

Influence of seeding density and fertilizing on water consumption, growth and development of maize hybrids

V.I. Polyakov, L.M. Karpuk, I.D. Prymak, A.A. Pavlichenko, V.M. Karaulna,
L.V. Yezerkovksa, R.M. Kulyk, S.S. Shokh

*Bila Tserkva National Agrarian University
Soborna Square 8/1, Bila Tserkva, Kyiv region, Ukraine
E-mail: lesya_karpuk@ukr.net, polyakov-vlad@ukr.net*

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We presented the analysis of water consumption, growth, and development of maize hybrids depending on crops and fertilizer density. We conducted our research under Bila Tserkva National Agrarian University (Ukraine) educational and production center conditions in 2017-2019. During the active growing season of corn plants (June), moisture reserves in the 0-20 cm layer of the soil decrease to the level of unsatisfactory, and the plants experience a lack of moisture. Although, as results of defining moisture stocks in 0-100 cm layer of soil show, plants begin to assimilate it in the third ten-day period of May actively, and there is a sharp transition to good moisture stocks in the first ten-day period of June and to poor ones in the second and third ten-day periods of June. Cultivation of maize hybrids with FAO over 400 in unstable moisture conditions is quite risky because plants experience a significant lack of moisture in periods of their active growth and development. We have proved that at the density of crops within 55000/ha, the highest coefficients of water consumption were observed compared to plant densities of 65000 and 75000/ha. At hybrid DO Pivikha, the difference between average values of coefficient of water consumption at densities of crops 65000 and 75000/ha, was 25.5 and 46.75 m³/t, at hybrid DO ORLIK – 14.25 and 41.0 m³/t and at hybrid DO SARMAT respectively 17.5 and 39.0 m³/t. We found that the mineral system of fertilization compared with the organic-mineral and organic promotes water consumption growth per unit production in DN Pivikha by 4-15 m³/t, in DN ORLIK by 1-7 m³/t, and in DN SARMAT by 7-15 m³/t. The obtained patterns, for the most part, do not exceed the value of NIRO.05. In general, the duration of the growing season of the plants of the hybrid DO Pivikha was 109 days, and the hybrid DO ORLIK was 122, and the hybrid DO SARMAT was 129 days. These hybrids were in optimal conditions for growth and development and met the declared values of FAO, since for PO Pivikha, the limits of the optimal duration of the vegetation period were determined as 107-115 days, for the hybrid DO ORLIK - 120-125, and for the hybrid DO SARMAT - 128-130 days.

Keywords: maize, varietal characteristics, plant growth and development, water consumption, similarity, seeding density.

Introduction

The study of peculiarities of corn plants' growth and development in ontogenesis is significant in creating practical energy-saving technologies for growing corn hybrids adapted to the region's biological needs and opportunities. Under the conditions of the right-bank Forest-steppe of Ukraine, corn conservation in critical dry periods is relevant. Although this crop has a good resistance to drought and can restore growth and development after short dry periods and partial loss of turgor, in recent years, the lack of precipitation, ground or air drought, and exposure to high temperatures occur more often at critical stages of growth and development of maize. Thus, the plants have less chance of developing a high level of productivity later on.

To safeguard against the coincidence of unfavorable growing conditions and critical periods of growth and development of crops, scientists advise growing hybrids of different ripeness groups. After all, even with a difference of 3-4 days, plants' situation can change dramatically. In corn, the more late-ripening hybrids, the more effective it is to grow them because they accumulate much more solar energy in the harvest than early-ripening hybrids, which is not entirely true for the conditions of the Kyiv region. Thus, moisture reserves in the soil and available opportunities for precipitation in recent years are minimal, and in conditions of unstable moisture may not be enough moisture to realize the high productivity potential of late-ripening hybrids. Besides, the harvesting of hybrids with high FAO values falls in late autumn, when precipitation is active and, consequently, the grain does not meet the requirements and requires post-harvest drying (Tsikov, 2003; Belov, 2018; Tomashuk, 2018; Ushkarenko et al., 2016). From the physiological point of view, maize is an essential issue to create an optimal photosynthetically active agrophytocenosis and provide plants with sufficient amounts of nutrients. After all, the fibrous root system works effectively mainly in the upper soil layers. Therefore, mineral nutrition does not work effectively in conditions of total moisture deficit, and organic cannot provide a significant need of corn plants in elements of nutrition in a relatively short period (Morgun, 2001; Likhovid, 2015; Barlog et al., 2008; Troyer, 2004).

