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ORIGINAL ARTICLE

The yield of winter wheat depending on sowing terms

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To study the influence of sowing dates of winter wheat of Kubus variety on yield, including late ones after sugar beet. The following sowing dates were investigated: September 1, 10, 20, and 30, October 10 and 20, November 10 and 30, and December 20. It was found that at later sowing dates, the field germination decreases: in October to 88.0–86.8 %, in November to 84.1–80.4 %, in December to 76.4 %. Plant survival was 84.1–94.2 %. Plant density, productive stems, and tillering coefficient were the highest during sowing on September 30. During sowing in November and December, the plants did not reach the beginning of tillering phase; the coefficient of productive tillering approached one (1.12–1.14). It was found that the number of ears in the ear was stable for all sowing dates (16.6–17.4 pieces), the maximum number of grains in the ear (48 pieces) was recorded during the sowing on September 30. The weight of grain from the ear in all variants was high; during sowing on September 30, October 10, and 20, it was equal to 1.61–1.60 g. In November-December, it decreased up to 1.55 g, 1.52 g, and 1.45 g. The highest grain yield (9.43 t/ha) of winter wheat in the western forest-steppe of Ukraine was formed during sowing on September 30. In November, the yield decreased by 1.31 t/ha and 1.89 t/ha compared to sowing on September 30 and by 2.40 t/ha in December. The optimal sowing dates of winter wheat of the Kubus variety in the conditions of the western Forest-Steppe fall on the period from September 20 to October 10. In the conditions of global climate changes, the possibility of obtaining 7–8 t/ha of grain during sowing in November-December is substantiated. For a yield of 9 t/ha and above, the following combination of structural elements is optimal: the density of productive stems should be approximately 600 pcs/m^2, the weight of grain from the ear – 1.60 g.
Keywords: winter wheat, sowing terms, yield structure, yield.

Introduction

Many years of research in Ukraine and the EU countries show that only during sowing in the optimal terms can plant fully use all the necessary life factors to grow and develop and ensure the highest grain yield of winter wheat. It was found that plant productivity decreases both during the early and late sowing rates (Sokolov et al., 2018; Falcone et al., 2019).

In the early stages of sowing, winter wheat develops a large vegetative mass and has a high total tillering. Due to overgrowing, plants begin to use intensively spare substances, become less resistant to adverse conditions, reduce winter hardiness, and are prone to wilting. Such sowings are usually more damaged by diseases and pests (Stasiv et al., 2019). Plants of late sowing dates have a long sowing-germination period, do not have time to bush in the fall, develop a sufficient root system and aboveground mass. They form mainly a single-stem plant morphotype. Thus, in the Chernihiv region, during sowing in September, winter crops begin to tillering for 15–20 days, in October – for 50-60 days (Volkogon et al., 2015). As a result, their yields also decrease. Favorable conditions for sowing winter wheat occur when the average daily air temperature is 14–15 °C, autumn vegetation lasts 40–50 days, and the plants form three shoots (Sokolov et al., 2018). Over the past 25 years, there have been significant climate changes, especially regarding temperature. Therefore, the optimal sowing dates have shifted to later in almost all soil and climatic zones. For example, until 1990, for the conditions of the western Forest-Steppe, most researchers considered the optimal calendar sowing dates to be on September 10–25, and for the Polissya zone – on September 5–25. Now the optimal sowing dates have shifted to later: on September 20 – October 5. The optimal sowing dates for the conditions of the western forest-steppe, according to researchers, can be different: on September 20 (Ulich, 2018), on September 30 (Petrichenko & Lykhochvor, 2020), on September 15-30 (Stasiv et al., 2019). Due to global warming processes, the optimal sowing dates in the Rivne region shifted from September 15-25 of 1980–the 1990s to September 25-October 5 in the XXI century (Polovyy et al.,

