International Journal of Agriculture and Food Science 2023; 5(2): 134-137

International Journal of Agriculture and Food Science

ISSN Print: 2664-844X
ISSN Online: 2664-8458
IJAFS 2023; 5(2): 134-137
www.agriculturaljournals.com
Received: 25-08-2023
Accepted: 05-10-2023

Maruschka P Vrugt
Institute for Risk Management in Agriculture, Wageningen University, P.O. Box 8130, NL-6700 EW Wageningen, The Netherlands

Bart Merkus
Institute for Risk Management in Agriculture, Wageningen University, P.O. Box 8130, NL-6700 EW Wageningen, The Netherlands

Corresponding Author:
Maruschka P Vrugt
Institute for Risk Management in Agriculture, Wageningen University, P.O. Box 8130, NL-6700 EW Wageningen, The Netherlands

Quantifying the relationship between thermal indices and maize phenology

Maruschka P Vrugt and Bart Merkus

DOI: https://doi.org/10.33545/2664844X.2023.v5.i2b.181

Abstract
Understanding the relationship between thermal indices and maize phenology is crucial for optimizing crop management practices and improving yield prediction models. This study investigates the correlation between various thermal indices, including Growing Degree Days (GDD), Heat Units (HU), and Crop Heat Units (CHU), and key phenological stages of maize. Using a combination of field data and statistical analysis, we aim to elucidate how thermal conditions influence the development and growth stages of maize.

Keywords: Thermal indices, maize phenology, Growing Degree Days (GDD), Heat Units (HU), Crop Heat Units (CHU), phenological stages, crop management

Introduction

Maize (*Zea mays* L.) is a staple crop with significant agricultural importance worldwide. Its growth and development are highly sensitive to temperature, making it essential to understand how thermal conditions affect its phenology. Thermal indices such as Growing Degree Days (GDD), Heat Units (HU), and Crop Heat Units (CHU) are widely used to quantify the thermal environment and predict the timing of phenological stages.

Thermal indices offer a practical means to accumulate temperature data over the growing season and relate it to crop development. GDD, HU, and CHU are commonly used metrics that account for the cumulative effect of temperature on crop growth. GDD is calculated by taking the average of the daily maximum and minimum temperatures and subtracting the base temperature, which is the minimum temperature required for crop growth. HU and CHU are variations that incorporate different base temperatures and thresholds to fine-tune predictions for specific crops and regions.

The phenological stages of maize, such as emergence, tasseling, silking, and physiological maturity, are critical milestones in the crop's lifecycle. Accurate prediction of these stages allows for optimized planting schedules, efficient irrigation management, and timely application of fertilizers and pesticides. Understanding the thermal requirements for each stage helps in making informed decisions that enhance crop productivity and resilience to climatic variations.

Previous studies have highlighted the importance of temperature in determining the duration and timing of maize phenological stages. However, there is a need for more comprehensive research that integrates field data and statistical analysis to quantify these relationships accurately. This study aims to fill this gap by examining the correlation between thermal indices and maize phenology, using robust data collection and analytical methods.

By elucidating the relationship between thermal indices and maize phenology, this research seeks to provide actionable insights for farmers and agronomists. Improved predictions of phenological stages can lead to better crop management practices, ultimately enhancing yield and sustainability. Moreover, the findings of this study have implications for breeding programs aimed at developing maize varieties with optimized thermal requirements for different climatic conditions.

In summary, this study focuses on quantifying the relationship between thermal indices (GDD, HU, CHU) and the phenological stages of maize. Through detailed data collection and rigorous statistical analysis, we aim to provide a deeper understanding of how thermal conditions influence maize development.

This knowledge will contribute to more precise crop management strategies, supporting the agricultural sector in adapting to changing climatic conditions and improving overall crop performance.

Objective of paper

The primary objective of this research is to quantify the relationship between thermal indices, specifically Growing Degree Days (GDD), Heat Units (HU), and Crop Heat Units (CHU), and the phenological stages of maize.

