Scientific Papers Series Management, Economic Engineering in Agriculture and Rural Development
Vol. 23, Issue 4, 2023
PRINT ISSN 2284-7995, E-ISSN 2285-3952

STRATEGY FOR THE DEVELOPMENT OF CORN GROWING TECHNOLOGY UNDER CLIMATE CHANGE

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Abstract

The results of research on the impact of sowing dates on economic efficiency, yield, and harvest moisture of corn hybrids of different FAO groups in the conditions of the Southern Steppe of Ukraine are presented. The genotypic response of corn hybrids of different FAO groups to sowing dates was established. From an economic and agrotechnical point of view, each group of FAO corn hybrids in the irrigation conditions of southern Ukraine has its optimal sowing period. Cultivation of corn hybrids of the FAO group 400–500 in the early (April 15) and late (May 15) sowing periods is associated with a certain risk for production with the possibility of a loss of net income in the range of 21–46% (350–790 EUR/ha). These hybrids are the most productive (13.61–15.13 t/ha of grain) under optimal sowing dates (25.04–05.05) and the most profitable (1,473–1,714 EUR/ha) under irrigation conditions. Corn hybrids with FAO 190–290 have the prospect of being used in organic production without the use of herbicides during the late sowing period (May 15). Corn hybrids FAO 300–390 can be used with high efficiency at optimal sowing times, however, their sowing in early and late periods can be risky due to low cold resistance and high harvest humidity in some wet years.

Key words**:** *corn, hybrids, FAO groups, productivity, harvesting moisture, economic efficiency*

INTRODUCTION

Over the last decades, the yield of grain crops on a global scale has increased significantly. The increase in productivity was mainly due to selection and genetic improvement of the varietal composition, increase in the productivity potential of genotypes, adaptability to the variability of agro-climatic factors, tolerance to stress factors of biotic and abiotic origin. This emphasizes the importance of the main direction in increasing productivity – selection and genetic developments, which, according to the testimony of leading scientists, provide the main increase in productivity and gross harvests in recent years [17, 7, 13].

Today, the main grain crop in the world is corn (*Zea mays* L.). The fundamental task of increasing the yield and expanding the area of corn cultivation is the use of hybrids adapted to certain geographical areas and adapted to specific technologies. This question becomes especially relevant in the conditions of climate change in the direction of aridification. The rapidly progressing change in the Earth's climate, caused by global warming, is probably one of the biggest threats to the development of natural ecosystems, the agro-industrial complex, the economy and humanity in general, as warned by annual studies by climatologists [1]. In this direction of research, the development of models of adaptive technologies is of primary importance for the growth of corn productivity in agro-ecological zones suffering from global climate changes in the direction of aridity, soil erosion and temperature stress [18, 9].

Selection and technological research on the improvement of adaptation of corn growing systems under conditions of climate change in the direction of aridity becomes relevant precisely in the conditions of the arid Steppe of Ukraine, where the aridity of the climate is increasing, but the duration of the growing season of corn is also lengthened due to the increase in effective temperatures, which allows the use of a wide range of corn hybrids of different maturity groups from FAO 190 to FAO 500. Therefore, the question of developing a technology for ultra-early, optimal and late sowing periods of corn hybrids in the conditions of the Southern Steppe of Ukraine for a more complete use of the bioclimatic potential of the region arises.

Previous studies by scientists have established that the improvement of the technology of growing corn hybrids of various FAO groups is of particular relevance in the context of climate change in the direction of increasing the sum of effective temperatures and extending the duration of the growing season by up to 10%. In the conditions of the arid Steppe of Ukraine, the only limiting factor for the cultivation of intensive innovative corn hybrids is the lack of natural precipitation. This problem is successfully solved by artificial irrigation using different watering methods. Global and regional climate changes, manifested in an increase in the temperature regime against the background of a decrease in precipitation, require the adaptation of elements of corn cultivation technology, taking into account breeding achievements and increasing the bioclimatic potential of the region [6].

Crops with a high need for water, such as corn, need special adaptation to temperature stress, which is accompanied by climatic changes and increased temperature during the growing season. An important indicator of the efficiency of the cultivation technology is the water productivity (WP). There is considerable scope for improving the water productivity of plants under conditions of climate change in the direction of warming [15].