2018). New wheat ideotypes are already being developed to ensure high yields, considering future climate change for the period up to 2050 (Senapati, 2019).
Other researchers also found a tendency to shift the sowing terms of winter wheat in the direction of later: compared with the sowing terms in the 50s of last century – by 30 days; 70s – by 20; 80s – by 15–20; 90s – by 10 days. The optimal sowing terms are currently on September 30 and largely depend on the genotype (Ulich, 2018). In addition, there are conflicting data as to sowing dates. In the conditions of Polissya, the maximum grain yield of winter wheat (3.56 t/ha) was obtained during sowing on September 10. During sowing on October 10, wheat grain yield decreased by 1.02 t/ha (Tkachuk & Timoshchuk, 2020).
The regularity in the steppe of Ukraine to sow early is also observed, while in the forest-steppe, and especially in the western forest-steppe, later terms are recommended. There are also recommendations as to the sowing dates at the presence of productive moisture in the soil.
In the Poltava region, the highest yields of winter wheat, depending on weather and climatic conditions, were obtained in a wide range – from August 25 to October 5. It is concluded that it is necessary to determine the optimal sowing terms of winter wheat for the conditions of a particular year (Lyashenko & Marenich, 2010). According to other data, in the Poltava region, due to different levels of meteorological support and different sowing dates, the highest yield (5.36 t/ha) was provided by Bohemia variety during sowing on September 20 and Kosovitsa variety for sowing terms on September 30 (5.29 t/ha) (Shakaliy et al., 2020. In the conditions of the southern Forest-Steppe, the highest grain yield was obtained during sowing on October 5 (Gavrilyuk & Kalenych, 2018).
According to the Institute of Grain Crops of NAAS in the northern subzone of the Steppe, the maximum yield in 2016–2018 was formed at the optimal sowing date (September 25). With the shift of sowing dates both towards the early ones (September 5) and towards the late ones (October 10), the grain yield of winter wheat decreased by an average of 0.36 and 0.56 t/ha, respectively (Yaroshenko, 2020). Researches of the Institute of Plant Breeding by V.Ya. Yuryev NAAS for the last ten years established that the best sowing terms in the forest-steppe zone of the Kharkiv region are the period from 10 to September 25, and in the steppe – from 15 to September 30. The acceptable sowing terms for the forest-steppe zone are on October 1, and for the steppe zone – on October 5. If there is moisture in the soil in early September and an unfavorable forecast for the probability of precipitation, it is advisable not to delay sowing but to sow seeds treated with combined pesticides with an insecticidal component (Kirichenko et al., 2018).
According to the Institute of Agriculture and Agricultural Production of NAAS for the conditions of Polissya, the optimal sowing terms are September 1 – October 10 (Volkogon et al., 2015). For the Steppe conditions, the sowing terms are somewhat later on – 20.09 - 10.10 (Shevchenko et al., 2017).
In the Republic of Poland, depending on the region, sowing terms are recommended from early September 5–15 to October 5–20. There is a shift in sowing terms (Oleksiak, 2014). In Uzbekistan, the highest yields of winter wheat were obtained during sowing on October 1–20 (Gandjaeva, 2019). Due to global warming, other researchers (Ding et al., 2016; Allard et al., 2019; Dong et al., 2019) also point to the need to shift sowing terms to later ones in different regions of the world.
Thus, as a result of experimental field studies, it was found that the optimal and acceptable sowing terms in different soil and climatic zones differ. However, some agricultural formations sow much later than the recommended term due to predecessors who leave the field late: corn for grain, sugar beet, soybeans, sunflowers. Therefore, there is a need to investigate the impact of late sowing of winter wheat on the processes of growth and development and the formation of yield and grain quality. It should be noted that such late sowing terms have previously been studied in other countries (Madhu et al., 2018).