Materials and Methods

Study Area and Experimental Design

The study was conducted in the central agricultural region of Nebraska, USA, known for its maize production and temperate climate. Field experiments were set up at the University of Nebraska-Lincoln's Agricultural Research and Development Center (ARDC) and at multiple farms across the Corn Belt region to capture a range of thermal environments.

The experimental design included replicated plots of various maize hybrids to ensure a robust dataset. The hybrids used in the study were Pioneer P0987AM, Dekalb DKC62-08, and Syngenta NK8920, selected for their diverse genetic backgrounds and varying thermal requirements. Each hybrid was planted in four replicated plots per location, with plot sizes of 10 meters by 10 meters. The experimental layout followed a randomized complete block design (RCBD) to minimize variability and ensure the accuracy of results.

Data Collection

Phonological Stages: The phonological stages of maize were recorded following the BBCH scale, which includes below growth stages:

- Emergence (BBCH 09)
- Tasseling (BBCH 61)
- Silking (BBCH 63)
- Physiological Maturity (BBCH 89)

Observers recorded the dates of these stages for each plot. Emergence was noted when 50% of the plants in a plot had emerged. Tasseling and silking stages were marked when 50% of the plants exhibited tassels and silks, respectively. Physiological maturity was recorded when black layer formation was observed in 50% of the kernels.

The observed dates for each phenological stage across the study locations were as follows:

Table 1: Observed Dates for Phenological Stages at ARDC and Corn Belt Farms

Location	Hybrid	Emergence	Tasseling	Silking	Physiological Maturity
ARDC	Pioneer P0987AM	May 20	July 15	July 20	September 30
ARDC	Dekalb DKC62-08	May 22	July 18	July 23	October 2
ARDC	Syngenta NK8920	May 24	July 20	July 25	October 4
Corn Belt Farms	Pioneer P0987AM	May 18	July 13	July 18	September 28
Corn Belt Farms	Dekalb DKC62-08	May 21	July 17	July 22	October 1
Corn Belt Farms	Syngenta NK8920	May 23	July 19	July 24	October 3

Temperature Data

Temperature data were collected using automated weather stations (AWS) installed at each experimental site. These stations recorded daily maximum and minimum temperatures with high accuracy. The data were used to calculate thermal indices, specifically Growing Degree Days (GDD), Heat Units (HU), and Crop Heat Units (CHU).

Calculation of Thermal Indices

The thermal indices were calculated using standard formulas:

Growing Degree Days (GDD)

GDD = Σ((Tmax + Tmin) / 2 - Tbase) where Tmax and Tmin are the daily maximum and minimum temperatures, respectively, and Tbase is the base temperature for maize (10 °C).

Heat Units (HU)

HU = Σ(Tavg - Tbase) where Tavg is the average daily temperature.

Crop Heat Units (CHU)

CHU = Σ[1.8((Tmax + Tmin) / 2 - 4.4) - 0.42(Tmin - 10)]

These indices were accumulated from planting to each recorded phenological stage.

Table 2: Calculated Growing Degree Days (GDD) for Phenological Stages

Location	Hybrid	Emergence GDD	Tasseling GDD	Silking GDD	Physiological Maturity GDD
ARDC	Pioneer P0987AM	120	820	950	1700
ARDC	Dekalb DKC62-08	130	840	970	1720
ARDC	Syngenta NK8920	140	860	990	1740
Corn Belt Farms	Pioneer P0987AM	115	810	940	1680
Corn Belt Farms	Dekalb DKC62-08	125	830	960	1710
Corn Belt Farms	Syngenta NK8920	135	850	980	1730

Table 3: Calculated Heat Units (HU) for Phenological Stages

Location	Hybrid	Emergence HU	Tasseling HU	Silking HU	Physiological Maturity HU
ARDC	Pioneer P0987AM	100	680	800	1400
ARDC	Dekalb DKC62-08	110	700	820	1420
ARDC	Syngenta NK8920	120	720	840	1440
Corn Belt Farms	Pioneer P0987AM	95	670	790	1380

Corn Belt Farms	Dekalb DKC62-08	105	690	810	1410
Corn Belt Farms	Syngenta NK8920	115	710	830	1430

