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ORIGINAL ARTICLE

Influence of fertilization on the formation of grain productivity in different-maturing maize hybrids

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Aim. The research aimed to establish the influence of macro- and microfertilizer norms on grain yield and quality of different-maturing maize hybrids and to identify more adapted hybrids for the conditions of the Western Forest-Steppe of Ukraine. **Methods.** Methods are field, analytical and statistical. **Results.** A significant difference in yield between the studied hybrids by Duncan's test was proved; the average factor values were as follows for hybrids: KWS Kumpan 7.76 t/ha, KWS 4484 – 7.97, KWS 381 – 10.31, and KWS 2323 – 10.7 t/ha. We established that in Western Forest-Steppe, it is expedient to grow a medium-early hybrid of corn KWS 2323. This will allow obtaining yields of 10.9–11.1 t/ha with the application of diamophos in spring at the rate of 200–250 kg/ha. We also recommend using medium-ripe hybrid corn KWS 381 for yields of 10.5–10.7 t/ha, with the introduction of diamophos in the spring at a rate of 250–300 kg/ha and fertilization of these hybrids in the phase of 5–7 leaves of corn with microfertilizer "Harvest Grain" at the rate of 3 L/ha. All four hybrids showed a similar tendency in the effect of fertilizer on the weight of 1000 corn grains. Optimal indicators were obtained at increased fertilizer rates - 250 and 300 kg/ha and microfertilizer rates - 2 and 3 L/ha. The weight of 1000 grains in these variants was, respectively, in hybrids: KWS 2323 - 367.5-367.6 grams, KWS Kumpan - 252.3-256.2, KWS 381 - 359.9-361.5, KWS 4484 - 262, 6-262.7 grams. The optimal weight of 1000 grains of 359.9-367.6 grams was characterized by hybrids KWS 2323 and KWS 381. The maximum values of protein content in maize hybrids were recorded on the variants of fertilizer rates of 250 and 300 kg/ha and microfertilizer rates of 2 and 3 L/ha; the figures were: KWS 2323 - 9.5–9.6%, KWS Kumpan - 9.3–9.4%, KWS 381 – 9.4–9.5%, KWS 4484 - 9.9–10.0%. When determining the starch content, the most significant reaction to the increase in the rates of fertilizers and microfertilizers was shown by the hybrid KWS 4484, the indicator on the variants of fertilizers 250 and 300 kg/ha and microfertilizers 2 and 3 L/ha was 77.5-78,0%, which is 1.1-1.6% exceeded control. All variants of the medium-ripe group in terms of starch content exceeded the hybrids of the medium-early group.
Keywords: maize hybrids, yield, the weight of 1000 grains, protein content, starch content.

Introduction

Recently, we have seen a tendency to change weather and climatic conditions, so the technology of growing corn in the zone needs improvement. The issues of applying macro- and microfertilizers, particularly the norms of their application, are relevant. An important aspect is the selection of hybrids by maturity group and productivity in specific soil and climatic conditions of cultivation (Andreienko, 1969; Mazur et al., 2020b). Fertilizers – one of the primary and most influential factors in increasing crop yields, including corn. Important from an ecological and economic point of view is an adequately selected system of corn nutrition, taking into account the removal of nutrients from the soil for the planned harvest, the need for certain elements depending on the stages of plant development, weather and climatic factors, cultivation technology (Melnychuk, Patyka, 2011). The need for corn in nutrients is high (Snihovyi, 2003; Tsykov, 2018).

The main task in growing corn is to provide the plant with nutrients and achieve synergy between these elements during the growing season. However, it should be remembered that there is also opposition to one element – another (antagonism) or blocking them.

For the entire growth and development of corn plants and the formation of optimal plant productivity is not enough to meet the needs of plants in nitrogen, phosphorus, potassium, calcium, magnesium, and sulfur (Mazur et al., 2019c; Lavrynenko et al., 1996; Kaletnik et al., 2020b; Gamayunov, Gildenbrant, 1990; Pantsyreva et al., 2020; Didur et al., 2021; Filipiev, Krishtopa, 1985; Mazur et al., 2020a; Mikheev, Krinitsyn, 2001; Pantsyreva, 2018; Puyu et al., 2021; Rai et al., 2017; Vdovenko et al., 2018a; Vozhegova et al., 2012).

