

Relationship Between Air Temperature and Maize Growth Function

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Abstract – Maize is the oldest plant used by man in economic activity. It plays a significant role in the economy of many countries. Despite the accumulated experience in cultivation of this crop, the study of the relationship between temperature and growth function remains relevant today. Five main phases of its development have been identified in the present research. Connection of temperature indicators and development phases has been revealed by monitoring maize growth during vegetation period. The research had been carried out for 6 years according to the authors' methodology and tested in four farms of the Nikolaevsky district of the Volgograd region on light chestnut soils of the Kislovskaya and Zavolzhsкая irrigation systems. Research objects are represented with late-ripening hybrids (double interline hybrid of Volgograd selection and hybrid VC-183), mid-ripening triple interline hybrid Dneprovsky-98MV (FAO 200), and mid-ripening variety Elora produced by Pioneer company. Samples have been selected in the zone of forest belts impact at the distances multiple of the height of a forest belt. Samples refer to the following stages: emergence stage, third-leaf stage, panicle stage, milky ripeness stage, and gold ripeness stage. Logistic function has been used when modeling growth processes by correlation and regression analysis in the computer program Statistica (StatSoft Russia) with a confidence interval of 0.95 and determination coefficient identification (R^2). The data on heat requirements have been calculated on the basis of growth patterns. Distinctive areas corresponding to the phases of crop morphogenesis have been identified in logistic function to assess crop's condition and predict further growth.

Keywords: *prediction of maize growth morphogenesis of maize logistic function connection of mean daily and active air temperatures and duration of phases of development*

I. INTRODUCTION

Maize plays an important role among grain crops grown in Russia. According to the Russian State Statistics Service (Rosstat), the yield of maize amounted to 16.7–41.8 c/ha in 1990–2010, and in 2011–2017 the yield increased and amounted to 43.5–57.5 c/ha. This increase is associated with improvement of hybrid characteristics of maize, therefore in our studies, we pay attention to hybrids that differ in maturity and responsiveness to environmental conditions of growth. Today's Russian market is rich in producers and suppliers of seeds. The European company RAGT

SEMENCES alone offers up to 200 maize hybrids. The Russian company ROSAGROTRADE LLC disposes of about 140 demonstration fields for selection of hybrids the most suitable to soil and climatic conditions of Russia. This list can be continued further [1, 2]. In current conditions of interaction between Russian manufacturers and foreign partners with agricultural producers, it is difficult for the latter to choose the most adapted hybrids for growing in their own fields. Due to the above facts, research into physiological features of maize hybrids development is urgent.

Systemic studies on the physiological characteristics of maize growth and cultivation, which are still popular today, were actively conducted by the USSR scientific centres in the 1950–1960s [3]. Today, these studies have been developed through further research into growth patterns and organogenesis in plants [4], the use of mathematical modeling in biology with differential calculus [5,15], techniques of agricultural yield increase [6]. The problems of modeling the process of plant growth under the influence of various environmental factors [1,7] based on space monitoring data [8–10], probabilistic changes [11–13] related to global warming and their consequences for agriculture [14] are thoroughly considered by researchers with an emphasis being placed on various physiological features [15–16]. However, the issues of modeling and forecasting the stages of maize hybrids growth in the system of forest belts, taking into account the peculiarities of temperature indicators, are insufficiently studied.

II. MATERIALS AND METHODS (MODEL)

The research novelty consists in identifying the patterns of temperature impact through specific parameters and coefficients on the morphogenesis of maize hybrids that differ in terms of maturation using correlation and regression analysis.

The research aim is to forecast the development of irrigated maize hybrids in the forest belt system through physiological features of growth functions for identifying their adaptive capabilities to the conditions of cultivation.

In the course of the research, the height of maize plants was determined at different stages of morphogenesis. In the 1st and the 2nd years, the fields were planted with the

double interline hybrid of Volgograd selection, late-ripening, with a vegetation period of 135 days; in the 3rd year – the hybrid VC-183, late-ripening, recommended for cultivation for grain, with a vegetation period of 135 days; in the 4th year – the triple interline hybrid Dneprovsky-98MV, mid-ripening (FAO 200), with a vegetation period of 110 days; in the 5th and 6th years – Elora variety produced by Pioneer company (USA), mid-ripening, with a vegetation period of 120 days. Samples have been selected in the zone of forest belts impact at distances multiple of the height of a forest belt (2,5; 5; 10; 15; 20 H) at different phases of crop growth. Distances equal or exceeding 30 heights of a forest belt were used as control points.