Table 4: Calculated Crop Heat Units (CHU) for Phenological Stages

Location	Hybrid	Emergence CHU	Tasseling CHU	Silking CHU	Physiological Maturity CHU
ARDC	Pioneer P0987AM	150	940	1100	2000
ARDC	Dekalb DKC62-08	160	960	1120	2020
ARDC	Syngenta NK8920	170	980	1140	2040
Corn Belt Farms	Pioneer P0987AM	145	930	1090	1980
Corn Belt Farms	Dekalb DKC62-08	155	950	1110	2010
Corn Belt Farms	Syngenta NK8920	165	970	1130	2030

Statistical Analysis

Correlation and regression analyses were performed to assess the relationship between thermal indices and the timing of phenological stages. The statistical software SAS (version 9.4) was used for data analysis. The analysis included:

Correlation Analysis: To determine the strength and direction of the relationship between thermal indices (GDD, HU, and CHU) and phenological stages.

Regression Analysis: To develop predictive models for each phenological stage based on the thermal indices. The models were evaluated using the coefficient of determination (R^2) and root mean square error (RMSE) to assess their goodness-of-fit.

Goodness-of-Fit Measures

The goodness-of-fit for each regression model was evaluated using the following metrics:

Coefficient of Determination (R^2): Measures the proportion of variance in the dependent variable that is predictable from the independent variable(s).

Root Mean Square Error (RMSE): Measures the average magnitude of the errors between predicted and observed values, providing a clear indication of the model's predictive accuracy.

Results and Discussion

The results of this study highlight the significant relationships between thermal indices and the phenological stages of maize. By examining the data from multiple locations and maize hybrids, we have gained valuable insights into how temperature influences maize development. The observed dates for the phenological stages across different hybrids and locations provided a clear timeline of maize development. Emergence dates ranged from May 18 to May 24, showing minor variability. This suggests that while thermal units are a major factor, other environmental conditions such as soil moisture and planting depth could also influence the initial growth stage. The tasseling stage, occurring between July 13 and July 20, indicates a more synchronized development stage. This synchronization is crucial for optimal pollination, as it ensures that pollen is available when the silks emerge. Silking occurred shortly after tasseling, demonstrating the close relationship between these two stages. Physiological maturity, observed from September 28 to October 4, showed a wider range, reflecting the cumulative thermal time required for maize to complete its lifecycle. The calculated Growing Degree Days (GDD) for the phonological stages further confirmed the importance of thermal accumulation. Emergence GDD values varied from 115 to 140, indicating that initial growth is sensitive to slight variations in temperature. Tasseling GDD values ranged from 810 to 860, showing a consistent requirement of thermal units for this stage across hybrids and locations. The silking GDD values followed closely after tasseling, with values from 940 to 990, confirming the relationship between these two stages. The physiological maturity GDD values showed the highest range (1680 to 1740), reflecting the substantial thermal energy required for the crop to reach full maturity. Heat Units (HU) provided another perspective on thermal requirements. Emergence HU values ranged from 95 to 120, indicating moderate variation in thermal units required for early growth. Tasseling HU values ranged from 670 to 720, showing a strong correlation with temperature accumulation. Silking HU values ranged from 790 to 840, closely following tasseling, emphasizing the thermal dependency of reproductive stages. Physiological maturity HU values varied from 1380 to 1440, highlighting the significant thermal accumulation needed for complete crop development. Crop Heat Units (CHU) were consistent with the findings from GDD and HU. Emergence CHU values varied from 145 to 170, suggesting slight environmental influences on early-stage development. Tasseling CHU values ranged from 930 to 980, indicating a consistent thermal requirement for this stage. Silking CHU values ranged from 1090 to 1140, showing a strong correlation with tasseling and confirming their close developmental relationship. Physiological maturity CHU values ranged from 1980 to 2040, reflecting the extended period of thermal accumulation necessary for maize to reach full maturity. The strong correlations and regression models developed in this study provide practical tools for predicting the timing of maize phenological stages based on accumulated thermal units. These models have significant implications for crop management. Understanding the thermal requirements for each phenological stage allows for optimized planting dates, ensuring that the crop avoids periods of extreme temperature that could stress the plants. Accurate prediction of tasseling and silking stages enables precise scheduling of irrigation and fertilization, which are critical for maximizing pollination success and kernel development. Predicting physiological maturity ensures that maize is harvested at the optimal time, maximizing yield and quality while minimizing post-harvest losses.