The genotypic response of hybrids to the sowing time was determined. It has been established that an increase in temperature accelerates the ontogenesis of hybrids of different maturity groups. Early-maturing hybrids showed greater yield stability at different sowing times and at different locations. Late-maturing hybrids were more productive at early sowing times, and early-maturing hybrids at late times were at the same level as late ones, or exceeded them [19].

Early sowing times in southern Ukraine can be risky due to insufficient soil temperature, therefore corn hybrids that germinate at a soil temperature of 8°C were created through selective development. These are mostly precocious hybrids with siliceous grains [5]. Such hybrids are suitable for use in the northern regions of Ukraine and have prospects for use in the southern regions during very early sowing periods. When sowing corn, it is necessary to take into account the individual reaction of hybrids. Breeding programs for the creation of precocious hybrids of corn with increased cold resistance, which are able to germinate at a soil temperature of +6°C, are quite in demand today. Sowing of such hybrids can be carried out in the beginning of the term [4].

Heat stress is the biggest threat to future global corn production. Adaptation of corn to future climate changes in the direction of warming requires a better understanding of plant response to temperature increase [14].

Corn grain yield consists of different proportional contributions of factors at all stages of organogenesis. For a better understanding of the influence of climatic and technological effects on the yield of corn, comprehensive studies are needed that determine the influence of soil, climatic conditions, sowing dates and biological features of the genotype. The date of sowing can play an important role in the formation of yield, grain quality, minimization of biotic and abiotic stresses [11].

A detailed analysis of the relationship between growing technologies and growing season weather showed that corn yield reflects two components – yield potential and potential losses caused by weather and pests. It has been proven that the introduction of adaptive genotypes affects the yield potential, and excess heat reduces soil moisture reserves and the efficiency of nitrogen use [10].

An analysis of corn production in the U.S. Corn Belt has shown that yield increases over the past 40 years are the result of continuous genetic improvement, improvements in growing techniques, and the synergistic effect of improved genetics and agronomy. Increasing yields in the future may be difficult as on-farm corn yields approach potential, but an important element of efficient production is agrotechnical measures that reduce input costs and increase profits [8].

The genetic potential of corn hybrids can be correlated with the timing of sowing. Thus, Indian studies have established optimal sowing rates for certain varieties of corn. The timing of sowing significantly affects the productivity of products and, what is important for farmers, provides an opportunity to forecast the maximum gross profit, net profit and regulate the ratio of profit and costs [16].

The date of sowing in regions with a temperate climate is determined by weather conditions during the pouring of grain. Corn plant growth rates at grain filling were slower in late plantings due to low daily incident radiation and radiation use efficiency. The effective duration of grain pouring depended on the presence of assimilates and on the speed of grain pouring when sowing was late. A decrease in the source of assimilates in the later sowing period led to a lower mass of grain at harvest. It was established that the effective rate of grain pouring was strongly influenced by temperature [3].

The timing of sowing determines the processes of plant growth and development, as well as the formation of its productivity, the immunological state of crops. Until now, there are ongoing discussions regarding the timing of corn sowing. Science and practice discuss both earlier, compared to the optimal, and later sowing dates. Researchers note that the influence of sowing dates on corn yield is closely related to weather conditions during seed germination and at the beginning of plant development. The early sowing period can be more effective than the following one, and when sowing in cold and unheated soil and the return of cold weather, it can be inferior to it [2].

Growing corn using modern technologies, among which an important element is the correct selection of hybrids according to FAO groups and optimal sowing times in accordance with agro-ecological conditions, will allow to significantly increasing its productive potential and the level of corn production. In the Southern Steppe of Ukraine, the traditional recommended date for sowing corn was from April 25 to May 5 [22]. Such sowing dates took into account soil warming to 12–14°C, sufficient soil moisture, the possibility of using post-emergence herbicides and the use of mainly medium-ripening FAO 300–390 corn hybrids under irrigation conditions and early-ripening FAO 190–290 hybrids without irrigation. An increase in the sum of effective temperatures, an increase in the duration of the frost-free period, which has been observed in recent years in the south of Ukraine, allows growing hybrids with an extended growing season and higher potential yield.

