РЕЗУЛТАТИ ОТ ЧИСЛЕНИ ЕКСПЕРИМЕНТИ С МОДЕЛ ЗА ПРОРАСТВАНЕТО НА СЕМЕНАТА И ПОНИКВАНЕТО ПРИ ЦАРЕВИЦАТА
РЕЗУЛЬТАТЫ ЧИСЛЕННЫХ ЭКСПЕРИМЕНТОВ С МОДЕЛЬЮ ПРОРАСТАНИЯ СЕМЯН И ФОРМИРОВАНИЯ ВСХОДОВ КУКУРУЗЫ
RESULTS OF NUMERICAL EXPERIMENTS WITH MODEL MAIZE SEED GERMINATION AND SEEDLING EMERGENCE

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Резюме

Разглежда се влиянието на факторите на околната среда върху прорастването на семената и поникването при царевицата. Описано е влиянието на температурата и влажността на почвата върху скоростта на процесите, протичащи в семената в ранните етапи от онтогенезиса, а също и поникването на царевичните растения при различни условия на средата.

Целта на изследването е описание и обяснение на получените резултати от числените експерименти с разработения модел, който позволява да се оцени влиянието на агрометеорологичните условия върху срока на поникване.

В резултат от проведените експерименти е установено, че температурата на почвата оказва най-голямо влияние върху прорастването на семената, докато за натрупването в семената на необходимото количество влага за началото на растежните процеси главна роля има преди всичко влажността на почвата.

Резюме

Рассматривается влияние факторов окружающей среды на прорастание семян и формирование всходов кукурузы. Описано влияние температуры и влажности почвы на скорость процессов, возникающих в семенах на ранних этапах онтогенеза, а также на появления всходов при различных условиях среды.

Целью данной работы является описание и объяснение полученных результатов численных экспериментов с разработанной моделью, что позволяет оценить влияние агрометеорологических условий на формирование всходов, сроки их появления и полноту.

В результате проведенных экспериментов установлено, что температура почвы оказывает наибольшее влияние на стадии удлинения колеоптиля, в то время как на стадии накопления семенем необходимого количества влаги для начала ростовых процессов, главную роль играет преимущественно влажность почвы.

Abstract

The response of seed germination and seedling emergence of maize to the environmental factors is examined in the present article. The effect of temperature and humidity on the rate of the processes arising in the seed at the early stages of ontogenesis as well as on the emergence of seedlings under different soil conditions is described.

The purpose of this paper is to describe and explain the results of numerical experiments with the developed model as well as the impact of the agrometeorological conditions on seed germination and seedling emergence, their capacity and duration.

A number of numerical experiments were conducted and it was established that soil temperature has the greatest influence during the time of seedling formation, whereas soil humidity plays a major role in the absorption and accumulation of moisture by the sowed seed in order to start growing. The high sensitivity of the coleoptile elongation rate to the soil temperature and density was revealed as well.

Ключови думи: царевица, агрометеорологични условия, прорастване на семената, поникване.
Ключевые слова: кукуруза, колеоптиль, проростание семян, накльовывание, появление всходов.
Key words: maize, coleoptile, emergence, germination, imbibition, seedling.

INTRODUCTION

The problem of modeling and yields forecasting in varying degrees was considered by many scientists from all countries with developed agriculture. Currently there are a large number of models of different crops development and productivity. In most of these models the early stages of plant development are not considered or exist as consisting blocks of "weather - crop" models, but there are some independent models.

Development of calculation method and assessment of shoots formation conditions, its capacity and emergence time empower agro-meteorological support of agriculture, gives the opportunity to predict the state of crop development and make timely management solutions. Designed model is aimed to eliminate shortcomings and to improve previous models of the period from sowing to emergence.