Microelements in plant nutrition play an equally important role. The primary purpose of microelements is to increase the activity of enzymes, which in turn accelerate chemical processes in the plant body, increase the overall tone of plants, have a positive effect on plant growth and development (Mazur et al., 2018c; Lykhochvor, Petrichenko, 2006; Didur et al., 2019; Kokovikhin, 1996; Mazur et al., 2020a). Microelements in plant nutrition make it possible to use better water, light, nitrogen, phosphorus, and potassium. In addition, microelements promote tissue repair and significantly reduce the risk of plant diseases. The above factors are insufficiently studied in the Western Forest-Steppe of Ukraine and need to be improved (Mazur et al., 2018b; Barchukova, Kovalenko, 2013; Didur et al., 2020a; Dzyubetsky, 2000; Mazur et al., 2020b; Mohamed et al., 2009; Monarkh, Pantsyreva, 2019; Okanenko, 1997; Pantsyreva et al., 2019; Vdovenko et al., 2018b).

The fertilizer system should be developed depending on the soil growing conditions. Thus, scientists from the Institute of Irrigated Agriculture of NAAS found that on dark chestnut soils of southern Ukraine, the maximum yield of corn was obtained by applying fertilizers $N_{120}P_{90}$ on the background of irrigation (Bulygin et al., 2000; Mazur et al., 2020c; Palamarchuk et al., 2018). Maize needs loose, clean, breathable soils with a deep humus layer, well supplied with moisture and nutrients – these are chernozems and dark chestnut soils.

Biological removal from the soil and fertilizers of nutrients for the formation of one hectare of crops is nitrogen 181, phosphorus – 86, potassium 227 kg/ha, and rainy conditions 79, 24, and 90 kg/ha, respectively. Such data were obtained by the staff of the Institute of Irrigated Agriculture of NAAS. The norm of nitrogen fertilizers should be 180 kg at the density of sowing corn before harvesting 70 thousand plants per 1 ha; V.I. Krishtopa gives such recommendations for high-yielding medium-late hybrid Borisfen 430 AMV (Kaletnik et al., 2020a; Kokovikhin et al., 2010; Gamayunov, Koniashyn, 1989; Kaletnik, 2018; Kryshtopa, 1996; Mazur, 2018). Phosphorus for corn can be applied to the rows during sowing, 5 cm below or 5 cm away from the row simultaneously as sowing, in fertilization (liquid forms).

According to scientists, in the Southern Steppe of Ukraine, the irrigated lands to apply potash fertilizers for corn is impractical (except for soils that have a potassium content of less than 12 mg per 100 g of dry soil).

Corn forms a large organic mass, so it removes a significant amount of nutrients from the soil. Kokovikhin et al. (2010) argued that under irrigation, the share of fertilizers accounts for about 70% of the possible increase in yield. Moreover, their effectiveness depends on the introduction of a favorable ratio of nutrition. When irrigated, the increase in corn grain yield from fertilizers is from 37.5 to 56.5 c/ha. Gamayunov and Koniashyn (1990) indicated that it is the most expedient to apply $N_{150}P_{120}K_{30}$ fertilizer to corn for grain. The culture practically does not react to the increase of fertilizer norms to $N_{180}P_{150}K_{70}$. According to Gamayunov and Hildenbrant (1989), the maximum yield of corn on dark chestnut heavy loam soils can be obtained by applying fertilizers N240P160K80 and on gray-meadow when using $N_{90}P_{100}K_{30}$. Mikheiev and Krinitsyn (2001) recommended applying 80 t/ha of manure and $N_{180}P_{120}K_{30}$ to ensure the high productivity of corn plants.

Regarding foreign research, researchers at the University of North Carolina (USA) found that the maximum yield of corn is formed when using $N_{100-140}$, and the terms of fertilizer application, either for primary tillage or pre-sowing cultivation, does not affect their effectiveness.

Scientists claim that the need for corn for microelements is also quite significant: Zn – 85 grams (g), Mn – 110 g, B – 11 g, Cu – 14 g, Fe – 200 g, and Mo – 0.9 g. Corn absorbs macro- and microelements unevenly during the growing season. Zinc, iron, manganese, boron, copper are the essential microelements for corn. They affect the flowering of panicles and cobs, grain formation, movement of nutrients, including from the vegetative organs to the reproductive ones. Also increase drought resistance and heat resistance of corn, and zinc in particular – salt resistance.

Thus, the above indicates that the main methods that directly impact the productivity of corn, the qualitative composition of grain and green mass, are the application of mineral fertilizers and microfertilizers.

The study aimed to establish the influence of macro- and microfertilizer rates on grain yield and grain quality of different-maturing maize hybrids and to identify more adapted hybrids for the conditions of the Western Forest-Steppe of Ukraine.