Thus, the issue of technology development for ultra-early, optimal and late sowing periods of corn hybrids in the conditions of the Southern Steppe of Ukraine is acute. Analyzing data from the review of literary sources, we can draw a conclusion: the sowing period is one of the agrotechnical techniques that has a significant impact on the formation of corn grain yield. Scientists do not have a single opinion about the right temperature at which it is advisable to start sowing corn. Therefore, the study of the impact of sowing dates on the yield and economic efficiency of growing innovative corn hybrids of different FAO groups in the conditions of drip irrigation of the Southern Steppe of Ukraine is relevant for the stabilization of corn grain production.

The purpose of research – to determine the effect of sowing dates on economic efficiency, yield, and harvest moisture of corn hybrids of different FAO groups in the conditions of the Southern Steppe of Ukraine.

MATERIALS AND METHODS

The research was conducted during 2018–2020 at the experimental field of the Institute of Irrigated Agriculture of the NAAS, located in the subarid zone of the Southern Steppe of Ukraine under drip irrigation conditions. A two-factor experiment was conducted using the method of split randomized blocks [20]. The research was carried out in four repetitions. The sown area of the plots was 50.0 m^2, the accounting area was 30.0 m^2.

During the years of the study, the weather conditions were typical for the South of Ukraine with the amount of precipitation ranging from 150 to 170 mm. Insufficient precipitation is compensated by irrigation, the pre-irrigation soil moisture level was 80% of the lowest moisture content in the 0–50 cm layer, which is the optimal regime for all FAO groups.

Factor A – sowing period (date): April 15, April 25, May 5, May 15.

Factor B – innovative corn hybrids with different maturity groups: precocious Stepovyi (FAO 190), DN Meotyda (FAO 190); middle early Skadovs`kyi (FAO 290), DN Halateia (FAO 250); medium-ripe Inhul`s`kyi (FAO 350), DN Zbruch (FAO 350); middle-late Arabat (FAO 420), DN Anshlah (FAO 420).

RESULTS AND DISCUSSIONS

Our experimental studies in the irrigated conditions of the Southern Steppe of Ukraine showed that the timing of sowing significantly affects the development of plants, the formation of the grain yield of corn hybrids of different FAO groups. Depending on the factors of the experiment, corn plants fall into different agrometeorological conditions, grow and develop in different ways, and have different productivity. During the research period 2018–2020, the grain yield of corn hybrids of different FAO groups varied depending on the sowing dates from 8.03 to 15.92 t/ha (Table 1).

According to the results of the conducted research, it was established that under irrigation conditions, corn hybrids of different FAO groups showed the maximum yield during the late sowing periods (May 5 and 15).

Thus, the precocious hybrid Stepovyi (FAO 190) showed the maximum grain yield in 2018 and 2019 for sowing on 05.05 – 9.14 and 9.75 t/ha, respectively, in 2020 for sowing on 05.05 – 9.37 t/ha. The minimum yield of 8.15 t/ha was shown for sowing on 04/15, yield reduction – 0.92 t/ha, or 9.9% of the maximum yield for the optimal sowing period of 05/05.

The hybrid DN Meotyda (FAO 190) also showed the maximum grain yield in 2018, 2019 for sowing on 05.05 – 8.97 and 9.34 t/ha, in 2020 for sowing on 05.15 – 9.26 t/ha. The minimum yield of 8.04 t/ha was shown for sowing on April 15, but the average decrease in yield was insignificant – 0.82 t/ha, or 9.1%.

The mid-early hybrid Skadovs`kyi (FAO 290) also showed the maximum grain yield in 2018 and 2019 for sowing on 05.05 - 12.56 and 12.85 t/ha, in 2020 for sowing on 05.15 – 12.92 t/ha. The minimum yield was 8.67 t/ha for sowing on April 15, the decrease in yield was more significant and amounted to 4.18 t/ha, or 33.3%.

