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CORN FOR GRAIN IN CONTINUOUS GROWING UNDER DIFFERENT FERTILIZER SYSTEMS AND WEATHER CONDITIONS

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Abstract. *On the experimental field of the Poltava State Agricultural Experimental Station named after M. I. Vavilov of the The Institute of Pig Breeding and Agro-Industrial Production of the National Academy of Agrarian Sciences of Ukraine, during 1984-2023, on typical chernozem in conditions of unstable moisture of the Left-Bank Forest-Steppe, were conducted researches to study the continuous growing of corn for grain and its productivity. Precipitation is the leading factor in providing corn with available moisture in this region. Different hydrothermal conditions, especially the amount of moisture during the agricultural year and the vegetation, led to sharp fluctuations in grain yield over the years, which occurred in a wide range. The analysis of the average values of corn productivity for each 10 consecutive years of conducting these studies made it possible to establish that during the first decade of observations, the dynamics of this indicator in subsequent periods took place in the paradigm of its growth, albeit at a different level. Maize grain yield and its correlation with different weather conditions and fertilization systems, regardless of the replacement of maize hybrids, ranged from direct to inverse and from low to high. Long-term application of different doses and ratios of organic and mineral fertilizers contributed to changes in both quantitative and qualitative indicators of humus in the soil. It was determined that the content of total carbon in the fertilized areas was higher by 3,0 and 3,3 relative percent compared to the unfertilized ones. Special attention was paid to the ratio between humic and fulvic acids, which directly depends on the fertilization system. The different effect of this agrotechnical measure on the amount of humus accumulation in the soil is shown. Thus, in areas without fertilizers (control), its accumulation occurs at the level of an average indicator and a weak effect of organic acids on the mineral part of the soil, while under the organo-mineral fertilization system, this process takes place intensively, and the mineral part remains almost unchanged.*

Key words**:** *corn, continuous growing, hydrothermal conditions, productivity, humus, humus accumulation*

Relevance of research. The formation of sustainable agrosystems in agriculture is closely related to the optimization of the structure of crop rotations and the system of fertilization and soil cultivation [1–5].

In recent years, the specialization of farms has significantly narrowed, agriculture production has focused on the cultivation of certain economically attractive crops. The consequence of this transformation was systemic changes in the structure of crop rotations and their transition to short-rotational and repeated crops, especially corn, which many farmers sow in one field for several years [6–8].

Maize (Zea mays L.) is the most productive among all-purpose cereal crops. In the world, about 20 % of corn grain is used for food purposes, 15–20 % for technical purposes, and 60–65 % for fodder purposes [9, 10].

Analysis of recent research and publications. According to previous studies, corn has the ability to grow on the same plot as

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a monoculture without reducing productivity, as well as in crop rotations with a short rotation, subject to compliance with all technological elements of its cultivation [11–13].

At the same time, the generalization of the research results of other domestic and foreign scientists does not allow us to draw unambiguous conclusions regarding the productivity of corn depending on the place of its placement and fertilization. Disagreements were revealed regarding the lack of nutrients, optimal physical properties, water-air regime, as well as other unfavorable indicators of the quality of the soil and the negative impact of pests and diseases [14–15, 18]. Because of this, long-term experiments with monoculture of corn in the conditions of global climate change on the planet are widely represented in many countries of the world. The results of such studies can be one of the elements in solving the problem of short-rotational crop rotations [5, 12–17]. Inadequate accumulation of available soil moisture plays an important role in crop growth, development and formation, and in some dry years crop productivity is completely dependent on it.

Solving the problem of soil organic matter occupies one of the main places in agricultural science and is gaining more and more applied importance.

Humus is the most important component of soil organic matter. It is an integral indicator of its fertility, which, together with its mineral part, forms an absorption complex and determines the physico-chemical and physical absorption capacity, improves water permeability, heat capacity, moisture retention capacity, nutritional regime, microbiological activity of the soil [18–20].