The greatest achievements in this field have the United States (Chipanshi et al., 1997; Bewley and Black, 1985; Alm et al., 1993; etc.) and the European Commission (Debeaujon et al., 2000; Forcella et al., 2000; Aggarwal et al., 2006; Palosuo et al., 2011; etc.). Ukraine also has a series of studies concentrated on the developed statistical and biological models to predict crop yields. A number of scientists engaged in modeling crop cereals, in particular are Polyoviy (2008), Dmitrenco (2005), Drozd (2010), Antonenko (2002), Sirotenko (1981), Nemchenko and Musamenco (1982) and others. These models simulate the growth and development of plants under the influence of a wide range of environmental factors.

In this paper we describe and explain the results of numerical experiments with the developed model on the impact of agrometeorological conditions on seed germination and seedling emergence, its capacity and duration.

MATERIALS AND METHODS

The model is based on the achieved level of seed germination and shoots formation modeling, certain modifications and improvements made.

More information processes underlying the model were previously considered in (Polevoy and Sinitsyna, 2013), as well as mathematical basis of these processes. Below is a brief recall of the model content and main processes which will be discussed later.

The model describes the basic physical and biochemical processes occurring in seeds during germination and formation of shoots. Some of these processes occur simultaneously, but some change each other, that is consistent.

The model consists of the following blocks:

1) block of water imbibition by seeds;
2) block of hydrolysis of endosperm reserves;
3) block of respiration;
4) block of mass storage;
5) block of coleoptiles growth (elongation);
6) block of emergence capacity and its distribution on area.

The first block of the model is separated from the others, since the results of its work is the start point of hydrolysis, respiration and growth processes occurring in seeds. Since the moisture content of seeds remained unchanged throughout the period and does not directly affect the flow of processes the future of this unit is out of interest.

Hydrolysis of endosperm reserves, respiration, weight accumulation by axial organs and coleoptile elongation occur at the same time. But it should be noted that the work of hydrolysis and respiration block begins even before the direct growth. Respiration block conventionally divided into three blocks under:

1) sub-block of endosperm respiration;
2) sub-block of embryo respiration;
3) sub-block of germ respiration.

The first sub-block is used towards the end of germination. The other two are successive. This feature is due to the fact that after the launch of embryo growth processes it goes into a seedling (germ) and therefore has two newly created bodies.

Most interesting for consideration is the block of coleoptile growth (elongation). According to this block we can determine coleoptile length and time of emergence as a consequence.

Once a seed is placed in the soil it starts to absorb moisture rapidly. This process is due to the difference in water potential of the soil and seeds. The equation that describes the water imbibition by the seed is below.

$$\Delta W_s^j = S_s P_s \left(\psi_{soil}^{j-1} - \psi_s^{j-1}\right), \qquad (1)$$

where ΔW_s^j is water flow into the seed, g per day; j is step in time, day; S_s is absorptive surface of the seed cm^2, P_s is seed membrane permeability, sec per cm; ψ_{soil} is water potential of the soil, MPa; ψ_s is water potential of the seed, MPa.

After reaching a certain levels of moisture content the process of respiration and hydrolysis begin (marked as “crit 1” in the model algorithm) triggering of growth processes and start of axial organs (roots and coleoptiles) development (marked as “crit 2”), increasing their dry weight.

Coleoptile is a cylinder of constant radius.

The speed of coleoptile elongation is described as a function of its mass accumulation with regard to mechanical resistance of soil as determined soil density ρ_{soil} and its moisture content. As a result of laboratory experiments it is revealed that the elongation of coleoptile before germination occurs exponentially which is included in mathematical terms of the process

$$H_{sp}^{j} = \exp\left(m_{sp}^{j}\frac{1}{\rho_{sp}}\right)\frac{1}{\pi r_{sp}^{2}}k_{sp}(\rho_{soil})k_{sp}(W_{soil}^{j}) \qquad (2)$$

where H_{sp}^{j} is length of sprouts at the *j-th* day, cm; $m_{sp(r)}^{j}$ is weight of sprouts (roots), g; *ρ col* is specific density of sprout plant mass, g / cm^3; r_{sp} is radius of the sprout base, cm; $k_{sp}(\rho_{soil})$ is function of soil density effects on sprout growth; $k_{sp}(W_{soil})$ is function of upper soil layers moisture influence on the sprouts elongation.