Materials and methods

The research was performed during 2018–2020 in the conditions of "Kolos VS Corporation" of Borshchiv district of Ternopil region Bilche-Zolote village (branch of the departments of the Faculty of Agrotechnology and Nature Management). Maize hybrids were studied in the experiment: KWS 2323 (FAO 260), KWS Kumpan (FAO 290), KWS 381 (FAO 350), KWS 4484 (FAO 370) – factor A; NPK rate (diamophos): 150 (control), 200, 250 and 300 kg (pre-sowing application) – factor B. Under the main tillage the general background of fertilizers for all variants: diamophos (2 c/ha), ammonium sulfate (2 c/ha), anhydrous ammonia (2 c/ha); rate of application of microfertilizer "Harvest Grain": 1, 2, 3 L/ha – factor C. Microfertilizer was applied in the phase of 5-7 leaves. The variant without nutrition is taken as a control. The experiments were performed four times. Areas with crops were placed by a systematic (sequential) method. The sown area of the plots was – 100 m^2, accounting for – 56 m^2. All records, observations, and analyzes were carried out following generally accepted methods. Yield accounting was performed by the method of continuous plot threshing. Yields were brought to 100% purity and 14% humidity. Methods of variance, correlation performed statistical processing of research results and regression analysis with Statistica 6.0 software. The weight of 1000 grains was determined according to the State Standard SSTU 3484-96 (GOST 170-81-97) for each variant of the experiment (Dospekhov, B.A., 1985; Nychyporovych A., 1973).

The content of protein (crude protein) in corn grain was determined on the device of the system "Kjeltec Auto 1030 Analyzer" (company "Tecator", Sweden). Under the "crude protein" means the total amount of nitrogen determined by the Kjeldahl method, followed by conversion to protein. The starch content was determined by the polarimetric method (according to Evers) on a Kjeltec Auto-1030-Analyzer.

Results

The level of corn grain yield is determined mainly by the development of the leaf apparatus of plants and the photosynthetic potential of crops, which accumulates solar energy during photosynthesis. The photosynthetic potential is a kind of indicator of the culture potential. It plays an essential role in the accumulation of biomass and changes significantly under agronomic and biological factors. The study of morpho-physiological parameters of maize plants can provide specific recommendations for disclosing the reserve potential of plants in specific conditions.
In our studies, the photosynthetic potential during the growing season of corn had some differences in hybrids, fertilizer rates, and microfertilizers.

Table 1. The photosynthetic potential of maize hybrids depending on fertilizer, thousand m^2 × days/ha (average for 2018–2020)

Fertilizer rate, kg/ha	Rate of microfertilizer, L/ha	Hybrid			
		KWS 2323	KWS Kumpan	KWS 381	KWS 4484
150 (control)	Without microfertilizer (control)	1336.2	1086.3	1300.5	1081.2
	1	1341.3	1091.4	1305.6	1081.2
	2	1346.4	1132.2	1331.1	1142.4
	3	1366.8	1137.2	1336.2	1147.5
200	Without microfertilizer	1341.3	1076.1	1305.6	1071
	1	1341.3	1096.5	1310.7	1086.3
	2	1366.8	1137.3	1336.2	1147.5
	3	1366.8	1142.4	1341.3	1152.6
250	Without microfertilizer	1461.2	1185.6	1424.8	1232.4
	1	1466.4	1190.8	1430	1232.4
	2	1539.2	1274	1518.4	1315.6
	3	1544.4	1279.2	1523.6	1320.8
300	Without microfertilizer	1466.4	1190.8	1430	1237.6
	1	1466.4	1175.2	1435.2	1237.6
	2	1534	1279.2	1523.6	1320.8
	3	1539.2	1274	1528.8	1320.8
	V, %	*11.0*			