The purpose of the research is to identify and conduct a comparative evaluation of the long-term application of fertilizers during the continuous cultivation of corn for grain on its productivity, group and fractional composition of typical chernozem humus under different weather conditions. From a practical point of view, the results of such studies make it possible to predict the level of productivity of the crop and to grow it in short-rotational crop rotations or without changes until a certain time.

Research materials and methods. Research on the continuous growing of corn for grain at the experimental field of the Poltava State Agricultural Research Station named after M. Vavilov of the Institute of Pig Breeding and Agro-Industrial Production of the National Academy of Agrarian Sciences of Ukraine has been held since 1964 [21].

The soil of the experimental field is a typical medium-humus heavy loam chernozem on a loess rock. It is characterized by the following main agrochemical and agrophysical indicators: humus content – 3,9–4,2 %; easily hydrolyzed nitrogen (according to Tyurin and Kononova) – 119,1–127,1 mg/kg; P_2O_5 in acetic acid extract (according to Chirykov) – 100,0–131,0 mg/kg; exchangeable potassium (according to Maslova) – 171,0–200,0 mg/kg of soil. Soil density is 1,05–1,17 g/cm^3. The eotal porosity is 55,5–59,8. Field moisture content – 29,7–31,5 %. The total moisture content is about 39 %. The range of active moisture is about 25 mm. The moisture content of the rupture of capillary bonds is 20–22 %.

Total study area – 8640 m^2, accounting area – 29,4 m^2. Three fold replications.

Fertilization scheme in the experiment:

1. Without fertilizers (control).
2. Manure 20 t/ha + +$N_{60}P_{40}K_{60}$ every year.
3. Manure 20 t/ha (once every 3 years) + $N_{51}P_{51}K_{55}$.

The technology for growing corn included cultivating the soil with disc tools to a depth of 8–10 cm after harvesting the crop. The main tillage is plowing to a depth of 24–25 cm. In the spring, harrowing was carried out in 2 rows with heavy tooth harrows, the first cultivation at 4–5 cm, the pre-sowing at 6–7 cm. After that, corn was sown in a wide-row method with a row spacing of 70 cm using a precision seed drill with a sowing rate of 60,000 grains per 1 ha. During the growing season, inter-row loosening was carried out.

In the experiment, zoned varieties and hybrids of corn were grown: 1964–1974 Bukovynskyi 3; 1975–1987 Zherebkivskyi 86 MV; 1988–2001 Dniprovsky 273 MV; 2002–2005 Cadre 267 MV; 2006–2012 Podilskyi 274 MV; since 2013 – hybrid Orzhitsa 273 MB.

The protection system provided for the application of herbicides for weed control, particu-larry, soil applicable Proponit (propizachlor, 720 g/l) – 3,0 l/ha, and for vegetation in the phase of 5-6 leaves with tank mix Milagro 040 SC (dr. nicosulfuron, 40 g/l) – 1,25 l/ha + Prima (2,4D 2-ethylglyxyl ether 300,0 g/l and florisulam 6,25 g/l) – 0,4 l/ha with a working fluid consumption of 250 l/ha. The harvest was recorded manually, and the grain in each plot was weighed with an adjustment for the standard moisture content (14 %). The grain moisture content during harvesting was determined using the thermostat-weight method, the total area was collected using a combination of grinding and leaving by-products in the field.

Research results and their discussion. In Poltava region, as in most regions of Ukraine, one of the limiting factors of high productivity of crops is the amount of moisture reserves in the soil. The main source of providing rainfed crops with this natural component is precipitation. The hydrothermal conditions that formed during the years of observation were quite diverse both during the agricultural year in general and during the growing season in particular (Table 1).

Thus, the lowest air temperature during the full vegetation of corn, as well as during the critical period of its growth and development (the phase of shedding the panicle), and during the agricultural year in general, was observed in the first decade – 18,9; 21,0; 8,2 °C, and the highest during these periods in 2014–2023 – 20,5; 23,2; 9,5 °C. At the same time, the largest amount of precipitation during these periods of time was recorded in the second decade – 222,0; 70,8; 571,6 mm, and the smallest in the first – 194,8; 37,3; 457,8 mm.