Materials and methods

The field studies were conducted on dark gray soil on the farm "AgroExpressService" of the Mlyniv district of the Rivne region. The calculated area is 50 m2, the experiment is repeated three times. Placement of plots was – systematized. In 2016–2018 the optimal and acceptable sowing dates were studied with an interval of 10 days (Table 1). In 2018–2020 the research scheme included late and over late periods with an interval of 20 days, which are often used in production and which became possible due to global warming and the placement of winter wheat after sunflower, soybeans, and especially after corn for grain and sugar beet (Table 2).
The main elements of cultivation technology were as follows. Predecessor – sugar beet. Soil preparation – plowing and pre-sowing cultivation by the Compactor. The sowing rate is 3.0 million / ha. They sow with a seeder SN-16A with row spacing of 15 cm. The depth sowing was 3 cm, the winter wheat variety was Kubus. The seeds were treated by a fungicidal insecticide Celeste Top (1 L/t). The rate of mineral fertilizers application was $N_{180}R_{90}K_{120}$. Phosphorus and potassium fertilizers were applied under plowing, nitrogen in three fertilization in the spring. The first fertilization was carried out on thawed soil (N_{60}), the second one at the beginning of the plants in the tube (N_{80}), the third one in the earing phase (N_{40}). To ensure highly efficient fertilizers, destruction of weeds at the initial stages of growth in the fall crops was treated with herbicide Marathon (4 l/ha). In the spring, in the tillering phase, the morphoregulator chlormequat chloride (1.5 L/ha) was applied to protect against lodging, intensify the process of spring tillering, and synchronous development of stems. To protect against diseases, crops were sprayed three times by fungicides: for the first time at the beginning of the outlet of tube Flexiti (0.25 l/ha) was applied, at the second time on the flag leaf of Abacus (1.25 l/ha) was applied, at the third time in the flowering phase Osiris Star (1.5 l/ha) was applied. Fastak insecticide was applied to control pests (thrips, leeches).
Mathematical and statistical processing of research results was carried out by the variance method using Microsoft Excel and Statistica 6.0. The data in the tables are presented as the arithmetic mean with standard deviation (x ± SD).

Results

The results of the research showed that the best conditions for the growth and development of winter wheat variety Kubus on average in 2016–2018 were formed during sowing on September 30 (Table 1). The Kubus variety has been studied in other studies (Marenych et al., 2020). The germination of winter wheat was high and depended little on the sowing terms, as the seeds were protected by the pesticide Celeste Top from diseases and pests. It fluctuated between 89.8–90.5 % in September, and during sowing in October, it decreased to 86.8–88.0 %. This can be explained by the weakening of the protective effect of the mordant.

Plants overwintered better during later sowing terms (96.3–97.8 %), winter hardiness decreased in early sowing terms to 93.8–94.4 %, which is explained by a decrease of resistance to low temperatures and unfavorable wintering conditions in developed plants of early sowing terms. Plant survival from germination to harvest was higher during the sowing on September 30 and October 10. More plants fell during sowing in the early stages of September 1 and 10. The decrease of the survival level in the early sowing period is explained by the excessive growth of plants in the autumn period of their vegetation.

Before harvesting, the density of plants was the highest during the sowing on September 30, where it was 250 pcs/m^2. Due to higher survival in the variants with sowing on October 10 and 20, the plant density was higher than in the early sowing dates on September 1 and 10.

Table 1. The influence of sowing terms on the formation of plant density and stems of winter wheat of variety Kubus (average for 2016–2018, x ± SD, n = 6)

Term sowing	Field germination, %	Winter hardiness, %	Survival of plants from germination to harvest, %	The density of plants before harvest, pcs/m^2	Density productive stems, pcs/m^2	Coefficient of tillering
01.09	90.4 ± 2.1	93.8 ± 0.7	87.3 ± 0.6	222 ± 5.0	577 ± 8.2	2.60 ± 0.07
10.09	89.8 ± 1.9	94.4 ± 1.0	88.1 ± 0.7	224 ± 3.8	572 ± 7.8	2.55 ± 0.08
20.09	90.1 ± 2.3	96.4 ± 0.6	91.9 ± 1.0	239 ± 5.2	580 ± 8.1	2.43 ± 0.10
30.09	90.5 ± 2.0	97.8 ± 1.0	94.2 ± 1.1	250 ± 7.0	590 ± 8.8	2.36 ± 0.10
10.10	88.0 ± 1.7	97.5 ± 0.9	93.5 ± 1.3	240 ± 5.8	554 ± 6.4	2.31 ± 0.07
20.10	86.8 ± 1.5	96.3 ± 0.7	92.8 ± 1.0	232 ± 6.7	512 ± 7.2	2.21 ± 0.06

Note. Sowing rate - 3.0 million / ha

The density of productive stalks and the mass of grain from the ear are some of the most critical indicators of crop structure. According to the requirements of intensive technology, there should be 550-650 ears per 1 m^2. Our studies show that the number of ears did not depend much on sowing and ranged in the optimal range of 554–590 pieces / m^2. This is due to the ability of cereals to form the optimal density of stems due to the functioning of two interdependent processes. Intensive tillering of plants increases the density of productive stems. Reduction (death) of the shoots on the plant at later stages of growth and development reduces the density of the stem. The highest stem density was during sowing on September 30 (590 pcs/m^2), which can be explained by better survival of lateral stems, reducing their death in the process of stem selection compared to the variants with an early sowing. Since the sowing density of ears is highest during sowing on September 30, it is possible to indicate the ability of plants to form the highest density of productive stems at the optimal sowing terms and not at early ones.