The data in Table 1 show that the photosynthetic potential of maize hybrids ranged from 1300.5 to 1539.2 thousand m^2 × days/ha. In two hybrids: KWS 2323 and KWS 381, the indicator was higher and amounted to 1336.2–1539.2 and 13005–1528.8 thousand m2 × days/ha. In the hybrids, KWS Kumpan and KWS 4484 photosynthetic potential was significantly inferior to the abovementioned hybrids and was in the range of 1081.2–1320.8 thousand m^2 × days/ha.
Our research has shown that under the influence of macro- and microfertilizer application rates, the assimilation surface area and photosynthetic potential of maize hybrids increased, contributing to increased grain yield. Hybrid correlations were in the range (r = 0.82–0.88). The maximum correlation was recorded in the maize hybrid KWS 4484, which was characterized by the regression equation: Y = 5.4130 + 0.00214 PP.
We established that the maximum yield was formed by those hybrids and variants in which there was the greatest accumulation of dry aboveground mass. Optimal yield variants: medium-early hybrid KWS 2323 and medium-ripe KWS 381, background fertilizer 250–300 kg/ha, microfertilizers 2-3 L/ha. It should be noted that the grain yield of corn fluctuated significantly over the years; the least productive for all studied hybrids was 2020 and the most productive - 2018. The yield difference was 0.4-1.7 t/ha depending on the hybrid and fertilizer rates (Table 2).
There was a significant difference in yield between the studied hybrids. Thus, according to Duncan's criterion, the average factor values were as follows for hybrids: KWS Kumpan 7.76 t/ha, KWS 4484 – 7.97, KWS 381 – 10.31, and KWS 2323 – 10.7 t/ha. According to Duncan's test, all values were in different homogeneous groups, of which four were selected, which indicates a significant difference between the data on factor A (hybrid) (Table 3).

Table 2. Grain yield of maize hybrids depending on fertilizer, t/ha (average for 2018-2020)

Fertilizer rate, kg/ha	Rate of microfertilizer, L/ha	Hybrid			
		KWS 2323	KWS Kumpan	KWS 381	KWS 4484
150 (control)	Without microfertilizer (control)	10.1	7.3	10.0	7.7
	1	10.2	7.4	9.9	7.6
	2	10.2	7.5	10.1	7.8
	3	10.2	7.5	10.2	7.8
200	Without microfertilizer	10.4	7.5	10.1	7.7
	1	10.5	7.6	10.2	7.8
	2	10.7	7.8	10.4	8.0
	3	10.9	7.9	10.3	8.0
250	Without microfertilizer	10.7	7.8	10.2	7.9
	1	10.7	7.7	10.4	7.8
	2	11.0	8.0	10.4	8.2
	3	11.1	8.0	10.5	8.3
300	Without microfertilizer	10.9	7.9	10.4	8.0
	1	11.0	7.9	10.4	8.1
	2	11.1	8.1	10.6	8.3
	3	11.2	8.0	10.7	8.3

LSD_{05}: 2018:A – 0.15, B – 0.15, C – 0.15, AB – 0.30, AC – 0.30, BC – 0.30, ABC – 0.60
2019:A – 0.21, B – 0.21, C – 0.21, AB – 0.41, AC – 0.41, BC – 0.41, ABC – 0.82
2020:A – 0.16, B – 0.16, C – 0.16, AB – 0.32, AC – 0.32, BC – 0.32, ABC – 0.64

Table 3. Dependence of maize grain yield on hybrid according to the Duncan test (average for 2018–2020)

№	Hybrid	Yield	Homogeneous groups			
			1	2	3	4
1	KWS Kumpan	7.76	***			
2	KWS 4484	7.97		***		
3	KWS 381	10.31			***	
4	KWS 2323	10.70				***

A similar tendency is observed for factor B (fertilizer application rate); the average factor values were in the range of 8.9–9.43 t/ha, the variants were distributed among different homogeneous groups, which indicates the significance of the difference between them (Table 4).

Table 4. Dependence of maize grain yield on the fertilizer rate according to the Duncan test (average for 2018-2020)

№	Fertilizer rate	Yield	Homogeneous groups			
			1	2	3	4
1	150	8.90	***			
2	200	9.11		***		
3	250	9.29			***	
4	300	9.43				***

According to Duncan's criterion, the effect of the rate of microfertilizer "Harvest grain" application was as follows: without microfertilizer and variant with a rate of 1 L/ha were in the same homogeneous group, which indicates the inexpediency of such a rate, as yield margin is insignificant, but variants application of microfertilizers 2 and 3 L/ha had a direct impact on grain yield, these variants were in the same homogeneous group, but differed significantly from the control (Table 5).