Variability of corn grain yield under unchanged sowing and different fertilization systems occurred within wide limits (Table 2). The analyzed average productivity of this crop throughout the entire period of research within hybrids showed that the lowest among hybrids was observed on unfertilized plots in Dniprovskyi 273 MV (1988–2001) – 3,51 t/ha, and on fertilized ones in Zherebkivskyi 86 MV (1975–1987): manure: 30 t/ha every year + $N_{60}P_{40}K_{60}$ – 4,27 t/ha and manure 30 t/ha + 1 time in 3 years + $N_{51}P_{51}K_{55}$ – 4,37 t/ha. And it was the highest in the hybrid Kadr 267 MV (2002–2005) and, according to the variants of the experiment, was 6,63; 6,92; 7,06 t/ha, while on average for 46 years of observations, these indicators were equal to 4,55; 5,43; 5,63 t/ha.

The interval range between the maximum and minimum yield of corn grain, under different fertilization systems, respectively, was within the following limits: Zherebkivskyi 86 MW – 198,6; 294,3; 246,8; Dniprovsky 273 MW – 355,1; 377.4; 447,9; Cadre 267 MV – 160,0; 116,0; 110,6; Podilsky 274 MW – 403,8; 237,6; 121,1; Orzhitsa 273 MV – 172,2; 119,6; 112,4 %. The highest, this indicator, both for the control without fertilizers and for the application of mineral fertilizers on the background of manure, was observed in Dniprovsky 273 MB, and the lowest – in Kadra 267 MB. In such corn hybrids as Kadr 267 MV, Podilskyi 274, Orzhitsa 273 MV, fertilizers contributed to the reduction of the gap between their maximum and minimum productivity, and in Zherebkivskyi 86 MV and Dniprovskyi 273 MV – to an increase.

Calculations and analysis of research results made it possible to establish the dynamics of the productivity of this crop not only for the years of growing hybrids, but also for every 10 consecutive years of conducting this experiment. The lowest grain yield was observed in 1984-1993 and in the control (without fertilizers) it was equal to 3,22 t/ha, and in the options: manure 30 t/ha every year + $N_{60}P_{40}K_{60}$ – 4,51 t/ha and manure 30 t/ha ha + once every 3 years + $N_{51}P_{51}K_{55}$ – 4,66 t/ha. In the next 3 decades (1994–2003, 2004–2013, and 2014–2023), these indicators not only did not decrease, but even increased by 29,8, respectively, compared to the first decade; 11,8; 9,2 % and 62,1 %; 38,8; 42,3 and 45,0; 35,5; 33,3 %.

Therefore, the dynamics of this indicator to the first decade in subsequent years of observation took place in the paradigm of its growth, albeit at a different level.

Mathematical analysis of the data obtained from the results of research on the yield of corn grain and the effect on this indicator of different fertilization systems and weather conditions for the agricultural year in general and for the vegetation phases of its plants showed that the correlation between them covered a wide range from direct to inverse and from low to high.

Thus, the correlation coefficient between the indicators of corn productivity and the temperature regime during the growing season under different fertilization systems, control (without fertilizers), manure: 30 t/ha every year + $N_{60}P_{40}K_{60}$, manure 30 t/ha + once in 3 years +

1. Hydrothermal conditions during the research

Years	Weather conditions					
	Average air temperature, °C			Precipitations, mm		
	vegetation period	critical period	for the agricultural year	vegetation period	critical period	for the agricultural year
1984–1993	18.9	21.0	8.2	194.8	37.3	457.8
1994–2003	19.2	22.3	8.2	222.0	70.8	571.6
2004–2013	19.3	23.0	9.2	207.0	45.8	510.7
2014–2021	21.2	23.6	8.8	208.9	31.6	527.3
Average	*19.7*	*22.5*	*8.6*	*208.2*	*46.4*	*516.9*