The mid-early hybrid DN Halateia (FAO 250) showed the maximum grain yield in 2018, 2019 for sowing on 05.05 – 12.72 and

13.34 t/ha, in 2020 for late sowing on 05.15 – 13.56 t/ha. The minimum productivity of 8.74 t/ha was shown for sowing on 15.04 with a decrease in productivity of 4.60 t/ha, or 28.1%. The medium-ripe hybrid Inhul`s`kyi (FAO 350) showed the maximum grain yield in 2018, 2019 for sowing on 05.05 – 13.51 and 14.17 t/ha, in 2020 for sowing on 05.15 – 13.85 t/ha. The minimum yield of 8.92 t/ha was shown for early sowing on April 15. The yield reduction was 5.25 t/ha, or 36.8%.

Table 1. Grain yield of corn hybrids of different FAO groups depending on sowing dates, t/ha (estimated grain moisture content 14%)

Sowing period, days (factor A)	**Hybrid (factor B)**	**Years of research**			**Average for 2018-2020**	**On average, by factor B**
		2018	**2019**	**2020**		
April 15	Stepovyi (FAO 190)	8.15	8.54	8.35	8.35	8.85
	DN Meotyda (FAO 190)	8.04	8.43	8.16	8.21	8.66
	Skadovs`kyi (FAO 290)	9.43	10.72	8.67	9.61	11.35
	DN Halateia (FAO 250)	9.52	10.91	8.74	9.72	11.58
	Inhul`s`kyi (FAO 350)	10.61	10.35	8.92	9.96	12.14
	DN Zbruch (FAO 350)	10.85	10.92	9.14	10.30	12.47
	Arabat (FAO 420)	10.54	11.24	9.89	10.56	13.74
	DN Anshlah (FAO 420)	10.03	10.36	9.23	9.87	13.36
	Average by factor A	**9.65**	**10.18**	**8.89**	**9.57**	
April 25	Stepovyi (FAO 190)	8.34	8.92	8.54	8.60	
	DN Meotyda (FAO 190)	8.03	8.87	8.35	8.42	
	Skadovs`kyi (FAO 290)	11.64	11.92	9.74	11.10	
	DN Halateia (FAO 250)	11.73	12.13	10.17	11.34	
	Inhul`s`kyi (FAO 350)	12.25	12.61	10.56	11.81	
	DN Zbruch (FAO 350)	12.56	12.92	10.92	12.13	
	Arabat (FAO 420)	14.27	14.54	12.83	13.88	
	DN Anshlah (FAO 420)	14.04	14.23	12.56	13.61	
	Average by factor A	**11.61**	**12.02**	**10.46**	**11.36**	
May 5	Stepovyi (FAO 190)	9.14	9.75	8.93	9.27	
	DN Meotyda (FAO 190)	8.97	9.34	8.77	9.03	
	Skadovs`kyi (FAO 290)	12.56	12.85	11.23	12.21	
	DN Halateia (FAO 250)	12.72	13.34	11.35	12.47	
	Inhul`s`kyi (FAO 350)	13.51	14.17	12.25	13.31	
	DN Zbruch (FAO 350)	13.73	14.54	12.92	13.73	
	Arabat (FAO 420)	15.56	15.92	13.91	15.13	
	DN Anshlah (FAO 420)	15.34	15.63	13.84	14.94	
	Average by factor A	**12.69**	**13.19**	**11.65**	**12.51**	
May 15	Stepovyi (FAO 190)	8.75	9.36	9.37	9.16	
	DN Meotyda (FAO 190)	8.54	9.15	9.26	8.98	
	Skadovs`kyi (FAO 290)	12.12	12.43	12.92	12.49	
	DN Halateia (FAO 250)	12.66	12.12	13.56	12.78	
	Inhul`s`kyi (FAO 350)	13.15	13.47	13.85	13.49	
	DN Zbruch (FAO 350)	13.34	13.65	14.15	13.71	
	Arabat (FAO 420)	15.25	15.34	15.62	15.40	
	DN Anshlah (FAO 420)	14.64	15.15	15.21	15.00	
	Average by factor A	**12.31**	**12.59**	**12.99**	**12.63**	
LSD_{05}		**0.21**	**0.19**	**0.25**		

Source: Own calculation.