Table 5. Dependence of maize grain yield on the rate of microfertilizer according to the Duncan test (average for 2018-2020)

№	Microfertilizer rate	Yield	Homogeneous groups	
			1	2
1	0	9.04	***	
2	1	9.08	***	
3	2	9.30		***
4	3	9.32		***

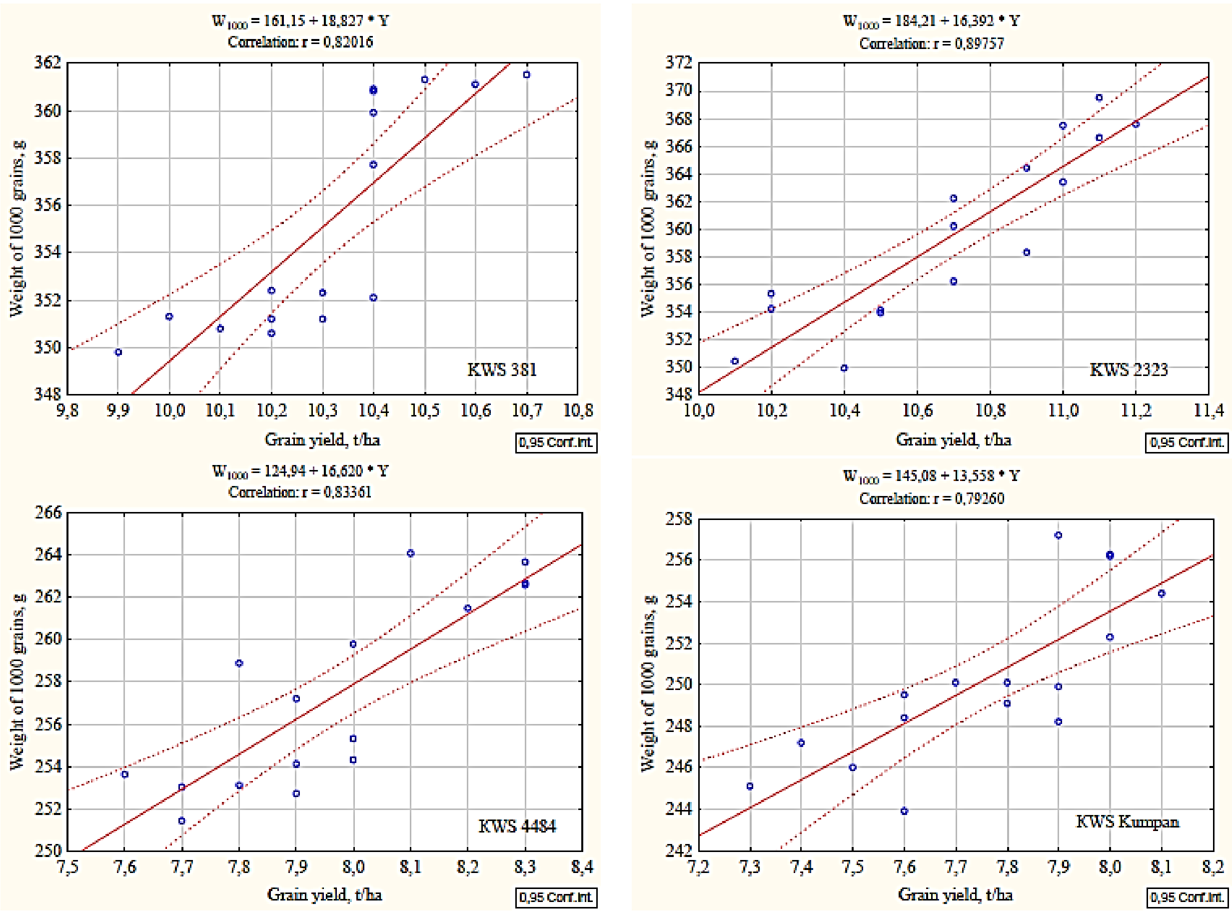

Fig. 1. Dependence of the weight of 1000 grains on the maize hybrid yields

In our studies, maize hybrids had a relatively high weight of 1000 grains; in the control variants, the indicator was in the range of 247.2-351.3 grams. In the medium-early group, the maximum weight of 1000 grains was characterized by a hybrid of KWS 2323 corn with an index in the range of 350.4–369.5 grams, and in the medium-ripe group – a hybrid of KWS 381 – with an index from 361.3 to 361.5 grams.

The data in Fig. 1 show a correlation analysis of the weight dependence of 1000 grains on grain yield in terms of maize hybrids. The correlation coefficient was in the range of r = 0.79–0.89. It was highest in the hybrid KWS 2323 and was characterized by the regression equation M_{1000} = 184.21 + 16.392 Y. Thus, the relationship is straightforward and proves the dependence of 1000 grains on the yield by 89%.