The research aimed to identify the features of water consumption, growth, and development of maize hybrids depending on the density of crops and fertilization regime.

Materials and methods

Studies were conducted under the conditions of the Bila Tserkva National Agrarian University's educational and production center in 2017-2019. We studied the influence of the density of crops and fertilizer system on the formation of yields of corn hybrids: DO Pivikha FAO 180 (early maturing), DN ORLIK FAO 280 (medium-early), DN SARMAT, FAO 380 (medium-early). Fertilizer patterns (Table 1) were N240P120K40 (1), N120P60K20 + 3.5 t organic compost (2), organic compost, 7 t/ha (3), manure 40 t/ha (4).

Phenological observations of plant growth and development phases and dynamics of corn mass accumulation were carried out according to state variety trials (Ermantraut et al., 2007). Statistical analysis of research results was performed using Statistica ver. 6.0 software (Methods of state testing of varieties of agricultural crops, 2000).

Results

Maize plants require significantly less moisture than C3-photosynthetic crops, in which excess moisture is needed to cool the leaf surface. However, they usually absorb only 7-8% of the total volume of water consumed during the vegetation period from the emergence of seedlings to the formation of 12-15 leaves, and up to the phase of milky ripeness, 69-73% of the total volume of water consumed during the vegetation period is spent. Accordingly, in conditions of the Right-bank forest-steppe of Ukraine, especially in the zone of unstable moisture, the central precipitation, which saturates soil moisture reserves, passes in the autumn-winter period. During the vegetation period of corn, precipitation is 40-60 mm per month. Under the influence of high temperatures and errors in soil preparation for sowing and care of plants, creating too condensed agricultural phytocenosis is extremely low for sufficient growth and culture development.

Table 1. Average deposits of productive soil moisture (2017-2019, mm)

Month	Decade	Deposits of productive moisture (mm) in the soil layer (cm)			
		0-10	0-20	0-50	0-100
April	I	20.3	35.7	88.7	176.7
	II	16.3	29.7	77.0	160.0
	III	19.7	35.7	85.3	166.0
May	I	19.0	31.3	76.3	150.0
	II	15.0	27.7	69.0	136.3
	III	14.7	27.7	72.0	137.3
June	I	11.7	17.7	43.7	99.3
	II	8.0	12.7	33.7	78.3
	III	9.7	13.3	23.7	50.0
July	I	8.3	15.3	27.7	49.3
	II	10.0	15.7	26.7	40.7
	III	16.3	25.0	35.7	42.0
August	I	8.7	13.0	27.0	41.3
	II	5.7	10.0	18.7	29.3
	III	5.7	11.3	18.0	30.0
September	I	8.0	12.7	21.0	31.3
	II	8.3	13.7	21.3	31.0
	III	7.3	14.0	21.0	33.3

If we evaluate moisture reserves in 0-20 cm layer of soil, they were at the level of satisfaction in the first third ten-day period of April, and moisture reserves in the meter soil layer can be evaluated as very good. Increase of temperatures and accordingly growth of evaporation from the field surface and vegetation of cultivated plants and weeds resulted in a decrease of moisture stocks in the 0-20 cm layer of soil in May to 27.7-31.3 mm. However, they all met corn moisture requirements and were rated as satisfactory, while reserves in the 0-100 cm layer decreased to 137.3 mm in the third ten-day month, although they were classified as useful.