The medium-ripe hybrid DN Zbruch (FAO 350) showed the maximum grain yield in 2018, 2019 for sowing on 05.05 – 13.73 and 14.54 t/ha, in 2020 for sowing on 05.15 – 14.15 t/ha. The minimum yield of 9.14 t/ha was shown for sowing on 15.04 with a decrease in yield of 5.40 t/ha, or 37.2%.

The mid-late hybrid Arabat (FAO 420) showed the maximum grain yield in 2018, 2019 for sowing on 05.05 – 15.56 and

15.92 t/ha, in 2020 for sowing on 05.05 – 15.62 t/ha. The minimum yield of 9.89 t/ha was shown for sowing on April 15. The yield reduction was 6.03 t/ha, or 38.3%. The hybrid DN Anshlah (FAO 420) showed the maximum grain yield in 2018, 2019 for sowing 05.05 – 15.34 and 15.63 t/ha, in 2020 for sowing 5.05 – 15.21 t/ha. The minimum yield of 9.23 t/ha was shown for sowing on April 15, with a decrease in yield of 6.40 t/ha, or 41.1%. Summarizing the productivity indicators, we observe that the productivity of all hybrids decreases with the use of early sowing dates. However, a minimal difference in yield at different sowing times was observed in precocious hybrids FAO 190. The decrease in yield at early sowing times was insignificant – in the range of 9.1–9.9%, which indicates their cold resistance. However, the grain yield of these hybrids was also low (in the range of 8–9 t/ha), which indicates their low productivity potential. These hybrids were created according to programs of cold resistance and early ripening, so their use may be appropriate for sowing in relatively cold soil.

In the modern conditions of agro-industrial production, when the cost of energy carriers has increased significantly, the creation of corn hybrids of different groups of maturity with a rapid return of moisture during ripening is an actual direction of selection. The intensity of grain moisture loss largely depends on the conditions of the external environment, in particular weather factors: temperature, relative humidity. The rate of moisture release by grain is determined not only by environmental conditions, but also by heredity. Low harvesting moisture of corn grain is primarily determined by the duration of the vegetation period, while the factor of early maturity is dominant [12].

Table 2 shows grain moisture data before harvesting. During the 2018-2020 research, this indicator for the grain of hybrids of different FAO groups before harvesting fluctuated within the hybrid maturity group and sowing dates. The grain moisture of all corn hybrids of different maturity groups at the time of harvesting was in the range from 12.1 to 27.0%, which indicates the extreme importance of studying this indicator as the main indicator of the technology of growing corn with high efficiency and profitability. Different sowing dates and FAO groups of hybrids determine the variation of this indicator. Increased moisture content of grain above 14%, in addition to the main additional costs for drying grain, increases costs for transportation, storage, loss of grain quality from fungal diseases and entomophages, which have been spreading in recent years under irrigation conditions [21].

The cost of dried grain can also be lower due to damage to the grain by cracks and fungal mycelia, so production is extremely interested in low harvesting humidity. Low harvesting moisture also depends on harvesting dates, and the delay in harvesting and postponement of dates to late autumn does not bring the expected natural drying of grain due to low rates of moisture transfer at low temperatures and secondary moistening during autumn rains. The maximum grain moisture content varied from 12.5% in hybrids FAO 190 to 27.0% in hybrids corn FAO 420 for sowing on May 15. The minimum moisture content of the grain varied from 12.1% to 14.9% for the studied hybrids of different FAO groups for sowing on April 15. With regard to the dependence of the harvesting moisture on the maturity groups of the hybrids, a clear pattern was observed – the minimum grain moisture characteristic of the hybrids FAO 190 Stepovyi and DN Meotyda – 12.1–13.1%, the maximum - in the hybrids FAO 420 Arabat and DN Anshlah – 14.8– 27.0%. The moisture content of hybrids FAO 250–290 in the early, optimal and late periods was almost at the same level. Thus, almost all hybrids, except for the FAO 420 hybrids, had the basic moisture content of the grain during all sowing periods, which allowed not carrying out the drying of the grain after harvesting, to bear losses from additional transportation and price discounts. This is important in the process of using energy-saving technologies for growing corn. The difference in grain moisture depending on the time of sowing was more clearly defined in hybrids with an extended growing season. These are such hybrids as Arabat and DN Anshlah. During the late sowing periods, the moisture content of the grain of these hybrids increased in some years by 10.7–11.2%, compared to the early ones. The difference in grain moisture between the early and optimal term (May 5) in Arabat and DN Anshlah hybrids was much smaller (from 1.9 to 2.5%). This indicates that the ripening period of these genotypes fell on August, a month when low relative air humidity, high day and night temperatures are observed, which contributes to accelerated moisture transfer and a decrease in grain moisture to optimal indicators for harvesting by a combine with direct threshing. Improving the elements of varietal agrotechnics of corn hybrids of different maturity groups provides an opportunity to increase crop productivity. It is not enough to determine the efficiency of any complex of agricultural measures only by the change in the level of the harvest, because the costs of its cultivation are not taken into account, therefore, it is necessary to determine not only the agrotechnical, but also the economic efficiency.