The model was adjusted using laboratory experiments on the maize seeds germination done with different temperatures (12, 18 and 22^o C) and constant moisture. Seeds were rolled into filtering paper and put horizontally in reservoirs with certain water layer to keep rolls constantly moistened during experiment. Seed samples were taken every day to determine moisture content using drying oven. After triggering growth processes dry weight and length of axial organs were determined as well.

Model verification was done using Odessa Hydro-meteorological Center data for 6 research stations in Odessa region for 5 years (from 2009 to 2013). Considered parameters are dates of sowing, germination and emergence, soil temperature and moisture content in 10 cm soil layer, precipitations and visual observations of upper soil layers moisture.

RESULTS

The model was implemented on a PC using Microsoft Office Excel. Corn was selected to identify the model parameters. Most of the initial parameters were obtained from the experiment with the germination of corn seeds in the laboratory environment. However, some parameters were obtained by analyzing the data available in the literature, as well as through optimization and manual selection.

A series of numerical experiments were implemented to investigate the sensitivity of the model to changes in environmental parameters during seed germination. The model is sensitive to changes in temperature by 1^o C, humidity of 1 mm and changes in soil density of 0,1 g / cm^3. Initial settings, seed size and its moisture content at sowing, moisture content depending on soil type could be changed as well. The time step was chosen as one day. Loamy soil layer thickness of 5 cm with the field moisture capacity of 10 mm was considered. The optimal soil moisture under those conditions is 8 mm.

The amount of agrometeorological factors that affect the time and capacity of emergence reduced to three the most important ones which are temperature, moisture and density of soil.

It is known that the process of germination consists of two consecutive phases: 1) seed moisture absorption and its swelling; 2) sprouts growth and reaching the soil surface. Therefore, the numerical experiment also was divided into two stages: 1) investigation of the rate of seed moisture accumulation; 2) investigation of coleoptile elongation rate influenced by environmental factors.

The first phase of the experiment describes the seeds water imbibition until the moisture level becomes sufficient for growth processes beginning under different soil temperature and moisture.

Below the process is described in details. Figure 1 clearly shows that soil conditions kept during the period in a level of 7-9 mm of moisture and 22^o C of temperature make seeds swell in 2 days. In the case of insufficient moisture content the period will be extended up to 3 days. Water absorption slows down with temperature decrement and imbibition period may last 3-5 days under optimal soil moisture and can be extended up to 7 days under insufficient moisture content (Fig. 1). After reaching critical water content (marked as “crit 2” on Fig. 1) seed moisture does not change.

There is no doubt that temperature is the main factor governing water imbibition rate of seed. The intensity of water accumulation varies with temperature. The increase in temperature accelerates the rate of seed water imbibition and decrease cases delaying the process.

An important role is played by soil moisture as well. Its reduction slows the water imbibition. Because of high water potential seeds can absorb moisture even from the soil with low moisture content, but not from the soil with moisture less then moisture of resistant wilding. Increased soil moisture accelerates water accumulation, but in the case of low temperatures there is a risk of seed damage by fungi and harmful bacteria that can cause further germination delays, their infrequent and death of plants. Seeds react strongly to limit soil moisture reserves, which delays the absorption of water, rather than raising them.

