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UNIQUE EXPERIMENT OF GLOBAL AGRICULTURE IN THE POLTAVA REGION – LONG-TERM WINTER RYE CULTIVATION

A. V. Kohan [1], L. D. Hlushchenko [1], V. V. Hanhur [2], O. A. Samoylenko [1], O. I. Len [1], R. V. Olepir [1], S. M. Kalinichenko [1], L. V. Kavalir [1]

[1] Poltava State Agricultural Experimental Station named after I. Vavilov, the Institute of Pig Breeding and Agroindustrial Production, NAAS of Ukraine 86, Shvedska Str., Poltava, Ukraine, 36014

[2] the Institute of Pig Breeding and Agroindustrial Production, NAAS of Ukraine 1, Shvedska Mohyla Str., Poltava, Ukraine, 36013

E-mail: v.gangur@rambler.ru

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Aim. To determine the impact of long-term effect of the complex of factors (anthropogenic and climatic) on the soil fertility, the change in the phytocenosis of weeds and the productivity of winter rye at permanent cultivation. **Methods.** The content of nitrogen in soil was defined by Kornfield's method, phosphorus and potassium – according to Chirikov; the content of non-organic chemical elements in the soil – by ICP-MS method using the emission mass-spectrometer Agilent-7700 × (USA). **Results.** It was determined that the average productivity of winter rye in 1884–2016 was 1.19 t/ha, but the level of crop productivity fluctuated depending on the favorable weather conditions of the year, the quality of soil preparation and the content of productive moisture in the cultivated soil layer during sowing, and the weediness of the experimental sowing. **Conclusions.** The results of the studies may be used to solve the fundamental issues of agriculture, for comprehensive complex investigations, the demonstration of the role of the main factors and conditions of vegetative life.

Keywords: rye, permanent cultivation, species, productivity, humus, weediness.

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INTRODUCTION

The farming experience of the enterprises of the leading countries, specialized in the production of vegetative products only, testifies to the fact that they grow a limited number of crops with a significant share of them in the structure of sowing, usually in short-term crop rotations [1, 2]. Current problems of short-term crop rotations may be studied using the experience ot long-term field experiments of Ukraine and other countries. The conditions orysuch experiments bring together the impact, interaction, and aftereffect of agrotechnical factors as well as changes in environment on the productivity of crops, phytosanitary condition of sowing, contet, and circulation of nutrients [3–11].

The fundamentals of studies on permanent crops were first established in Rothamsead (England), where a series of field experiments with permanent sowing of winter rye, grasses, etc. was launched in the period from 1843–1856 [12, 13].

In Ukraine, the first experiment in studying long-term monoculture cultivation, in particular, winter rye, was launched in 1884 in the Poltava experimental field on dark gray sod-podzolic soil [14, 15].

Numerous long-term experiments demonstrate that repeated and permanent cultivation decreases the performance of agricultural crops [2]. For instance, in the course of 125 years in Rothamsead experimental station, the yield of winter rye in permanent fields decreased more than twice, and though in case of applying fertilizers it did not decrease, it was still lower than the one for crop rotation. In similar experiments in Halle (Germany) in the course of 70 years the yield of winter rye in permanent fields decreased by 63 %, and in the experiments in Chartoryia experimental field (Zhytomyr region) in permanent fields with fertilizers the yield decreased by 32 % compeding to the crop rotation [16].

The research of Lebed [17] established the possibility of repeated cultivation of corn in crop rotations using the same field ane even long-term cultivation (up to 26 years) on the same plots. The best crop to interrupt the continuity of corn in the Steppe was peas, a worse one – barley, sunflower had the middle position between them. The studies demonstrated that the interruption of corn permanence with other crops of the rotation had positive effect only in the year of direct application of this measure.

In a number of cases the reason for the decrease in the crop performance while permanently cultivating these crops was the occurrence of conditions, favorable for the development of pests and agents of diseasese specific for this crop, as well as for the deterioration of the nutrient regime of the soil due to one-sided removal of macro- and microelements from it [18–21]. On the other hand, the growth and performance level of the monoculture were negatively affected by the root exudates of the very plants and the microbial products of soil microorganisms.

The aim of the study was to determine the impact of the long-term action of a complex of factors (anthropogenic, climatic) on soil fertility, the change in phytocenosis of weeds and productivity of permanently cultivated winter rye.

MATERIALS AND METHODS

The experiment in permanent cultivation of winter rye in the Poltava experimental field was launched at the area of 0.4 ha of dark gray sod-podzolic heavy loam soil in 1884. The agrotechnology remained unchanged during the whole study period. Every year aftee harvesting, the soil is tilled with heavy disc tillers, and 7–10 days later the soil is tilled at the depth of 22–25 cm with its simultaneous packing. The grubbing with tillers is applied along with the growth of weeds. Presowing grubbing with tillers and sowing of winter rye with subsequent soil packing is conducted in the second decade of September. No fertilizers or chemical agents tt control weeds, diseases, and pests are used. The experiment has no repeats. In the course of the whole historical period, 9 varieties of winter rye have been sown.