Table 2. Harvesting grain moisture of corn hybrids depending on the sowing dates, % (2018–2020)

Sowing period, days (factor A)	**Hybrid (factor B)**	**Years of research**			**Average for 2018-2020**	**On average, by factor B**
		2018	**2019**	**2020**		
April 15	Stepovyi (FAO 190)	12.1	12.2	12.5	12.3	12.5
	DN Meotyda (FAO 190)	12.2	12.4	12.7	12.4	12.7
	Skadovs`kyi (FAO 290)	12.5	12.6	12.6	12.6	13.0
	DN Halateia (FAO 250)	12.8	12.7	12.7	12.7	13.1
	Inhul`s`kyi (FAO 350)	13.4	13.5	13.5	13.5	13.7
	DN Zbruch (FAO 350)	13.4	13.5	13.6	13.5	14.0
	Arabat (FAO 420)	14.1	14.3	14.8	14.4	18.1
	DN Anshlah (FAO 420)	14.8	14.9	14.9	14.9	18.2
	Average by factor A	**13.2**	**13.3**	**13.4**	**13.3**	
April 25	Stepovyi (FAO 190)	12.3	12.4	12.5	12.4	
	DN Meotyda (FAO 190)	12.6	12.7	12.8	12.7	
	Skadovs`kyi (FAO 290)	12.7	12.8	12.9	12.8	
	DN Halateia (FAO 250)	13.0	12.9	12.8	12.9	
	Inhul`s`kyi (FAO 350)	13.6	13.7	13.7	13.7	
	DN Zbruch (FAO 350)	13.7	13.8	13.9	13.8	
	Arabat (FAO 420)	14.5	15.3	15.8	15.2	
	DN Anshlah (FAO 420)	14.8	15.9	15.7	15.5	
	Average by factor A	**13.4**	**13.7**	**13.8**	**13.6**	
May 5	Stepovyi (FAO 190)	12.4	12.6	12.6	12.5	
	DN Meotyda (FAO 190)	12.8	12.9	12.9	12.9	
	Skadovs`kyi (FAO 290)	12.9	13.0	13.6	13.2	
	DN Halateia (FAO 250)	13.0	13.1	13.5	13.2	
	Inhul`s`kyi (FAO 350)	13.1	13.5	13.6	13.4	
	DN Zbruch (FAO 350)	14.1	14.2	14.1	14.1	
	Arabat (FAO 420)	15.5	17.3	17.8	16.9	
	DN Anshlah (FAO 420)	15.8	16.9	17.7	16.8	
	Average by factor A	**13.7**	**14.2**	**14.5**	**14.1**	
May 15	Stepovyi (FAO 190)	12.5	12.8	13.1	12.8	
	DN Meotyda (FAO 190)	12.7	12.9	12.9	12.8	
	Skadovs`kyi (FAO 290)	13.2	13.1	14.1	13.5	
	DN Halateia (FAO 250)	13.1	13.5	14.5	13.7	
	Inhul`s`kyi (FAO 350)	13.5	13.8	14.9	14.1	
	DN Zbruch (FAO 350)	14.5	14.6	14.8	14.6	
	Arabat (FAO 420)	25.2	25.1	26.9	25.7	
	DN Anshlah (FAO 420)	25.0	24.9	27.0	25.6	
	Average by factor A	**16.2**	**16.3**	**17.3**	**14.1**	

Source: Own calculation.