Thus, the main factor which affects the rate

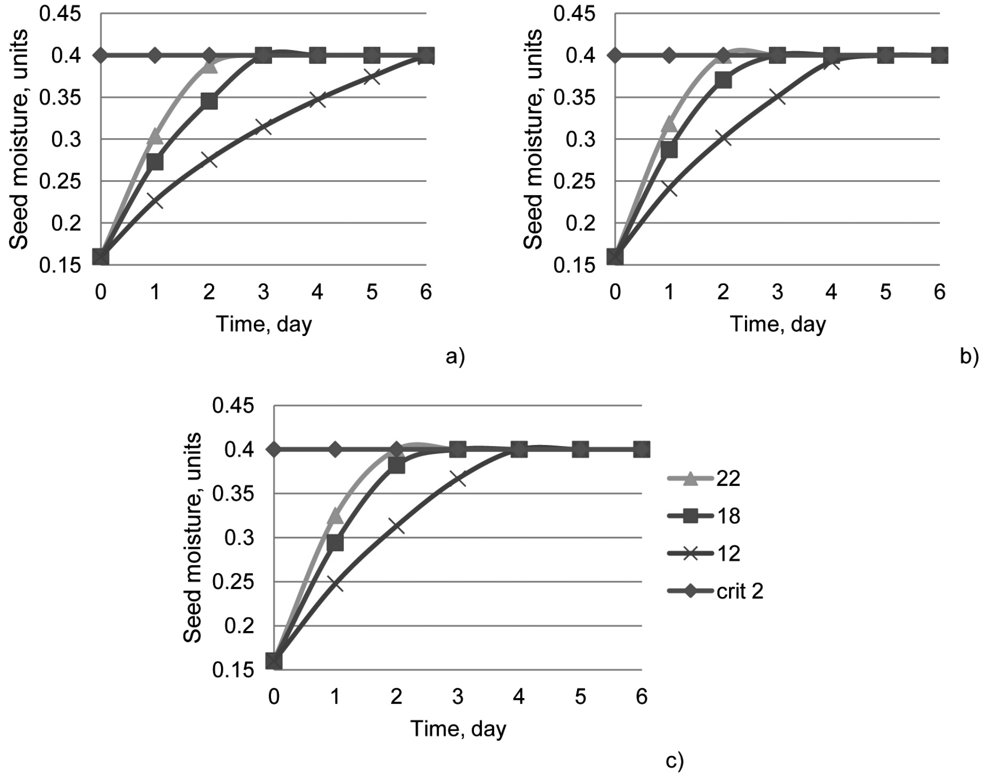

Рис. 1. *Динамика накопления влаги семенами при температуре почвы 12° C, 18° C, 22° C и различном содержании влаги в 5 см слое: a) 5 мм; b) 7 мм; c) 9 мм*
Fig. 1. *Dynamics of seed moisture accumulation at soil temperature 12° C, 18° C, 22° C and different soil moisture content in 5 cm layer: a) 5 mm; b) 7 mm; c) 9 mm*

of accumulation of seed moisture is soil temperature, but when the temperature is optimal the factor which limits the accumulation of moisture is soil moisture.

The results of water imbibition modeling coincide with the laboratory experiment in process orientation and obtained dynamic curves of moisture content in seeds. Startup growth processes are lightly different. According to the numerical experiments with the model its start 1 day earlier laboratory data represented. However, this can be explained by the conditions of the laboratory experiment. In the wild conditions soil tightly envelops seeds that involve the entire surface of grains, when during laboratory simulation grains can consume moisture only from its sides as it requires by the “roll” method which was used for research.

The second part of the experiment describes the effect of temperature, humidity and soil density on the rate of coleoptile elongation and emergence as a consequence.

Corn plant throughout its entire life cycle is a subject to various conditions that affect both favorably and unfavorably on the vital functions of the body and its performance. The ability to endure adverse conditions depends on conditions, under which plant was formed, and the depth and duration of individual factors and their combinations effects.

The experimental results were grouped by soil moisture conditions during the period.

Under the optimum moisture and optimum temperature the limiting factor for emergence formation is the density of the soil, namely increasing soil density prolongs germination time. So with the required density (0.8 g / cm^3) coleoptiles can reach the soil surface in 5 days after sowing, when the density is 1.4 g / cm^3 sprouts appear at least in 7 days (Fig. 2). Under greater soil density more energy and time required for coleoptile to make a way towards surface.

It should be noted that even under optimal moisture condition, soil temperature with decreasing intensity seed germination is also reduced. As at 18 °C sprouts appear in 7-10 days and at 12° C – at least in16 days after sowing.