The coefficient of productive tillering was high (2.21–2.60) in all variants, which is explained by the low sowing rate of 3.0 million / ha. Mostly tillering shoots were formed in autumn, except for the variant during sowing on October 20, where lateral shoots were also obtained in spring. The tillering process was facilitated by warm weather in November, December and spring. Thus, in 2016 the average monthly temperature in March was 4.8 °C (+ 4.3 °C), in 2017 - 6.0 °C (+ 5.5 °C). In addition, the intensification of spring tillering is also due to sufficient moisture reserves, the application in spring N_{60}, and morphoregulator Chlormequat chloride.

In connection with the shift of sowing terms in production conditions to later terms, late sowing terms were studied in another experiment. Researchers point to a close interaction between sowing terms and sowing rates (Allard, 2019). In our second experiment, conducted in 2018–2020, this relationship was taken into account by increasing the sowing rate. The sowing rate was set based on the need to have before harvest 600 ears / m^2. It amounted to 3.0 million / ha during the September sowing period, in October – 5.5 million/ha, in November – 7.0 million/ha, in December – 7.5 million / ha. They were sowing with an interval of 20 days allowed to cover the sowing period for 4 months. Considering the duration of yarovization (for 40 days), winter wheat can be sown even in winter intervals in January and February, which requires further study.

It was found that the field germination of winter wheat seeds during the sowing in November - December decreased by 84.1–76.8 %, which is less than the sowing on September 30 – by 14.8 % (Table 2). Winter hardiness of plants remained high at later sowing terms. Plant survival indices, as in previous researches, are the highest during the sowing on September 30. The density of plants before harvesting depended primarily on the sowing rate. Due to the late sowing terms, it was impossible to use a sowing rate of 3.0 million / ha on all variants due to the lack of autumn tillering with the help of high sowing rates formed mainly single-stemmed plant, because the ear on the spring shoots of tillering is inferior to the level of individual productivity of the ear on the main stem.

Table 2. The influence of sowing terms on the formation of plant density and stems of winter wheat variety Kubus (average for 2018–2020, x ± SD, n = 6)

Term sowing	Sowing rate, million / ha	Field germination, %	Winter hardiness, %	Plant survival, %	Plant density before harvest, pcs / m^2	Density productive stems, pcs / m^2	Coefficient of tillering
10.09	3.0	91.0 ± 2.1	95.8 ± 1.0	89.2 ± 0.9	234 ± 6.0	580 ± 9.8	2.48 ± 0.07
30.09	3.0	91.6 ± 2.3	98.7 ± 1.0	90.4 ± 1.2	245 ± 6.7	608 ± 9.0	2.48 ± 0.09
20.10	5.5	87.2 ± 2.1	97.2 ± 1.1	88.0 ± 0.9	411 ± 8.3	560 ± 7.5	1.36 ± 0.60
10.11	7.0	84.1 ± 1.8	95.4 ± 0.9	86.8 ± 0.5	487 ± 8.0	545 ± 7.8	1.12 ± 0.05
30.11	7.0	80.4 ± 1.6	93.3 ± 0.6	85.9 ± 0.7	451 ± 7.0	512 ± 6.5	1.14 ± 0.07
20.12	7.5	76.8 ± 1.9	92.8 ± 0.7	84.1 ± 0.9	450 ± 7.2	502 ± 6.0	1.12 ± 0.05

It is noted that the density of productive stems (580 and 608 pcs/m^2) and the tillering coefficient (2.48) is the highest for sowing in September. At later sowing terms, the density of ears decreased to 502–545 pieces/m^2 due to the lack of autumn tillering, but it was sufficient to form high yields. The tillering coefficient above one was obtained due to the formation of lateral shoots on the part of the plants with the restoration of spring vegetation.