During the active growing season of corn plants (June), moisture reserves in the 0-20 cm soil layer decrease to the level of unsatisfactory, and at this time, the plants experience a lack of moisture. Although, as the results of determination of moisture reserves in 0-100 cm layer of soil show, plants start to actively assimilate it from reserves in the third ten-day period of May, there is a sharp transition to sufficient moisture reserves in the first ten-day period of June and to poor ones in the second and third ten-day periods of June. In July, trends of June were retained - moisture stocks in the soil layer 0-20 cm were at the level of unsatisfactory and only in the third ten-day period of July due to rains restored to the level of satisfactory - 25.0 mm. However, moisture stocks in the 0-100 cm layer were relatively insignificant and can be classified as very poor. In August, only 10-13.0 mm of moisture remained in 0-20 cm layer, which negatively affected the growth and development of corn plants, especially of late groups of ripeness, where we registered the active growth in July-August. During this period, insignificant and very poor were moisture reserves in the 0-100 cm layer of soil.

So, the cultivation of maize hybrids with FAO over 400 in unstable moisture conditions is quite risky, because the plants experience a significant shortage of rainfall during the periods of active growth and development.

Table 2. Water consumption of maize hybrids depending on the density of crops and fertilization regime (average for 2017-2019, m³)

Hybrid	Harvest density, thousands	Fertilizing	Evapotranspiration ratio, m ³ /t
DN Pivikha, FAO 180 (short-season)	55	N ₂₄₀ P ₁₂₀ K ₄₀	325
		N ₁₂₀ P ₆₀ K ₂₀ + 3.5 t Organic compost	315
		Organic compost, 7 t/ha	318
		Manure 40 t/ha	310
	65	N ₂₄₀ P ₁₂₀ K ₄₀	298
		N ₁₂₀ P ₆₀ K ₂₀ + 3.5 t Organic compost	294
		Organic compost, 7 t/ha	285
		Manure 40 t/ha	289
	75	N ₂₄₀ P ₁₂₀ K ₄₀	278
		N ₁₂₀ P ₆₀ K ₂₀ + 3.5 t Organic compost	270
		Organic compost, 7 t/ha	267
		Manure 40 t/ha	266
Dn Orlik, FAO 280 (mid-early)	55	N ₂₄₀ P ₁₂₀ K ₄₀	314
		N ₁₂₀ P ₆₀ K ₂₀ + 3.5 t Organic compost	310
		Organic compost, 7 t/ha	307
		Manure 40 t/ha	310
	65	N ₂₄₀ P ₁₂₀ K ₄₀	299
		N ₁₂₀ P ₆₀ K ₂₀ + 3.5 t Organic compost	296
		Organic compost, 7 t/ha	294
		Manure 40 t/ha	295
	75	N ₂₄₀ P ₁₂₀ K ₄₀	272
		N ₁₂₀ P ₆₀ K ₂₀ + 3.5 t Organic compost	271
		Organic compost, 7 t/ha	265
		Manure 40 t/ha	269
55	N ₂₄₀ P ₁₂₀ K ₄₀	304	
	N ₁₂₀ P ₆₀ K ₂₀ + 3.5 t Organic compost	297	
	Organic compost, 7 t/ha	295	
	Manure 40 t/ha	297	
DN Sarmat, FAO 380 (mid-season)	65	N ₂₄₀ P ₁₂₀ K ₄₀	287
		N ₁₂₀ P ₆₀ K ₂₀ + 3.5 t Organic compost	280
		Organic compost, 7 t/ha	277
		Manure 40 t/ha	279
	75	N ₂₄₀ P ₁₂₀ K ₄₀	269
		N ₁₂₀ P ₆₀ K ₂₀ + 3.5 t Organic compost	258
		Organic compost, 7 t/ha	256
		Manure 40 t/ha	254
HIP _{0.05}			11

The transpiration factor of maize can usually be 250 m³/t, although to form a high level of productivity, plants need 450-600 mm of rainfall during the growing season, and therefore the optimal transpiration factor for this crop is defined as 300-400 m³/t (Tomashuk, 2018). Our studies show that in corn crops under unstable moisture conditions in the Right-Bank Forest-steppe of Ukraine, the transpiration factor varied from 254 to 325 m³/t. We also proved that at a density of 55000/ha, the highest water consumption coefficients were observed compared to 65000 and 75000/ha. Thus, in DO Pivikha, the difference between water consumptions at densities of 55000-65000 and 55000-75000/ha was 25.5 and 46.75 m³/t, in DO ORLIK - 14.25 and 41.0 m³/t, and in DO SARMAT - 17.5 and 39.0 m³/t.