Temperature accelerates the hydrolysis of reserve substances grains, breathing and

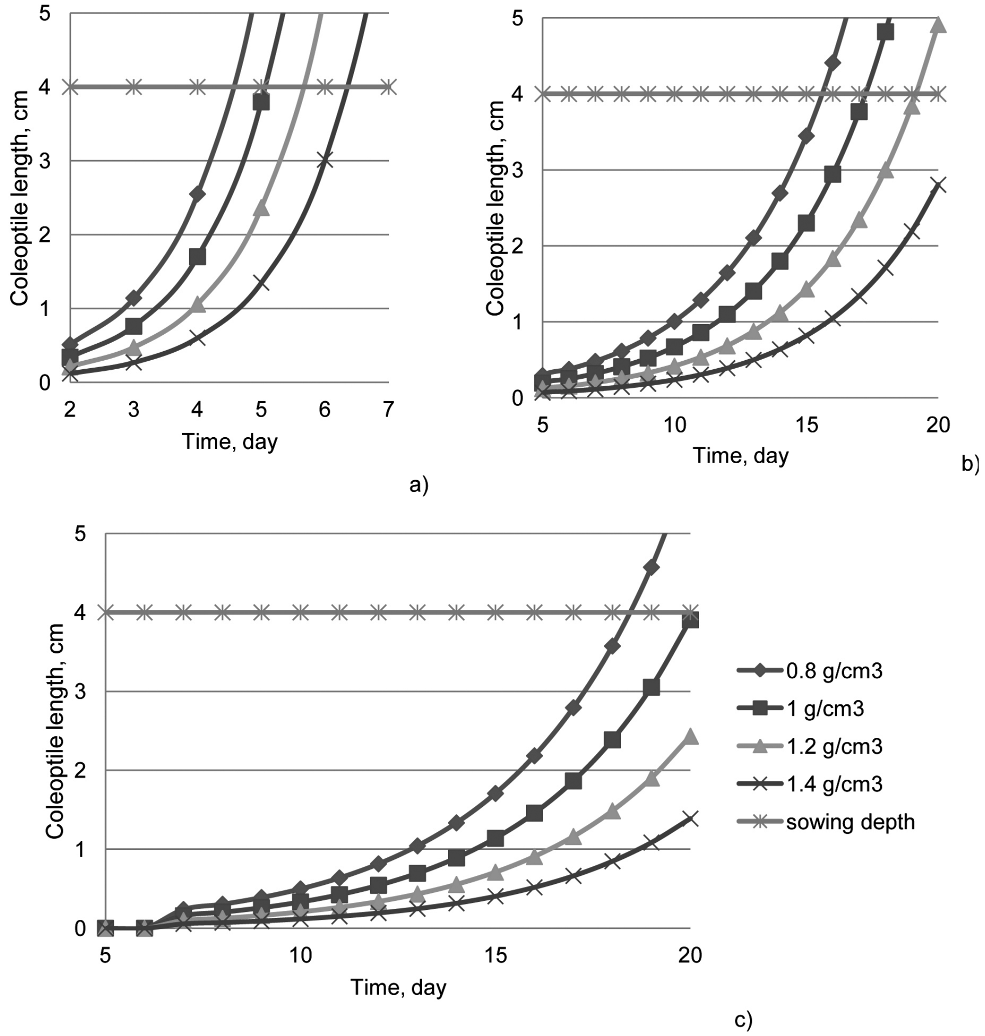

Рис. 2. *Динамика удлинения колеоптиля в почве с различной температурой и содержанием влаги в слое 5 см и плотностью почвы от 0,8 до 1,4 г/см³: a) 22°C и 7 мм; b) 12°C и 7 мм; c) 12°C и 5 мм*
Fig. 2. *Dynamics of coleoptiles elongation at different soil temperature and moisture content in 5 cm layer with soil densities from 0.8 to 1.4 g / cm³: a) 22° C and 7mm; b) 12° C and 7mm; c) 12° C and 5 mm*

accumulation of root and sprouts dry weight that visually displays the extension of coleoptile (Stroganova et al., 1983). Seefeldta et al. (2002) also noted that the most favorable temperature for germination is 20.2-25.2°C. Equally important an increase in temperature increases the activity of α-amylase which accelerates the excretion of enzymes that contribute to the transformation of reserve substances in the endosperm available for growth compounds as a result of increased funds compounds that used to increase the axial organs.