In the process of economic analysis of indicators of the cultivation of corn hybrids, the conditional net profit of the cultivation of corn hybrids of different FAO groups for different sowing periods was calculated. The results of the economic analysis of cultivation indicate that the FAO group of the hybrid, the sowing period significantly affect the indicators of the economic efficiency of crop cultivation (Table 3).

Table 3. Conditionally net profit when growing corn hybrids of different FAO groups depending on the sowing time in the conditions of the Southern Steppe of Ukraine under irrigation, EUR/ha

Sowing period, days (factor A)	**Hybrid (factor B)**	**Years of research**			**Average for 2018-2020**	**On average, by factor B**
		2018	**2019**	**2020**		
April 15	Stepovyi (FAO 190)	605	785	825	738	779
	DN Meotyda (FAO 190)	584	664	795	681	749
	Skadovs`kyi (FAO 290)	647	707	874	743	1,059
	DN Halateia (FAO 250)	813	735	893	814	1,171
	Inhul`s`kyi (FAO 350)	888	746	925	853	1,165
	DN Zbruch (FAO 350)	1,012	934	967	971	1,246
	Arabat (FAO 420)	976	875	885	912	1,388
	DN Anshlah (FAO 420)	894	846	976	905	1,355
	Average by factor A	**802**	**787**	**893**	**827**	
April 25	Stepovyi (FAO 190)	620	724	854	733	
	DN Meotyda (FAO 190)	574	708	815	699	
	Skadovs`kyi (FAO 290)	1,122	969	1,053	1,048	
	DN Halateia (FAO 250)	1,145	998	1,121	1,088	
	Inhul`s`kyi (FAO 350)	1,124	1,064	1,192	1,127	
	DN Zbruch (FAO 350)	1,165	1,108	1,254	1,176	
	Arabat (FAO 420)	1,523	1,439	1,585	1,516	
	DN Anshlah (FAO 420)	1,492	1,392	1,534	1,473	
	Average by factor A	**1,096**	**1,050**	**1,176**	**1,107**	
May 5	Stepovyi (FAO 190)	740	830	915	828	
	DN Meotyda (FAO 190)	713	873	884	823	
	Skadovs`kyi (FAO 290)	1,262	1,108	1,303	1,124	
	DN Halateia (FAO 250)	1,294	1,215	1,321	1,277	
	Inhul`s`kyi (FAO 350)	1,415	1,327	1,475	1,406	
	DN Zbruch (FAO 350)	1,446	1,433	1,596	1,492	
	Arabat (FAO 420)	1,724	1,653	1,764	1,714	
	DN Anshlah (FAO 420)	1,693	1,649	1,756	1,699	
	Average by factor A	**1,286**	**1,261**	**1,377**	**1,308**	
May 15	Stepovyi (FAO 190)	694	774	984	817	
	DN Meotyda (FAO 190)	667	746	965	793	
	Skadovs`kyi (FAO 290)	1,153	1,212	1,592	1,319	
	DN Halateia (FAO 250)	1,232	1,574	1,704	1,503	
	Inhul`s`kyi (FAO 350)	1,106	1,263	1,455	1,275	
	DN Zbruch (FAO 350)	1,134	1,395	1,503	1,344	
	Arabat (FAO 420)	1,335	1,234	1,657	1,409	
	DN Anshlah (FAO 420)	1,237	1,203	1,584	1,341	
	Average by factor A	**1,070**	**1,175**	**1,431**	**1,225**	

Source: Own calculation.

According to the stock exchange, the price of a ton of corn grain in 2018 was EUR 153/t, in 2019 it was EUR 146/t, and in 2020 it was EUR 170/t. It was calculated that the highest profits in the steppe zone of Ukraine are provided by hybrids with FAO more than 400 (on average 1,355 and 1,388 EUR/ha), however, the variation of profit from the cultivation of these hybrids was also the largest - from 1,764 EUR/ha in 2020 for sowing on 05.05 up to 846 euros/ha in 2019 for sowing on 05.04. The halving of profit is explained by the negative impact of early sowing on grain yield in late-ripening hybrids and the increase in costs for bringing wet grain to conditions.

