. Correl.	EN	TENS	F.BEFORE	DATE	F.AFTER
YEAR 1	y=24.64+1.41 cos (0.17x-1.30)	0.91	0.45	7.29	8/12	13/3	11/6
YEAR 2	y=24.61+1.37 cos (0.17x-1.28)	0.91	0.46	7.53	10/12	15/3	13/6
YEAR 3	y=24.58+1.39 cos (0.17x-1.28)	0.92	0.44	7.53	10/12	15/3	13/6
YEAR 4	y=24.58+1.42 cos (0.17x-1.26)	0.93	0.39	7.41	9/12	14/3	12/6
YEAR 5	y=24.65+1.44 cos (0.17x-1.20)	0.94	0.36	7.06	6/12	11/3	9/6
YEAR 6	y=24.65+1.36 cos (0.17x-1.21)	0.92	0.40	7.12	6/12	11/3	9/6
YEAR 7	y=24.55+1.24 cos (0.17x-1.34)	0.89	0.45	7.88	14/12	19/3	17/6

YEAR 8	y=24.65+1.43 cos (0.16x-1.19	0.92	0.43	7.44	9/12	14/3	12/6
YEAR 9	y=24.58+1.46 cos (0.18x-1.40)	0.93	0.40	7.78	13/12	18/3	16/6
YEAR 10	y=24.67+1.35 cos (0.17x-1.25)	0.92	0.40	7.35	9/12	14/3	12/6
YEAR 11	y=24.61+1.42 cos (0.18x-1.40)	0.92	0.43	7.78	13/12	18/3	16/6
YEAR 12	y=24.56+1.46 cos (0.17x-1.28)	0.93	0.42	7.53	10/12	15/3	13/6
YEAR 13	y=24.71+1.32 cos (0.16x-1.17)	0.91	0.44	7.31	8/12	13/3	11/6
YEAR 14	y=24.56+1.43 cos (0.18x-1.38)	0.91	0.45	7.67	12/12	17/3	15/6
YEAR 15	y=24.65+1.37 cos (0.17x-1.29)	0.92	0.42	7.59	11/12	16/3	14/6
YEAR 16	y=24.59+1.43 cos (0.17x-1.22)	0.90	0.50	7.18	7/12	12/3	10/6
YEAR 17	y=24.64+1.45 cos (0.17x-1.25)	0.91	0.47	7.35	9/12	14/3	12/6
YEAR 18	y=24.61+1.37 cos (0.17x-1.29)	0.91	0.43	7.59	11/12	16/3	14/6
YEAR 19	y=24.61+1.43 cos (0.17x-1.34)	0.92	0.43	7.88	14/12	19/3	17/6
YEAR 20	y=24.54+1.39 cos (0.18x-1.35)	0.92	0.41	7.50	10/12	15/3	13/6
YEAR 21	y=24.63+1.46 cos (0.17x-1.34)	0.92	0.45	7.88	14/12	19/3	17/6
YEAR 22	y=24.62+1.41 cos (0.17x-1.19)	0.92	0.44	7.00	5/12	10/3	8/6
YEAR 23	y=24.66+1.35 cos (0.17x-1.15)	0.91	0.45	6.76	3/12	8/3	6/6
YEAR 24	y=24.64+1.36 cos (0.18x-1.41)	0.92	0.41	7.83	13/12	18/3	16/6
YEAR 25	y=24.56+1.43 cos (0.18x-1.39)	0.94	0.38	7.72	12/12	17/3	15/6
YEAR 26	y=24.64+1.41 cos (0.17x-1.24)	0.92	0.44	7.29	8/12	13/3	11/6
YEAR 27	y=24.57+1.35 cos (0.17x-1.27)	0.93	0.39	7.47	10/12	15/3	13/6
YEAR 28	y=24.60+1.41 cos (0.17x-1.33)	0.92	0.43	7.82	13/12	18/3	16/6
YEAR 29	y=24.63+1.43 cos (0.17x-1.34)	0.91	0.46	7.88	14/12	19/3	17/6
YEAR 30	y=24.58+1.34 cos (0.17x-1.28)	0.91	0.44	7.53	10/12	15/3	13/6

The evaluation of the sum of probabilities shows that there is a 75% probability that the maximum temperature will occur before March 17 and after March 13 (Figure 2).