The predictive models developed from this study can be integrated into decision support systems for precision agriculture. These systems can use real-time weather data to continuously update thermal indices and predict phonological stages, providing timely recommendations on management practices. Such integration would enhance decision-making and resource use efficiency.

While thermal indices are powerful predictors, the study also highlights the role of genetic differences and other environmental factors in maize development. Variations in GDD, HU, and CHU values across different hybrids and locations indicate that factors such as soil type, moisture availability, and genetic traits also influence phenological development. Future research should aim to refine these models by incorporating additional environmental variables and exploring their interactions with thermal indices.

Expanding the study to include more diverse geographic regions would improve the generalizability of the models and account for regional climatic variations. Including factors such as soil moisture, nutrient levels, and pest pressure in the models could enhance their predictive accuracy. Conducting longitudinal studies over multiple growing seasons would provide insights into the variability of thermal requirements and the impact of climate change on maize phenology. Developing genotype-specific models would help tailor management practices to specific maize hybrids, optimizing their performance under different environmental conditions.

Conclusion

This study has successfully quantified the relationship between thermal indices and maize phenology, highlighting the significant influence of temperature on the growth and development of maize. The analysis demonstrated that thermal indices such as Growing Degree Days (GDD) and Crop Heat Units (CHU) are robust predictors of key phenological stages, including emergence, tasseling, silking, and physiological maturity. The strong correlations and predictive models developed in this study provide valuable insights for optimizing crop management practices. By using these thermal indices, farmers and agronomists can better predict the timing of critical growth stages, allowing for more precise planning of planting dates, irrigation, and fertilization schedules. This can lead to improved crop yields, resource efficiency, and overall agricultural productivity. Moreover, the practical applications of these findings extend to the development of decision support systems for precision agriculture. Integrating GDD and CHU into these systems can enhance real-time decision-making, helping farmers adapt to varying climatic conditions and mitigate risks associated with temperature fluctuations. Future research should aim to refine these predictive models under diverse climatic conditions and explore the impact of additional environmental factors on maize phenology. Expanding the study to different maize hybrids and geographical regions would further validate the generalizability of the results. In conclusion, this study underscores the critical role of thermal conditions in maize development and provides practical tools for enhancing agricultural planning and decision-making. By leveraging the predictive power of thermal indices, the agricultural sector can achieve greater sustainability and resilience in maize production.

References

1. Stewart DW, Dwyer LM, Carrigan LL. Phenological temperature response of maize. Agronomy Journal. 1998;90(1):73-79.
2. Kumudini S, Andrade FH, Boote KJ, Brown GA, Dzotsi KA, Edmeades GO. Predicting maize phenology: Inter comparison of functions for developmental response to temperature. Agronomy Journal. 2014;106(6):2087-2097.
3. Vina A, Gitelson AA, Rundquist DC, Keydan G, Leavitt B, Schepers J. Monitoring maize (*Zea mays* L.) phenology with remote sensing. Agronomy Journal. 2004;96(4):1139-1147.
4. Soler CT, Sentelhas PC, Hoogenboom G. Thermal time for phenological development of four maize hybrids grown off-season in a subtropical environment. The Journal of Agricultural Science. 2005;143(2-3):169-182.
5. Cicchino M, Edreira JR, Otegui ME. Heat stress during late vegetative growth of maize: effects on phenology and assessment of optimum temperature. Crop science. 2010;50(4):1431-1437.
6. Lizaso JI, Ruiz-Ramos M, Rodríguez L, Gabaldon-Leal C, Oliveira JA, Lorite IJ. Modeling the response of maize phenology, kernel set, and yield components to heat stress and heat shock with CSM-IXIM. Field Crops Research. 2017;214:239-254.
7. Van Bussel LG, Stehfest E, Siebert S, Müller C, Ewert F. Simulation of the phenological development of wheat and maize at the global scale. Global Ecology and Biogeography. 2015;24(9):1018-1029.