The logistic function was used for modeling the height of maize stalks. It is of physical nature, and it was first applied by Ferhulst and Perl in 1838 to calculate population growth. The function was modified by the authors for investigation of maize hybrids in the forest belt system:

$$P_p = P_{\max} / (1 + e^{-a-b\tau}) \quad (1)$$

where τ – vegetation period (number of days depending on cultivation conditions and varietal characteristics), e – base of natural logarithms, a and b – constants determining the slope, bend and inflection point of the curve, P_p – calculated height of a plant, P_{\max} – maximum height of a plant at the end of vegetation period [17]. Parameters a and b were determined in the computer program Statistica (StatSoft Russia) by correlation and regression analysis with a confidence interval of 0.95 and determination coefficient identification (R^2).

Temperature indicators were based on meteorological data for each object under study for a vegetation period for each year.

The logistic function is universal in modeling forecasts of natural and anthropogenic systems. It allows obtaining models of plant growth in the ecosystem space, calculating bioproductivity of crops with sufficiently high accuracy. Based on empirical data obtained by using the program Statistica (StatSoft Russia), logistic functions were constructed for all maize hybrids and varieties studied at different distances from forest belts. As a result, the growth function over the vegetation period was described (Fig. 2). The theory of function justification and construction was considered in detail by the authors in the previous work [17]. Parameters of the logistics function changed: a – from 3.08 in the 1st year for the double interline hybrid of Volgograd selection to 8.60 in the 4th year for the triple interline hybrid Dneprovsky-98MV; b – from 0.06 in the 1st year to 0.20 in the 2nd year for the double interline hybrid of Volgograd selection. The accuracy of approximation (R^2) is 0.98-0.99.

III. RESULTS AND DISCUSSION

The research had been carried out for 6 years according to the authors' methodology [17, 18] and tested in four farms of the Nikolaevsky district of the Volgograd region on light chestnut soils of the Kislovskaya and Zavolzhsckaya irrigation systems (48.7° N.Lat. and 44.5° E.Lon.). Forest belts dating back to 1973-1976 years are represented with the two-row pyramidal poplar plantations of openwork design. Wind permeability in leafy condition is 40-50%.

Width of the inter-belt fields is 450-800 m. Heat requirements of maize groups, differing in vegetation period and expressed in the sums of temperatures was determined by numerous studies in the European and Asian parts of the globe [3, 15, 19, 20]. This approach was supplemented by in-house research and modeling in synchronization of temperature parameters and maize morphogenesis.

Maize needs enough heat to grow and develop. Individual phases of development require different temperatures. Height growth of stems is uneven in time, which is associated with the length of daylight, the amount of nutrients, water supply, but primarily with average daily air temperature. So, at an average daily temperature below 15°C and above 25°C growth processes are significantly suppressed.

The stages of morphogenesis differ in cereals, and each of them has its own value for crop growth and formation. Phenophases and morphometric features, discussed below, are of great scientific and industrial importance, as they help to assess the variety by precocity, allow making up a calendar of various agricultural works, make it possible to approach the issue of zoning and adaptation of the hybrid to field conditions from a scientific viewpoint. The study of phytometric characteristics of maize corresponding to the five main stages of its development are discussed below and are included in the research task. The data on heat requirements based on the sum of active temperatures have been calculated in accordance with the growth patterns of maize of different groups of ripeness.

Date of sowing maize by year varied from April 29 to June 10 and depended on soil and air temperatures. Duration of the period from sowing to emergence varied from 5 to 16 days. The longest period was marked in the 4th year (on day 16) at the average daily temperature of 14.1°C. In the 5th year, at the lower average daily temperature of 13.9°C, the period was slightly shorter (on day 14) (Fig. 1). The reduction of this period was affected by the late date of sowing in the 5th year at a higher soil temperature. In the 6th year, seedlings emerged on day 8 at the average daily air temperature of 16.1°C. In the 1st, 2nd and 3rd years, despite the fact that late-ripening hybrids were sown, seedlings emerged on day 5-6 at high average daily air temperatures of 23.4-26.1°C and, accordingly, in a more heated soil (planting time referred to late May – early June) (table I). In the diagram of the logistic function, this stage (I) is indicated by the point of transition to the stage of biomass and stem growth, emergence of leaves involved in photosynthesis (Fig. 2).