Despite the fact that soil moisture is one of the main factors influencing the rate of germination, but with increasing moisture content up to 9 mm while sprouting virtually unchanged at an optimum temperature of 22°C and also is 5-7 days after seeding and 7-10 days at 18°C . But at temperature of 12°C emergence can be expected only after 15 days. However, with decreasing humidity to 5 mm coleoptile reaches the sowing depth not earlier than 6 days at optimum temperature and the lowest density of soil, 9-11 days at 18°C and 19 days at 12°C (Fig. 2, c). Furthermore, in low moisture and temperatures close to the minimum biological cultures, with increasing density of the soil the plant is threatened with death before reaching the surface. In this case the endosperm is depleted by nutrient reserves on growth, but the shoot has not yet reached the earth's surface and plant photosynthesis cannot take place to support further growth.

DISCUSSION

The obtained results are close to Chirkov (1969) data, confirming the fact that when the soil moisture is optimal corn seed germination rates depend mainly on temperature. So at 11-12º C germination starts in 7-9 days and at 18-22º C in 2-3 days. The resulting simulation values coincide with the data by Chirkov in the range of 18-22º C, the lower temperature is slightly different.

The rapid initial moisture absorption apparently due to absorption of water covering tissues of seeds and germ stuff, playing the role of inputs to further water penetration into the endosperm according to Polevoy V.V. (1989). Reversible seed swelling indicates that participation in outdoor water awakening seed is limited mainly by hydration reaction. This however increases mobility in the material bound water and seed enzymes and biochemical reactions begin to occur which are responsible for its germination.

Poluektov et al. (2006) proposed detailed scheme of seed moisture uptake, where water potentials of embryo and endosperm are separated. As in our case the main result of moisture absorption block is the start of hydrolysis and growth of axial organs, so there is no need for additional destabilization and calculations of sufficient seeds and soil water potentials are general.

Also there is a slightly different presentation regarding the physiology of seed germination process in Poluektov et al. (2006) model. By separating the embryonic stage of feeding type, i.e. under standard laboratory conditions for the first 3 days the embryo uses only its own reserves, from 3 to 5 day while reserves of grains and endosperm and only after 5 days there is a complete shift in the endosperm type of feeding. However, as the embryo is usually only 10% of the seeds and it contains relatively small nutrient reserves, so the developed model is neglected regarding this details and considers only embryo - endospermic type of feeding.

Unfortunately we cannot compare the results of numerical experiments with real field observations data of agrometeorological stations. According to the Guidelines of agrometeorological stations and posts (2007) germination phase is observed when the first embryonic root broke the coating shell and visibly moved outside, to simulate the same is more interesting phase only seed swelling. That observation indicates when growth processes have already begun, but it marks the time of their launch.

Obviously, the early moisture accumulation is faster. Experiments conducted by Mushketova and Kazakova (2009) to study the moisture accumulation of barley seeds during the first two days after hydration also show a jump intensity of this process, namely the first hour of seeds accumulate for about 16% moisture (14% are collected by first 20 minutes after contact with water) and only 2% for the second hour. Further reduced rate of water imbibition and water accumulation in seed is very smooth and slow. This jump coincides with the swelling phases: first is physical and second is physiological swelling (Smylovenko, 2004; Tretyakov et al., 1998). Physical swelling is a process of water absorption by seeds as a porous body. It is rapid and complete within the first six hours (Alekseychuk, 1999). This step is the same with dead and alive seeds. Physiological swelling is water absorption by cells biocolloids. At this stage the seed growth in size, hydrolysis of endosperm reserve substances begins. These processes are typical only for alive seeds.

Speed of germination has an absolute value for the next harvest. Rubin et al. (1969) was established inverse relationship with the yield of spring wheat and duration of period from sowing to emergence. Rapid germination of barley causes rapid kinking roots increases plant productivity. With the acceleration of germination decreases the probability of decay and death of seeds, especially damaged ones.

Dependence of germination period duration on temperature is not in doubt, but in a different dampening effect of temperature has been changing and is characterized by varying degrees of connection (Fedoseev, 1968).