Under the influence of sowing dates, the elements of ear productivity also changed (Table 3). The length of the ear was more significant than during the sowing on September 1 and 10. The number of spikelets is the highest in the second variant – 17.4 pcs. However, the number of grains in the ear and grain weight is more critical for yield formation. These figures were higher than during the sowings on September 30. Thus, the number of grains during sowing on September 1 was 42 pieces, and for sowing on September 30 increased to 48 pieces. The weight of grain from the ear during sowing on September 30 increased by 1.61 g. During the October sowing period, the weight of grain from the ear remained at the level of the variant with sowing on September 30.

Table 3. Elements of ear productivity of winter wheat variety Kubus depending on the sowing term

Sowing term	Ear length, cm	Number of spikelets in the ear, pcs	Number of grains in the ear, pcs	Grain weight from one ear, g
01.09	8.6 ± 0.12	17.2 ± 0.57	42 ± 1.16	1.49 ± 0.05
10.09	8.6 ± 0.09	17.4 ± 0.60	42 ± 1.23	1.54 ± 0.03
20.09	8.5 ± 0.14	17.0 ± 0.58	45 ± 1.20	1.56 ± 0.07
30.09	8.5 ± 0.09	17.0 ± 0.62	48 ± 1.22	1.61 ± 0.06
10.10	8.4 ± 0.13	16.8 ± 0.60	46 ± 1.20	1.61 ± 0.05
20.10	8.4 ± 0.10	16.6 ± 0.57	45 ± 1.18	1.60 ± 0.07

Similar results were obtained in an experiment of the study of late sowing terms. During sowing in November and December, ear productivity decreased compared to sowing on September 30 and October 20 (Table 4). However, the weight of grain from the ear remained high due to the high-intensity technology of growing winter wheat. In the late sowing terms, single-eared plants were formed, but high nitrogen (N180) was applied in the spring. Under such conditions, nitrogen was effectively used to increase the productivity of one ear on the main stem.

Table 4. Elements of productivity of an ear of winter wheat of the Kubus variety depending on sowing term (average for 2018–2020, x ± SD, n = 6)

Sowing term	Ear length, cm	Number of spikelets in the ear, pcs	Number of grains in the ear, pcs	Grain weight from one ear, g
10.09	8.6 ± 0.10	17.2 ± 0.62	45 ± 1,33	1.55 ± 0.05
30.09	8.6 ± 0.12	17.2 ± 0.64	47 ± 1,30	1.60 ± 0.07
20.10	8.5 ± 0.08	17.2 ± 0.60	48 ± 1,33	1.61 ± 0.04
10.11	8.4 ± 0.07	17.0 ± 0.62	45 ± 1,27	1.55 ± 0.06
30.11	8.3 ± 0.10	16.8 ± 0.61	43 ± 1,30	1.52 ± 0.05
20.12	8.3 ± 0.11	16.8 ± 0.69	42 ± 1,28	1.45 ± 0.04

Sowing terms significantly impacted the grain yield of the winter wheat variety Kubus (Table 5). On average, for three years, the highest yield (9.22 t/ha) was formed during sowing on September 30. This variety had the highest indicators of the density of productive stems (590 pcs/ m^2) and grain weight from the ear (1.61 g).

The minor decrease of the yield was when the sowing term was deviated by ten days towards early and late. Thus, during sowing on September 20, the yield decreased to 8.83 t / ha, and during sowing on October 10 - to 8.88 t/ha, which is 3.9 t/ha (4.2 %) and 3.4 t ha (3.7 %) less, respectively, compared to sowing on September 30. The shift of sowing terms to September 10 and September 1 led to a sharper decrease in yield (respectively 8.51 t/ha and 8.32 t/ha). The deviation in the first variant from the optimal term by 30 days towards the early ones caused a decrease in yield by 0.90 t/ha (9.8 %). Compared with September 10, early sowing on September 1 led to a decrease in yield by 0.19 t/ha. It should be noted that the yield during sowing on October 10 was 0.37 t/ha higher, compared with the sowing on September 10.