In our opinion, the obtained regularities are associated with the features of formation of the appropriate microclimate by plants in dense and optimal crops, which is confirmed by other studies (Morgun, 2001; Kolpakova, 2017; Mikova et al., 2013; Kalinova

et al., 2014) and testifies the correct spatial arrangement of plants and the choice of their density for optimal conditions of photosynthesis and water consumption. In addition to the identified regularities, we also determined the peculiarities of corn fertilization systems' influence on their water consumption coefficients. Thus, we found that the mineral system of fertilization compared with organic-mineral and organic promotes the growth of water consumption per unit production in DN Pivikha by 4-15 m³/t, in DN ORLIK by 1-7 m³/t, and in DN SARMAT by 7-15 m³/t. For the most part, the obtained patterns do not exceed the value of HIP_{0.05} (Table 3).

Table 3. Germination and sprouting density of maize hybrids depending on the fertilization and seeding density (average for 2017-2019).

Hybrid	Plant density, thousands	Fertilizing	Laboratory germination, %	Field germination, %	Sprout density	Harvest density	
DN Pivikha, FAO 180 (short-season)	55	N ₂₄₀ P ₁₂₀ K ₄₀	93.6	85.5	59378	54801	
		N ₁₂₀ P ₆₀ K ₂₀ + 3.5 t Organic compost	93.6	85.4	59339	54979	
		Organic compost, 7 t/ha	93.6	85.7	59482	55239	
	65	Manure 40 t/ha	93.6	85.8	59553	55023	
		N ₂₄₀ P ₁₂₀ K ₄₀	93.6	85.6	71354	66081	
		N ₁₂₀ P ₆₀ K ₂₀ + 3.5 t Organic compost	93.6	85.8	71503	66386	
	75	Organic compost, 7 t/ha	93.6	85.7	71393	66248	
		Manure 40 t/ha	93.6	85.6	71292	66299	
		N ₂₄₀ P ₁₂₀ K ₄₀	93.6	84.9	81612	75075	
	55	N ₁₂₀ P ₆₀ K ₂₀ + 3.5 t Organic compost	93.6	85.1	81837	75952	
		Organic compost, 7 t/ha	93.6	85.2	81918	75431	
		Manure 40 t/ha	93.6	85.1	81855	75804	
Dn Orlik, FAO 280 (mid-early)	55	N ₂₄₀ P ₁₂₀ K ₄₀	94.2	85.6	59053	54583	
		N ₁₂₀ P ₆₀ K ₂₀ + 3.5 t Organic compost	94.2	85.5	59014	54762	
		Organic compost, 7 t/ha	94.2	85.7	59157	54833	
	65	Manure 40 t/ha	94.2	85.8	59228	54917	
		N ₂₄₀ P ₁₂₀ K ₄₀	94.2	85.7	70964	65303	
		N ₁₂₀ P ₆₀ K ₂₀ + 3.5 t Organic compost	94.2	85.9	71113	65459	
	75	Organic compost, 7 t/ha	94.2	85.8	71003	66018	
		Manure 40 t/ha	94.2	85.6	70902	65463	
		N ₂₄₀ P ₁₂₀ K ₄₀	94.2	84.9	81162	74723	
	55	N ₁₂₀ P ₆₀ K ₂₀ + 3.5 t Organic compost	94.2	85.2	81387	75043	
		Organic compost, 7 t/ha	94.2	85.3	81468	75657	
		Manure 40 t/ha	94.2	85.2	81405	75506	
DN Sarmat, FAO 380 (mid-season)	55	N ₂₄₀ P ₁₂₀ K ₄₀	93.9	85.5	59215	54746	
		N ₁₂₀ P ₆₀ K ₂₀ + 3.5 t Organic compost	93.9	85.5	59176	54945	
		Organic compost, 7 t/ha	93.9	85.7	59319	55135	
	65	Manure 40 t/ha	93.9	85.8	59391	55214	
		N ₂₄₀ P ₁₂₀ K ₄₀	93.9	85.7	71159	65410	
		N ₁₂₀ P ₆₀ K ₂₀ + 3.5 t Organic compost	93.9	85.8	71308	65872	
	75	Organic compost, 7 t/ha	93.9	85.7	71198	66069	
		Manure 40 t/ha	93.9	85.6	71097	65747	
		N ₂₄₀ P ₁₂₀ K ₄₀	93.9	84.9	81387	74778	
	HIP _{0.05}		N ₁₂₀ P ₆₀ K ₂₀ + 3.5 t Organic compost	93.9	85.1	81612	75189
			Organic compost, 7 t/ha	93.9	85.2	81693	75491
			Manure 40 t/ha	93.9	85.2	81630	75679