2. The level of productivity of corn per grain under unchanged cultivation under different fertilization systems (t/ha)

Time period (10 years)	Hybrid	Years of cultivation	Duration of cultivation, years	Productivity level	Fertilization system					
					without fertilizers (control)		manure30 t/ha per year + $N_{60}P_{40}K_{60}$		manure 30 t/ha once every 3 year + $N_{51}P_{51}K_{55}$	
					for the entire period of hybrid cultivation	average for 10 years	for the entire period of hybrid cultivation	average for 10 years	for the entire period of hybrid cultivation	average for 10 years
	Zherebkivskyi 86 MV	1975–1983	13	max	4,39		6,23		5,34	
1984–1993	Zherebkivskyi 86 MV	1984–1987		min	1,47	3,22	1,58	4,51	1,54	4,66
				average	3,58		4,27		4,37	
	Dniprovsky 273 MV	1988–1993	14	max	4,87		5,92		6,63	
1994–2003	Dniprovsky 273 MV	1994–2001		min	1,07	4,18	1,24	5,04	1,21	5,09
				average	3,51		4,62		4,81	
	Cadre 267 MV	2002–2003	4	max	7,93		8,10		8,36	
2004–2013	Cadre 267 MV	2004–2005		min	3,05	5,22	3,75	6,26	3,97	6,63
				average	6,63		6,92		7,06	
	Podilsky 274 MV	2006–2012	7	max	8,05		8,71		8,40	
				min	1,60		2,58		3,80	
				average	4,66		5,98		6,47	
	Orzhitsa 273 MB	2013	11	max	6,56		7,38		7,52	
2014–2023	Orzhitsa 273 MB	2014–2023		min	2,41	4,67	3,36	6,11	3,54	6,21
				average	4,36		5,35		5,48	

$N_{51}P_{51}K_{55}$ was respectively at low level: r = 0,25; 0,18; 0,15, while for the critical period of plant growth and development and the full agricultural year, respectively, at high: r = 0,79; 0,71; 0,66 and r = 0,87; 0,93; 0,94.

A completely different correlation dependence was observed between the level of corn grain yield, organo-mineral fertilization systems and the amount of precipitation. If, in general, during the growing season and the agricultural year, these indicators were at an average level in control, the correlation coefficient was 0,43 and 0,45, and in the fertilized variants it was low, respectively r = 0,24; 0,15 and 0,26; 0,17, then already during the critical period of its development, their values were as follows: r = 0,13; −0,01; −0,06.

Long-term use of different doses and ratios of organic and mineral fertilizers contributed to changes in the soil's quantitative and qualitative indicators of humus (Table 3).

It was found that the content of total carbon in the soil in unfertilized plots was equal to 3,01 %, while in fertilized (30 t/ha every year + $N_{60}P_{40}K_{60}$) and (manure 30 t/ha + 1 time in 3 years + $N_{51}P_{51}K_{55}$) it was higher and, respectively was equal to 3,11 and 3,10 %.

Agrochemical analysis of the soil to determine the group and fractional composition of humus showed the unequal influence of fertilization systems on the number of humic and fulvic acids fractions in percentages, as individually and in their sums. On plots without fertilizers (control), the sum of fractions of humic acids was 32,8 %, and on fertilized plots (30 t/ha every year + $N_{60}P_{40}K_{60}$) – 44,3 % and (manure 30 t/ha + 1 time in 3 years + $N_{51}P_{51}K_{55}$) – 43,9 %. Fulvic acid according to fertilization systems – 67,0; 43,9 and 44,1 %.

Separately, it is worth paying attention to the ratio between humic and fulvic acids. As is known, the overall activity of humic acids relative to the mineral part of the soil depends on the value of this indicator. The observations made it possible to establish that in plots without fertilizers (control), this value was at the level of 0,49, and led to an average rate of humus accumulation and a weak effect of organic acids on the mineral part of the soil. Another regularity was observed for organo-mineral fertilization systems, where the ratio between these organic acids was at the level of 1,01 and 1,00, which shows an intensive accumulation of humus in the soil, and the mineral part remains almost unchanged.

Conclusions. The weather conditions over 39 years of observations have been quite diverse. The average air temperature for the agricultural year from 1984 to 1993 corresponded to the value of 8,2 °C, and from 2004 to 2013 – 9.2 °C and from 2014 to 2023 – 9,5 °C, while precipitation respectively – 457,8 mm, 510,7 mm, 577,2 mm.