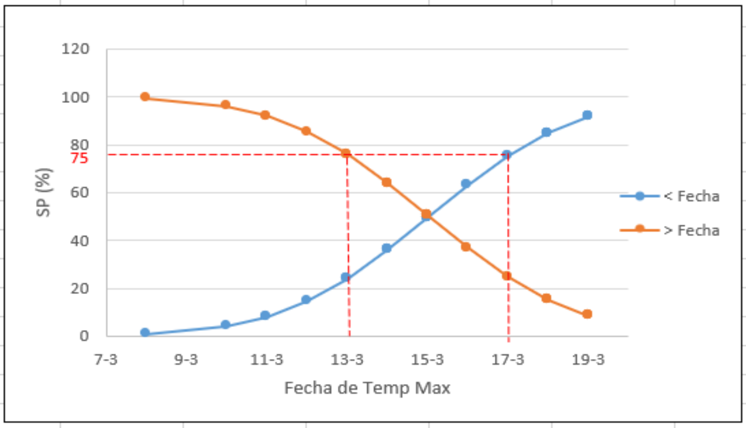

Figure 2. Sum of probabilities of the dates of manifestation of the maximum temperature before and after in Babahoyo canton, Los Ríos province. Source: Authors' own elaboration.

The sum of effective temperatures for the selected periods, according to the methodological procedure, fluctuated in the range 2170-2266 ºC . The sum of effective temperatures for tomato fluctuates between 1150 and 1350 degrees Celsius (De Fina, 1979) and according to the results, the temperature sums obtained in the canton can determine a reduction of one third of the vegetative period of the crop until harvest, with the implications that this has on inputs and risks of pests and extreme events. The temperature sums in the canton exceed the 1350 ºC required by the crop at the lowest value (Figure 3).

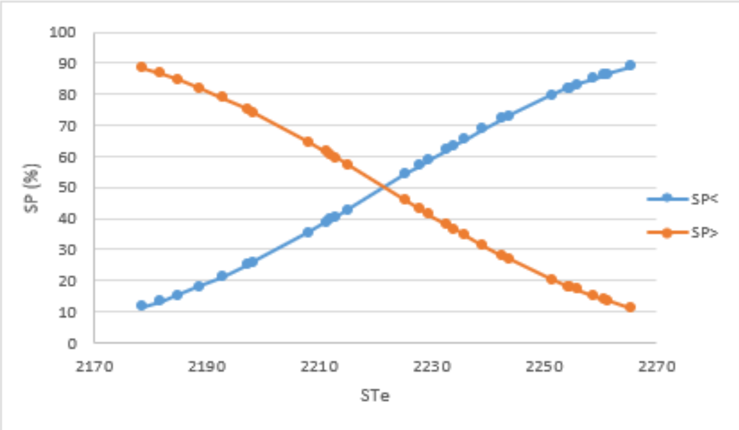

Figure 3. Sum of probabilities of the sum of effective temperatures in the tomato crop in the periods of highest temperature in Babahoyo canton, Los Ríos province. Source: Authors' own elaboration.

5. Conclusions

The model with the best fit was the sinusoidal model due to the cyclical and periodic nature of the annual temperatures. The correlation coefficients were high, although with direct observation models in each of the years, the adjustments obtained could be somewhat improved. The use of differential calculus to determine the dates of maximum temperature was of great support to achieve the objective of this work, providing an applicable model for the forecast of the periods with the highest thermal supply in the Babahoyo canton. The sum of probabilities of the date of manifestation of maximum temperatures presents a small variation in the range, which corresponds to the behavior of the thermal conditions present in the Babahoyo canton, Los Ríos province, Ecuador. The values of the sum of probabilities of the sum of effective temperatures indicate that, in Babahoyo canton, with an intelligent agriculture that integrates agroclimatic knowledge, it is possible to achieve more efficient and sustainable productions.

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