The results of the numerical experiments with the model are close to the calculations made by Dmitrenco (1961), based on the equations describing the influence of temperature on germination duration for barley, oats, rye and wheat. But note that the resulting Dmitrenco (1961) equations are based on experiments which exclude random effects of soil moisture, depth of seeding and seed quality. According to Dmitrenco (1961), at a temperature of 22^{o} C sprouts appear in 5 days, which agrees with the results in the optimal (7 mm) and above optimum (9 mm) soil moisture content with a soil density of 0.8–1 g/cm^3. At a temperature of 18^{o} C the duration is 6 days, which compared with modeled data differs by 1-2 days. In the case of small water supplies larger deviations are also observed. In temperatures close to the biological minimum of maize there are some differences. This is because corn is a thermophilic crop and lower temperature retards the rate of growth to a greater extent than for wheat and barley, and the equation was developed mainly for them. Dmitrenco (1961) calculated duration of the period with techniques suggested by Ulanova (1958), Rudenko (1950), Ventskevich (1958) and Geslin (1952), what allows us to compare the value of a large number of existing techniques. A comparison revealed similar dependence, however, the highest degree of similarity is with Rudenko (1950) for 18o C. There are significant differences with the method of Ulanova (1958), which also explains the specific techniques for wheat.

According to Chirkov (1969) under favorable conditions seedlings appear within 6-10 days and 20-25 days under unfavorable, which also coincides with the results of numerical experiments.

According to the model developed by Pavlova (1983) in low soil moisture and temperature 13°C sprouts appear within 20 days, under optimum temperature within 3-5 days, which also agrees with the results of numerical experiments.

These results agree with the data by Jame and Cutforth (2004) where germination time and coleoptile elongation rate are measured at temperatures above 15°C, as the authors consider the characteristics of spring wheat germination which is less demanding to temperature and can grow at temperatures much lower than the ones demanded by corn. Obtained by the author beta - function describes the dependence of the daily increment of the coleoptile length due to temperature, at a time when soil moisture is not a limiting factor. The simulation results agree with the above calculated data of the beta - features and emergence time and conducted experiments by De Jong and Best (1979). However, the authors take as a basis the assumption that in maintaining a constant level of daily temperature a constant elongation takes place (mm per day), whereas the developed model takes into account a daily gradual increase in intensity of growth since the launch of coleoptile growth processes in the seeds.

Special role in the emergence and its capacity belongs to low temperatures. Low temperatures violate the biological balance between beneficial and pathogenic microorganisms in favor of the latter, fungi begin to develop that damage the seeds and young plants swelling.

Corn belongs to the thermophilic plants, i.e. such that die or have significant damage as delayed growth and significantly reduced performance when they are cooled to a temperature of about 0°C.

Maize grown in cold soil (8-10° C) in the early phase shows delayed accumulation of dry matter as carbohydrates and ascorbic acid, reduced tissue respiration and photosynthesis, its enzyme activity varies considerably and the absorption of mineral nutrients and water is slower. In crymophylactic plant physiological processes such violations are less pronounced or not observed (Rubin et al., 1969). At a lower temperature different maize varieties react differently. More resistant to it are the ripening varieties. High sensitivity to low temperatures is a characteristic of the late varieties.

Different responses to low temperatures have been observed during swelling and seed germination. Such responses are varying speed of the transition to active plant life as well as rate of water absorption, and hence swelling grains, higher in more cold-resistant plants.

The negative impact of low soil temperature on maize grains is enhanced by the fact that they can be damaged by fungi. Most seeds are dying, field germination is reduced, and the crops are reduced as well. Typically, to reduce the damage being inflicted by fungi, pre-seed cultivation of various substances which could destroy the fungi is used.

Sensitivity of maize grains to low temperature depends on its effect on the embryo. The seeds of not crymophylactic varieties do not germinate at low temperatures even in the case than enough amount of water was absorbed. In such seeds low temperature slows the process of converting spare substances as starch, protein and, fat in a form that is absorbed by the embryo and makes it difficult to transport it to active state.