The third-leaf stage marks the moment of leaf unfolding. This phenophase has a certain value for cereals, as it means the transition of the plant to nutrition of all unfolded germ leaves through photosynthesis. Maize forms five germ leaves in the embryophyte, and it is more correct to mark the fifth-leaf stage as the completion of germ leaves unfolding process. But in practice it can be difficult to track this phenophase, due to the rapid emergence of the fourth and fifth leaves. Duration of this stage for late-ripening hybrids in the 1st, 2nd and 3rd years made 7-10 days at favorable average daily air temperatures of 22.9-25.3°C (Fig. 1). In the 4th year duration of the third-leaf stage for early-ripening hybrid Dneprovsky-98MB was the highest (20

days) at the average daily air temperature being below optimum for this period of 14.2°C. In the 5th year – 16 days, and in the 6th year – 7 days at average daily temperatures of 16.8°C and 15.6°C, respectively (table I). In the diagram of the logistic function, the third-leaf stage (II) corresponds to the point of transition to the rectilinear site and the stage of active stem growth (Fig. 2). The largest increase of 15 and even 20 cm per day in warm and humid days, is observed before panicle formation from the upper leaf and at the beginning of the panicle flowering. It is represented with a rectilinear section of the logistic function (Fig. 2). Maximum growth of the stem is reached at the inflection point of the logistic function (III) and corresponds to the panicle stage: on day 42 in the 1st year; on day 24 in the 2nd year; on day 45 in the 3rd year; on day 62 in the 4th year; on day 55 in the 5th year; on day 53 of the 6th year. The sum of active temperatures, both for late-maturing and early-maturing hybrids and varieties was approximately the same and amounted to 944-1092.6°C (table II). In the 2nd year, duration of the third stage made 12 days with the average daily temperature of 21.8°C and an insufficient sum of active temperatures equal to 564.6°C, which affected the productivity of maize cobs. In the 6th year, the period from the third-leaf stage to the panicle stage was the longest one – 38 days at the average daily temperature of 18.4°C, whereas in other years at this stage the duration was 25-30 days at an average daily temperature of 21.6-23.4°C.

Height growth of stems is most often completed by the time of panicle flowering completion, and a bit rarer – by the time of cob formation completion. At the same time, after the beginning of panicle flowering, stem growth takes place not only due to the uppermost internode but also due to intercalary growth of internodes with shoots bearing productive cobs. It is known from the literature source [4] that all 9 stages of panicle development and 12 stages of organogenesis of maize cob development can be traced by the growth cone. Deep processes are very difficult to track with this methodological approach. Moreover, they are not decisive in identifying the correlation between temperature and morphological stages of maize development. Therefore, the main emphasis was placed on the five stages presented in Fig. 2.

Height growth of maize stems practically stops by the milk ripeness stage (IV), and all nutrients serve to the formation of cobs. In the diagram, this is the transition point to saturation plateau (Fig. 2). In the 1st year, it is the 70th day of vegetation; in the 2nd year – the 55th day; in the 3rd year – the 78th day; in the 4th, 5th and 6th years – the 80th day of vegetation. The sum of active temperatures at the stage of milk ripeness varied from 1284.1°C in the 2nd year to 1832.9°C in the 3rd (table II).

The last point on the logistic function corresponds to the phase of gold ripeness (V), which in the 1st year came on day 103 of vegetation at the sum of active temperatures of 2331.3°C. In the 2nd year, it is respectively the 100th day of vegetation at the sum of active temperatures 2035.6°C. In the 3rd, 4th, 5th and 6th years, it is the 110th day of vegetation at the sum of active temperatures 2414.8°C, 2170.3°C, 2264.7 °C and 2115.4°C, respectively (table II).

TABLE I. DURATION OF GROWTH STAGES OF MAIZE OF DIFFERENT GROUPS OF RIPENESS DEPENDING ON THE SUM OF ACTIVE TEMPERATURES BY YEARS

sowing data		May 28	June 10	June 1	April 29	May 17	May 16
I	T _{av.}	23.4	26.1	23.7	14.4	13.9	16.1
	N	5	5	6	16	14	8
II	T _{av.}	25.7	25.0	22.7	14.2	19.3	14.6
	N	7	7	10	20	16	7
III	T _{av.}	21.6	21.8	23.4	22.2	21.6	18.4
	N	30	12	29	26	25	38
IV	T _{av.}	22.9	23.2	23.6	23.1	22.9	21.9
	N	28	31	33	18	25	27
V	T _{av.}	22.7	16.7	18.3	22.2	21.6	19.5
	N	33	45	32	30	30	30