Determination of laboratory germination of seeds of the studied maize hybrids showed their high sowing qualities, and we noted only minor differences. Thus, the average laboratory germination of hybrid DO Pivikha was 93.6%, hybrid corn DO ORLIK - 94.2%, and hybrid DO SARMAT - 93.9%. The field germination rate was determined by the conditions of moisture availability of the upper layers of soil and granulometric composition (quality of pre-sowing preparation). Since we sowed the hybrids understudy on the same day, we did not observe significant differences between different experiment variants, and on average field germination was 85.5%. Differences between the field germination of hybrids were corrected by determining the laboratory germination and adjusting the seed rate indicators accordingly. We believe that laying experience with the formation of the correct values of plant density at the time of harvest can only consider the differences between real and optimal germination rates. Besides, to properly determine the possible losses of plants during the growing season, we analyzed the work of other scientists and found that during the growing season of maize, losses can be 5-15. However, in general, the survival rates of maize hybrids that are weakly bushy reach at least 90%. Therefore, we increased the seeding rate by 10% based on the end of the growing season to get the density of hybrids' crops understudy at 55000, 65000, and 75000 ha.

Availability of sufficient reserves of soil moisture in the layer 0-20 cm contributed to the formation of good sprouts. Thus, at full sprouts, the density of DO Pivikha at the calculated density of 55000/ha was 59 438/ha, at a density of 65000 - 71386/ha, and a density of 75000 - 81806/ha. Similar density data at the full sprouting time were obtained for two other hybrids: DO ORLIK 59113, 70996, and 81356/ha, and DO SARMAT 59275, 71191, and 81581/ha, respectively. Differences between the variants of different fertilizer systems were mainly within the error of the experiment. A significant deviation of seed germination in the variant of application of mineral nutrition was not observed, which in our opinion is due to the correct application of fertilizer following the agronomic requirements. Only in the case of the too close location of the fertilizer's mineral component to the seed may inhibit its growth processes due to the absorption of moisture by granules of mineral fertilizer. In the process of growth and development, a particular part of plants was lost due to damage by pests and diseases, exposure to adverse conditions (deficit of precipitation, thermal stress - frost or high temperatures), and due to destruction by technical means with which agronomic operations were carried out (plant nutrition, pesticide treatment).

As evidenced by the results of determining the preharvest density of corn crops, we could reach the planned values with slight deviations of density to the lower or higher side. Over the years of research, the average value of plant survival was 91%. Knowledge of the peculiarities of the duration of phenological phases of growth and development of maize hybrids will allow adapting the technology of growing to the needs of culture and avoiding critical periods of plants on the lack of nutrition factors by adjusting the timing of sowing and the possible use of growth regulators. The study of the duration of the phenological phases of growth and development showed that the hybrids DO Pivikha and DO ORLIK sprouted on the 12th day, and only DO SARMAT hybrid appeared on the 13th day. The third leaf in the hybrid DO Pivikha appeared on the sixth day after full sprouts, in DN ORLIK on the seventh, and in DN SARMAT on the eighth. We did not record any differences between the experiment variants. Accordingly, the difference in the fifth leaf's appearance was one day between hybrids DO Pivikha, DO ORLIK, and DN SARMAT. On the ninth day after the fifth leaf in the DO Pivikha hybrid, the seventh leaf appeared on the 10th day in the DO ORLIK hybrid and the 11th day in the DO SARMAT hybrid. However, the ninth leaf appeared on the sixth day in the DO Pivikha hybrid and on the other hybrids' seventh day. On the 17th day after the ninth leaf in hybrid DO Pivikha, the fifteenth leaf appeared on the 19th day in hybrid DO ORLIK, and on the 18th day in hybrid DO SARMAT.