Table 5. The yield of winter wheat variety Kubus depending on sowing terms (x ± SD, n = 6)

Sowing term	Years			Average for three years, t / ha	Decrease of yield	
	2016	2017	2018		t / ha	%
1.09	8.28 ± 0.12	8.28 ± 0.10	8.40 ± 0.13	8.32 ± 0.22	-0.90	-9.8
10.09	8.49 ± 0.07	8.45 ± 0.11	8.59 ± 0.12	8.51 ± 0.18	-0.71	-7.7
20.09	8.80 ± 0.17	8.81 ± 0.09	8.88 ± 0.16	8.83 ± 0.20	-0.39	-4.2
30.09	9.19 ± 0.19	9.17 ± 0.13	9.30 ± 0.18	9.22 ± 0.24	max	-
10.10	8.86 ± 0.13	8.87 ± 0.15	8.91 ± 0.10	8.88 ± 0.25	-0.34	-3.7
20.10	8.09 ± 0.10	8.03 ± 0.10	8.12 ± 0.12	8.08 ± 0.19	-1.14	-12.4

The lowest grain yield of winter wheat of the Kubus variety was obtained, as expected, during sowing in the latest terms on October 20 – 8.08 t/ha. When mixed from the optimal term by only 20 days towards the late ones, the yield decreased by 1.14 t/ha (12.4 %). Comparison of early (September 1) and late (October 20) terms shows that postponement of sowing for 30 days earlier than the optimal term does not lead to such a decrease of yield (0.90 t/ha) as shifting the sowing period by only 20 days towards late ones (1.14 t/ha).

Yields also varied over the years, but the dependence on sowing terms was similar.

In the conditions of global warming, in Ukraine, in some winter months, the soil does not freeze, there is no snow cover, so it is possible to sow winter wheat very late. In the second experiment, the November and December sowing dates were studied compared to the early ones. As in the first experiment in 2016–2018, the highest yield (9.43 t/ha) was obtained with the sowing on September 30 (Table 6). However, in the later sowing terms in the second experiment, the conditions for winter wheat growth were more favorable due to the higher temperature. Thus, during sowing on October 20 in 2016–2018, the yield decreased compared to September 30 from 9.22 t/ha to 8.08 t/ha, or by 1.14 t/ha, while in 2018–2020, this difference is only 0.68 t/ha.

Table 6. Yield of winter wheat variety Kubus depending on sowing rates (x ± SD, n = 6)

Sowing term	Years			Average for three years, t/ha	Decrease of yield	
	2018	2019	2020		t/ha	%
10.09	8.67 ± 0.10	8.62 ± 0.07	8.75 ± 0.18	8.68 ± 0.16	-0.75	-8.0
30.09	9.43 ± 0.17	9.36 ± 0.13	9.50 ± 0.20	9.43 ± 0.27	max	
20.10	8.69 ± 0.11	8.76 ± 0.19	8.80 ± 0.12	8.75 ± 0.22	-0.68	-7.2
10.11	8.10 ± 0.12	8.05 ± 0.10	8.21 ± 0.15	8.12 ± 0.25	-1.31	-13.9
30.11	7.44*±0.07	-**	7.64 ± 0.06	7.54 ± 0.18	-1.89	-20.0
20.12	-**	-**	7.03 ± 0.08	7.03 ± 0.20	-2.40	-25.5

* In 2017, sown on November 26 for the 2018 harvest.

** Sowing during this period was impossible due to the freezing of the soil and the presence of snow.

Analysis of experimental data shows that in the absence of predecessors who vacate the field early, during late sowing terms can also get high yields. It is much lower than sowing in the optimal time, so for sowing on November 30, the yield decreased by 1.89 t/ha, and on December 20 – by 2.40 t/ha. However, the yield of 7.03 t/ha also provides a high profit—climatic conditions allowed to sow on November 10 in all three years of research. The average yield was 8.12 t/ha. On average, for two years, during the sowing on November 30, it decreased to 7.54 t/ha. Even for sowing on December 20, 2019, winter wheat formed in 2020 a yield above 7 t/ha, which was economically advantageous.

Conclusions

The highest yield (9.22 t/ha and 9.43 t/ha) of winter wheat of the Kubus variety is formed during sowing on September 30. Grain yields are also high during sowing in the period from September 20 to October 10.

It is possible to get 7–8 t/ha for sowing in late terms in November-December. Given that the duration of the vernalization process is approximately 40 days, winter wheat can be sown even in winter intervals in December, January, and February if the physical condition of the soil allows it.

Yields above 9 t/ha are achieved by the following combination of the main indicators of the structure: the density of productive stems should be approximately 600 pcs/m^2, grain weight from the ear – 1.60 g

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