Corn hybrids grown in a permanent crop have different average productivity by year, which largely depends on weather conditions and fertilization systems. The variability of the average yield of corn grain, its level over a decade under unchanged cultivation and different fertilization systems occurred within wide limits and depended to a lesser extent on the research period. The correlation between corn productivity to different fertilization systems and weather conditions ranged from direct to inverse and from low to high.

In unfertilized areas, humus accumulates moderately, and the effect of organic acids on the mineral part of the soil is weak, while in fertilized areas, humus accumulates intensively, and the mineral part remains constant.

3. The influence of different fertilization systems on the group and fractional composition of typical heavy loamy chernozem humus under unchanged grain corn cultivation (soil layer 0–20 cm)

The fertilization system	Carbon (C) general,%	Humic acids, fractions, %				Fulvic acids, fractions, %					Humin, %	Ratio humic acids / Ratio fulvic acids
		1	2	3	sum	1^a	1	2	3	sum		
Without fertilizer (control)	3,01	4,9	20,2	7,7	32,8	8,9	12,6	23,9	21,6	67,0	29,9	0,49
Manure 30 tons/ha every year + + $N_{60}P_{40}K_{60}$	3,11	5,5	30,9	7,9	44,3	6,6	8,7	21,5	13,7	43,9	33,6	1,01
Manure 30 tons/ha Once every 3 years + + $N_{51}P_{51}K_{55}$	3,10	5,2	30,2	8,5	43,9	4,9	7,9	17,1	14,2	44,1	32,4	1,00

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КУКУРУДЗА НА ЗЕРНО У БЕЗЗМІННОМУ ПОСІВІ ЗА РІЗНИХ СИСТЕМ УДОБРЕННЯ ТА ПОГОДНИХ УМОВ

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Анотація. *На дослідному полі Полтавської державної сільськогосподарської дослідної станції ім. М. І. Вавилова Інституту свинарства і агропромислового виробництва НААН України упродовж 1984–2023 рр. на чорноземі типовому в умовах нестійкого зволоження Лівобережного Лісостепу проводили дослідження з вивчення беззмінного вирощування кукурудзи на зерно та її продуктивність. Провідним фактором забезпечення рослин кукурудзи доступною вологою у цьому регіоні є атмосферні опади. Різні гідротермічні умови, особливо кількість вологи за сільськогосподарський рік та вегетаційний період, призвели до різкого коливання врожайності зерна за роками, яке відбувалося у широкому діапазоні. Аналіз середніх величин продуктивності кукурудзи за кожні 10 послідовних років проведення цих досліджень дав можливість встановити, що за перше десятиріччя наших спостережень динаміка цього показника у наступні періоди відбувалася у парадигмі його зростання хоч і на різному рівні. Урожайність зерна кукурудзи та її кореляційний зв'язок з різними погодними умовами і системами удобрення, незалежно від заміни гібридів кукурудзи, перебувала у діапазоні від прямого до оберненого та від низького до високого. Довготривале застосування різних доз та співвідношень органічних і мінеральних добрив сприяло зміні як кількісних, так і якісних показників гумусу у ґрунті. Визначено, що на удобрених ділянках вміст загального вуглецю щодо неудобрених був більшим на 3,0 і 3,3 відносного відсотка. Особлива увага була приділена на співвідношенню між гуміновими і фульвокислотами, яке напряму залежить від системи удобрення. Показано різну дію цього агротехнічного заходу на величину гумусонакопичення у ґрунті. Так, на ділянках без добрив (контроль) його акумулювання відбувається на рівні середнього показника та слабкої дії органічних кислот на мінеральну частину ґрунту, тоді як за органо-мінеральної системи удобрення цей процес проходить інтенсивно, а мінеральна частина залишається майже беззмінною.*

Ключові слова: *кукурудза, беззмінний посів, гідротермічні умови, продуктивність, гумус, гумусонакопичення*