In general, no significant acceleration or inhibition of phenological phases depending on growing technology elements was found. The differences were observed at the level of biological features of the hybrids under study. During the transition from the vegetative to the generative stage of corn growth, we observed the phenophase duration patterns. Thus, the appearance of panicles in hybrids DO ORLIK and DO SARMAT at a density of 75000/ha was delayed by one day compared to other variants of density. Compacted crops somewhat slowed plants' generative growth, although we can not note this as a negative feature. The duration of onset of phases of panicle flowering and corn cob flowering was relatively short and was entirely determined by the biological features of the hybrids studied. Simultaneously, the onset of kernel milk line of corn grain depended not only on the hybrid properties of plants. Thus, we noted a difference in the day between the mineral fertilizer system and other systems. Nitrogen is thought to increase the vegetative growth of corn plants, but in our case, heavy precipitation usually fell already in the second half of the growing season, which may have increased nitrogen availability to plants in the interphase of tasseling-kernel milk line.

The grain's complete ripeness came after the milk ripeness in hybrids DO Pivikha in 13-14 days, the medium-early hybrid DO ORLIK in 14-15 days, and the medium hybrid DO SARMAT in 16-17 days. Early-ripening and mid-ripening hybrids had lengthening of the interphase period by a day at mineral fertilizer system. Such a trend was not observed for DO SARMAT, which is most likely due to the high consumption of mineral fertilizers, including nitrogen (Fig. 1).