With sufficient soil moisture similarity caryopsides and growth of seedlings depend mainly on soil temperature. The results of the numerical experiments coincide with the above published data. We add that the data fall into intervals calculated duration period, which in turn limited the density and moisture content of the soil. It is clear that when the density of the soil is lower, then sprouts appear earlier. For example, at a temperature of 18.1°C emergence should be within 9 days whereas in the calculation model based on variability of the soil duration it will be within 7-11 days.

Dependence of the maize seed germination on temperature is crucial for choosing the sowing time. This question has accumulated a lot of experimental data, from which hung corn is best to exercise when the soil temperature at a depth of seeding is 10-12°C.

In a more detailed processes of root apex growth of young maize seedlings in soil cooled to 12° C it was found that the intensity of the slowing of cell division, the growth of root tip in length and the accumulation of nucleic acids and proteins increases.

Thus the effect of temperature on germination described by the numerical experiments in the model is confirmed by field and laboratory experiments described in the literature.

Unlike most authors Forsella et al. (2000) emphasizes the need to consider the reaction of seeds to changing soil moisture. These labels are numerically equivalent to the soil water potential and show its effect on the time of emergence and its capacity. Most favorable for growth in his opinion is the water potential of 0.5 MPa, water stress occurs at 10 MPa which greatly limits the emergence. Our results in numerical terms are difficult to compare with experiments made by Forsella et al. (2000) but the orientation of the process is similar. In our case, with moisture of 5 mm the processes of growth are slowed and with moisture content of less than 3 mm it is observed there is plant water stress and depression.

Nosatovskyj (1950), based on experiments with wheat, found that the first green leaf of the wheat goes through the top of coleoptile or from the soil on its surface. At higher temperatures the first leaf makes its way through coleoptile earlier than coleoptile appears above ground, whereas a low temperature leaf appears after coleoptile reaches the surface, and in the second case the leaf during its growth in the soil is protected by coleoptile. Thus coleoptile protects the leaf from its direct contact with the soil and the pests contained therein. This is reflected in the plant resistance against some diseases. Including hiberella and hilmentosporum are more damaging sprouts of wheat at 25^{o}C than at lower temperatures when shoot breaks surface protected by coleoptile.

Jame and Cutforth (2004) also noted the possibility of the first leaf appearance in soil layer, but it is not possible for deep seed foundation and small density of the soil. The authors explain the process that coleoptile reaches sowing depth value of about 2.5 cm at its apex relaxed start to get some sunlight which stimulates the activity of the young plant to begin breaking coleoptile and emerge a first leaf. However, the authors did not determine the impact of the accelerated development of the further growth of vegetation and plant resistance.

CONCLUSIONS

1. Dynamic model of grain crops germination and seedling emergence developed. It allows defining and evaluating the date of germination, emergence capacity, distribution of plants with different sowing depth and number of plants per unit area. The model describes dynamics of seed moisture absorption and seed physiological and biochemical processes: hydrolysis of endosperm reserves, respiration, distribution of the products of hydrolysis between axis organs and their growth.

2. In numerical experiments it was found that the formation of shoots influenced by soil moisture is most pronounced at the stage of absorption and accumulation of moisture from seed sowing to start of growth process while the main role during whole considered period belongs to soil temperature. The high sensitivity of coleoptile elongation rate to soil density was discovered as well.

3. Under optimal conditions of surrounding soil environment seeds already afoot within 2 days, under a lack of moisture during this period is extended up to 3 days. With decreasing temperature the moisture accumulation is also slowing down and may last up to 3-5 days, but on the background of insufficient moisture may reach even 7 days.

4. In the conditions of maintaining optimum soil environment the limiting factor for germination is soil density. Thus under minimum value of soil density 0.8 g/cm^3 coleoptile can reach ground surface at 5-th day after sowing, when under soil density of 1.4 g/cm^3 shoots emerge only after 7 days. With soil temperature the seed germination rate is also reduced. So at 18^{o}C shoots will emerge after 7-10 days and at 12^{o}C at least after 16 days after sowing.

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