* I – emergence, II – third leaf, III – panicle, IV – milky ripeness, V – gold ripeness
T_{av.} – average daily air temperature, °C
N – number of days

TABLE II. DURATION OF GROWTH PHASES OF MAIZE OF DIFFERENT GROUPS OF RIPENESS DEPENDING ON THE SUM OF ACTIVE TEMPERATURES BY YEARS

Research year	Vegetation periods		
	sowing – panicle	sowing – milky ripeness	sowing – gold ripeness
1st	$\frac{42}{944.1}$	$\frac{70}{1581.6}$	$\frac{103}{2331.3}$
2nd	$\frac{24}{564.6}$	$\frac{55}{1284.1}$	$\frac{100}{2035.6}$
3rd	$\frac{45}{1051.6}$	$\frac{78}{1832.9}$	$\frac{110}{2414.8}$
4th	$\frac{62}{1092.6}$	$\frac{80}{1507.1}$	$\frac{110}{2170.3}$
5th	$\frac{55}{1042.3}$	$\frac{80}{1618.1}$	$\frac{110}{2264.7}$
6th	$\frac{53}{939.7}$	$\frac{80}{1529.4}$	$\frac{110}{2115.4}$

* numerator – duration in days
denominator – sum of active temperatures, °C

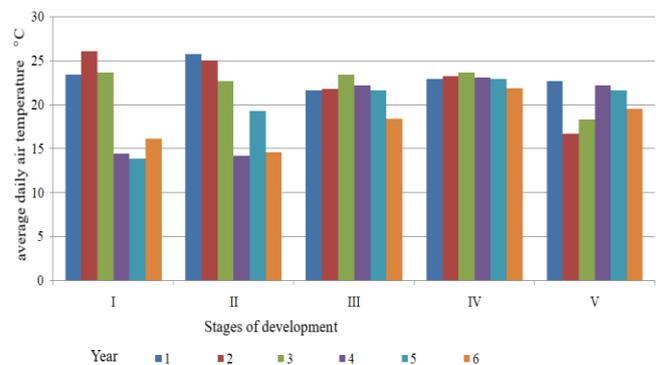


Fig. 1. Bar chart of average daily air temperature distribution by the stages of development for the six-year period

I – emergence, II – third leaf, III – panicle, IV – milky ripeness, V – gold ripeness

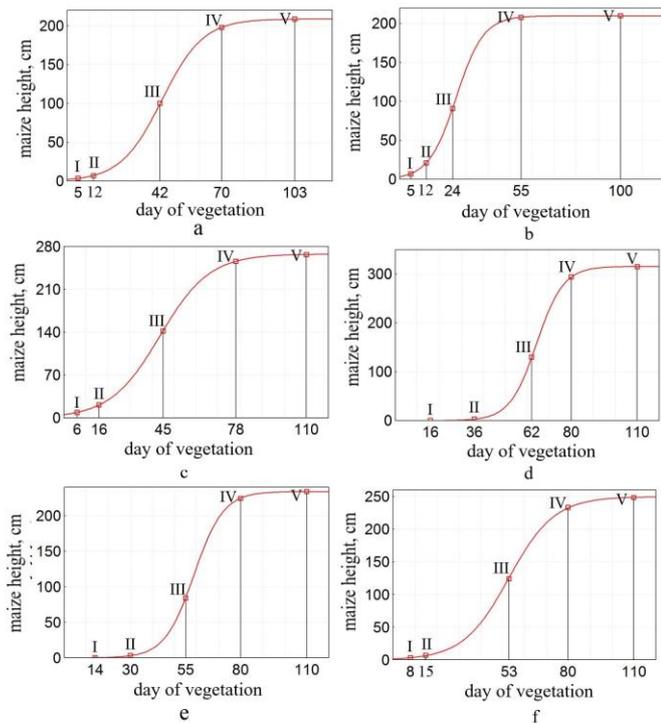


Fig. 2. Logistic dependence of maize growth by years and its connection with the stages of development

I – emergence, II – third leaf, III – panicleation, IV – milky ripeness, V – gold ripeness

A – the 1st year, B – the 2nd year, C – the 3rd year, D – the 4th year, E – the 5th year, F – the 6th year

IV. CONCLUSION

Analysis of morphometric indicators and stages of morphogenesis of maize development has shown their connection with the sum of active and average daily temperatures. The data on heat requirements have been calculated in accordance with the growth patterns of maize of different groups of ripeness. The main stages of irrigated maize growth presented in the form of determining points and logistic function areas have been allocated by calculations for assessing maize condition and forecasting the development.

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