In the conditions of modern production, it is necessary to take into account not only the maximum profit of one year, because the share of corn in crop rotations of southern Ukraine with irrigation is 12–33%. The next crops in the crop rotation after corn can be winter wheat, barley, rapeseed, therefore, the timing of corn grain harvesting is of great importance in corn cultivation. The terms of harvesting corn grain with a moisture content of no more than 14% directly depend on the genotype of the hybrid and the time of sowing. Thus, Stepovyi, DN Meotyda corn hybrids during the sowing period of 15.04 had dry grain (less than 13%) from mid-August and this made it possible to prepare the soil qualitatively for sowing winter crops – wheat, barley, rapeseed. Corn hybrids with FAO 290–420, due to the late harvesting period, could no longer guarantee the quality of soil preparation for sowing winter crops.

Corn hybrids with FAO 190–290 have the prospect of being used in organic production without the use of herbicides due to late sowing dates (May 15). Such sowing dates allow for 2–3 pre-sowing cultivations to destroy weeds.

Corn hybrids FAO 300–390 can be used with high efficiency at optimal sowing times, but their sowing in early and late periods can be risky due to low cold resistance and high harvest humidity in some wet years.

The favorable conditions of the Southern Steppe of Ukraine, namely the optimal temperatures for the growth and development of corn plants, the presence of irrigation, make it possible to grow all groups of ripeness, including late-ripening forms up to FAO 500. The most productive in the south of Ukraine, with the mandatory presence of irrigation, are hybrids of corn of the late-ripening group FAO. However, it should be noted that corn hybrids with FAO 400–500 at late sowing times may not form ripe grain every year due to insufficient effective temperatures and a cool, wet autumn.

Previous studies have established that in the third decade of September and October, grain moisture is significantly delayed and is not 1.2–1.5%, as in August – the first half of September, but decreases to 0.1–0.5% [21]. The main reason for the decrease in the rate of grain moisture release, starting from the second half of September, is a decrease in night temperatures to 10°C, which significantly slows down the ripening process. During the late sowing period, the phase of grain filling in the FAO 400–500 hybrids falls precisely on this period, which is reflected in the indicators of the grain moisture content, therefore, the cultivation of corn hybrids of the FAO 400-500 group at the late sowing period is associated with a certain risk for production.

In the researches of other authors, it was established that in regions with a moderate climate, the formation of the potential yield of corn can be limited by solar radiation and temperature conditions. Such restrictions are more harmful during the grain ripening period than during the grain filling period [22].

Our research is confirmed by the previous reports of scientists that the timing of sowing significantly adjusts indicators of productivity, quantity and quality of cobs and maximum net profit [16]. The results of such studies should be taken into account in the effective production of agricultural products in specific agro-climatic zones.

Climate changes require adjustment of corn cultivation technologies by US farmers, and the main element of improved technologies are innovative hybrids that provide a profitable economy of production [10]. Our research also confirms this conclusion about the need to determine the interaction of the genotype with agroclimatic factors that shape the yield and profitability of growing corn in the conditions of the dry Steppe of Ukraine.

CONCLUSIONS

In the agroclimatic conditions of the Southern Steppe of Ukraine, under irrigation, the genotypic response of corn hybrids of different FAO groups to the sowing dates was established. From an economic and agrotechnical point of view, each group of FAO corn hybrids in the irrigation conditions of southern Ukraine has its optimal sowing period.

Cultivation of corn hybrids of the FAO group 400–500 in early and late sowing periods is associated with a certain risk for production with the possibility of a loss of net income in the range of 21–46% (350–790 EUR/ha). These hybrids are the most productive (13.61–15.13 t/ha of grain) under optimal sowing dates (25.04–05.05) and the most profitable (1,473–1,714 EUR/ha) under irrigation conditions.

Corn hybrids with FAO 190–290 have the prospect of being used in organic production without the use of herbicides during the late sowing period (May 15). Hybrids of this maturity group show a minimal reaction to the timing of sowing. In early periods, they can be used in crop rotations as precursors for winter crops.

Maize hybrids FAO 300–390 can be used with high efficiency at optimal sowing times, however, their sowing in early and late periods can be risky due to low cold resistance and high harvest humidity in some wet years.

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