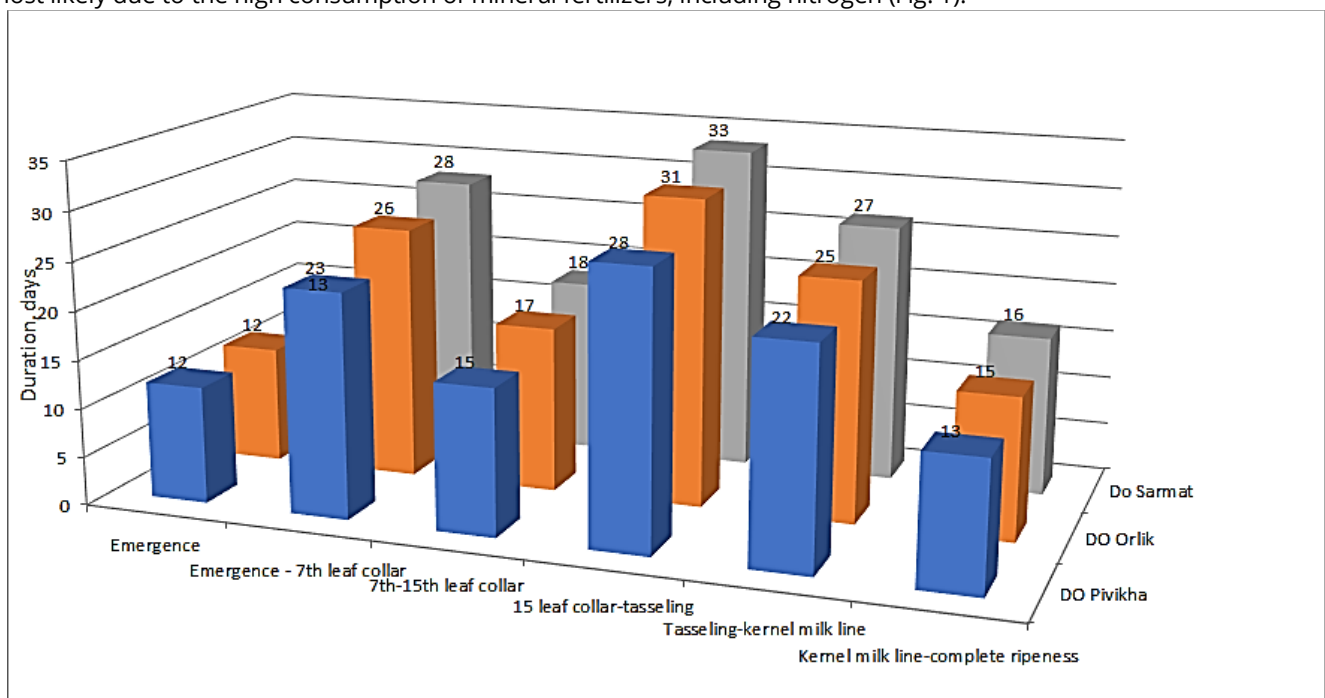


Fig. 1. The daily duration of interphase periods (average for 2017-2019).

Analysis of averaged data of the duration of interphase periods allows us to identify the studied hybrids' differences. Thus, the emergence - seventh leaf collar interphase period lasted 23 days in hybrid DO Pivikha, in hybrid DO ORLIK 26, and in hybrid DO SARMAT 28 days. It took 15 days to form the 7th-15th leaf collar in the DO Pivikha hybrid, 17 days in the DO ORLIK hybrid, and 18 days in the DO SARMAT hybrid. Similar differences were observed for the interphase period of 15th leaf collar - tasseling: 28, 31, and 33 days. It took 22 days from the moment of tasseling to the kernel milk line of the cobs in the hybrid DO Pivikha, in the hybrid DO ORLIK - 25, and in the hybrid DO SARMAT - 27 days. Similar differences were observed in the phase between kernel milk line and complete ripeness: 13, 15, and 16 days. In general, the duration of the growing season of the plants of the hybrid DO Pivikha was 109 days, and the hybrid DO ORLIK - 122 and the hybrid DO SARMAT - 129 days. The hybrids under study were in optimal conditions for their growth and development, and corresponded to the declared values of FAO, since the limits of the optimal duration of the vegetation period for the hybrid DO Pivikha were 107-115 days, the hybrid DO ORLIK - 120-125, and the hybrid DO SARMAT - 128-130 days.

Conclusions

Determination of laboratory germination of seeds of the studied maize hybrids showed their high sowing qualities with insignificant differences. Thus, the average laboratory germination of the hybrid DO Pivikha was 93.6%, the hybrid maize DO ORLIK 94.2%, and the hybrid DO SARMAT, respectively 93.9%. Field germination was determined by the conditions of moisture availability of the upper layers of soil and granulometric composition (quality of pre-sowing preparation). Considering that we sowed hybrids on the same day, we did not observe significant differences between the variants of the experiment. On average, field germination was 85.5%.

At plant density at harvest time of 55000/ha, the highest water consumption coefficients were observed compared to plant densities of 65000 and 75000/ha. The difference between the average water consumption at plant densities of 55000 and 65000, 55000, and 75000/ha for DO Pivikha was 25.5 and 46.75 m³/t; in DO ORLIK - 14.25 and 41.0 m³/t, and in DO SARMAT respectively 17.5 and 39.0 m³/t.

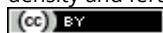
Analysis of data on the duration of interphase periods allows us to point out the differences in the hybrids under study. Thus, the interphase period between the emergence and the seventh leaf collar lasted 23 days in the hybrid DO Pivikha, 26 days in the hybrid DO ORLIK, and 28 days in the hybrid DO SARMAT, but the time between the formation of the seventh and the 15th leaf collar in the hybrid DO Pivikha was 15 days, 17 days in the hybrid DO ORLIK and 18 days in the hybrid DO SARMAT. Similar differences were in the interphase period of 15th leaf - cob flowering - 28, 31, and 33 days.

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