The optimal values of protein content in maize hybrids were recorded on the variants of fertilizer rates of 250 and 300 kg/ha and microfertilizer rates of 2 and 3 L/ha; the indicators were: KWS 2323 – 9.5–9.6%, KWS Kumpan – 9.3– 9.4%, KWS 381 – 9.4–9.5%, KWS 4484 – 9.9–10.0%.

When determining the starch content, the most significant reaction to the increase in the rates of fertilizers and microfertilizers was shown by the hybrid KWS 4484; the indicator on the variants of fertilizers 250 and 300 kg/ha and microfertilizers 2 and 3 L/ha was 77.5-78%, which is 1.1-1.6% exceeded control. All variants of the medium-ripe group in terms of starch content exceeded the hybrids of the medium-early group. The KWS Kumpan hybrid characterized the minimum starch content of 72.7–73.3% and the maximum was 76.4–78% by the KWS 4484 hybrid.

Fig. 2 shows that the correlations in the context of maize hybrids were strong between yield, the weight of 1000 grains, and chemical composition of grain (protein and starch content) and were in the range (r = 0.85-0.96), however depending on the hybrid, the indicators differed slightly.

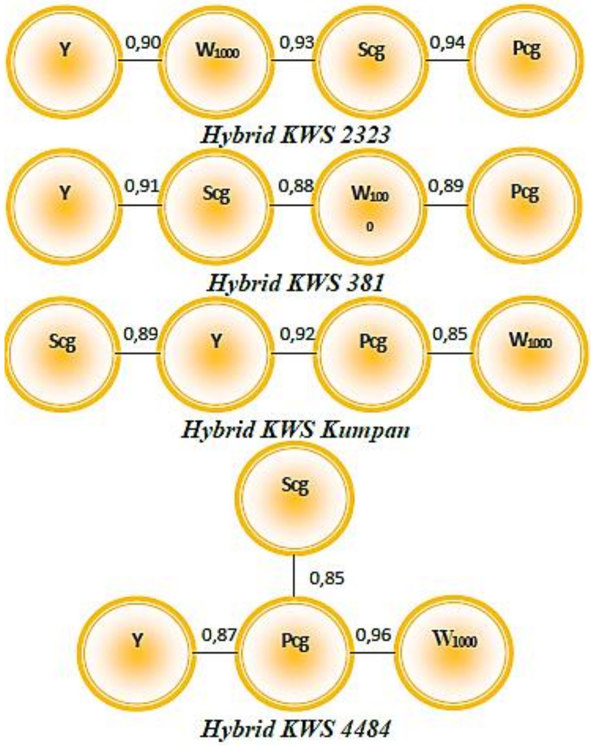

Fig. 2. Correlation galaxy of maize bond system (Y - yield; W_{1000} - weight 1000; Pcg - protein content in grain; Scg - starch content in grain)

Conclusions

The maximum photosynthetic potential of maize crops we recorded in a hybrid of medium-early group KWS 2323 and medium-ripe group KWS 381 – 1518.4-1539.2 thousand m^2 × days/ha on the background of fertilizers 250 and 300 kg/ha with fertilization "Harvest Grain" rates of 2 and 3 L/ha of sowing. The optimal yield was formed in the medium-early hybrid KWS 2323 and medium-ripe KWS 381. We registered 11.1-11.2 and 10.5-10.7 t/ha in variants with 250 kg/ha and 3 L/ha of microfertilizers, 300 kg/ha macrofertilizers, and microfertilizers 2 and 3 L/ha, respectively.

We obtained optimal weights of 1000 grains at increased fertilizer rates – 250 and 300 kg/ha and microfertilizer rates – 2 and 3 L/ha. The weight of 1000 grains in these variants was, respectively, in hybrids: KWS 2323 – 367.5-367.6 grams, KWS Kumpan – 252.3-256.2, KWS 381 – 359.9-361.5, KWS 4484 – 262.6-262.7 grams. Hybrids KWS 2323 and KWS 381 were characterized by the most significant weight of 1000 grains. The optimal protein content values in maize hybrids we recorded on the variants of fertilizer rates of 250 and 300 kg/ha and microfertilizer rates of 2 and 3 L/ha. The indicators were: KWS 2323 – 9.5-9.6%, KWS Kumpan – 9.3-9.4%, KWS 381 – 9.4-9.5%, KWS 4484 – 9.9-10.0%.

We revealed the most significant reaction to the increase of fertilizers and microfertilizers in hybrid KWS 4484 in variants with 250 and 300 kg/ha of fertilizers and 2 and 3 L/ha of microfertilizers. It was 77.5-78%, which exceeded control by 1.1-1.6% when determined the starch content.

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