Until 1930, the norm of sowing seeds was 90 kg/ha. From 1930 till 1972, the plot was divided into two parts; the norm of sowing winter rye in the first one was the same (90 kg/ha), and that in the second one was 150 kg/ha. The average yield in 43 years for the norm of sowing 90 kg/ha was 1.11 t/ha, and that for 150 kg/ha – 1.25 t/ha. Since 1972 a modern norm of sowing was introduced – 6 million viable seeds per hectare. The seeds are updated every year. The variety is changed onlr when the previous one becomes disposable.

Table 1. The productivity of different varieties of winter rye in conditions ot long-term cultivation

Variety	Period of cultivation, years (duration in years)	Average yield, t/ha	Meteorological indices, averaged by periods		
			Amount of annual precipitation, mm	Air temperature °C	Amount of precipitation for April-July, mm
Probshteynske	1885–1907 (23)	1.05	459	7.3	245
Poltavske	1908–1910 (3)	1.37	412	7.1	212
Petkuske	1911–1960 (50)	1.13	509	7.1	270
Kharkivske 194	1961–1964 (4)	0.93	417	7.6	208
Kharkivske 55	1965–1982 (18)	1.51	595	7.6	275
Kharkivske 78	1983–1992 (10)	1.58	544	7.7	274
Kharkivske 88	1993–1998 (6)	1.15	590	7.7	276
Kharkivske 95	1999–2009 (11)	0.89	584	8.9	236
Khamarka	2010–2016 (7)	1.27	586	9.2	251
$HCP_{0.95}$		0.34	–	–	–

The content of nitrogen in soil was defined by Kornfield's method, phosphorus and potassium – according to Chirikov; the acidity (pH) – by the potentiometric method in salt suspension; the hydrolytic acidity – according to Kappen-Hilkevitch. The determination of the composition and content of non-organic chemical elements in the experimental soil samples was conducted in the Institute of Plant Physiology and Genetics, NAS of Ukraine, by ICP-MS method using the emission mass-spectrometer Agilent-7700 × (USA).

RESULTS AND DISCUSSION

Despite the fact that while growing winter rye, its varieties were replaced with more modern ones (with higher genetic potential of performance), the crop productivity on dark gray sod-podzolic soil, lean in nutrients, did not depend on this factor considerably (Table 1). On average, during the years of cultivating different varieties of winter rye, the lowest yield was registered for Kharkivske 95 variety (0.89 t/ha), and the maximal yield – for Kharkivske 78 variety (1.58 t/ha).

The data analysis demonstrated that there was no clear correlation between the performance level of different varieties of winter rye, the average amount of precipitation for the year or for the spring-summer period.

Thus, if during the first 23 years of studies (1885–1907), at the average annual precipitation of 459 mm, the yield of winter rye grain of Probshteynske was 1.05 t/ha, in the following three years (1908–1910) and 50 years (1911–1960) though the varieties Poltavske and Petkuske showed higher yield (1.37 and 1.13 t/ha, respectively), this increase was not in direct proportion to the amount of precipitation for these periods (412 and 509 mm, respectively).

The maximal productivity of winter rye was observed in 1887 – 2.38 t/ha (Probshteynske variety), it was somewhat smaller in 1970 – 2.28 t/ha (Kharkivske 55 variety) and in 1991 – 2.26 t/ha (Kharkivske 78 variety). The minimal yield of winter rye was registered in 1954 – 0.15 t/ha (Petkuske variety) and in 2016 – 0.16 t/ha (Khamarka variety). The average yield of winter rye grain for 132 years of studies was 1.19 t/ha.

The content of highly digestible nutrients is a dynamic index, but its changes occur at a relatively stable level. For instance, if in 1964 the content of mobile phosphorus and exchange potassium in the 0–10 cm soil layer was 131 and 123 mg per 1,000 g of soil, according to Chirikov, 26 years later (in 1990) the values of the abovementioned indices remained almost unchanged and equaled 132 and 138 mg per 1,000 g of soil, respectively. According to the data of analytical studies in 2002, the content of mobile phosphorus and exchange potassium in the 0–20 and 21–40-cm layers of soil was 66 and 118, and 166 and 142 mg per 1,000 g of soil, while in 2014 the content of these nutrients changed and equaled 97 and 71, and 192 and 140 mg per 1,000 g of soil respectively.

The content of easily hydrolyzable nitrogen did not change considerably with the years. In particular, in 1964 and 1990, the content of this element in the 0–10-cm soil layer equaled 95 and 104 mg per 1,000 g of soil, respectively, and in 2002 and 2014 it was found to be at almost the same level in the 0-20-cm soil layer – 93 and 98 mg per 1,000 g of soil.

A similar regularity was observed regarding the content of general forms of nitrogen and phosphorus in

Table 2. The change in the content of a number of inorganic elements in soil in years of permanently cultivating winter rye

Inorganic elements	Content of the element, μg/kg		
	1969	1982	2014
Li	31.2	18.2	14.8
Be	6.1	3.2	2.2
Na	185	168	151
Mg	3815	3717	3710
K	4997	4869	5195
Ca	3913	3756	3706
V	38.7	40.0	36.7
Cr	36.5	36.5	35.0
Mn	928	856	833
Fe	17785	18439	17054
Co	9.0	9.2	8.7
Ni	11.8	9.8	8.4
Cu	20.1	17.7	20.2
Zn	55.5	50.2	56.2
Ga	38.7	38.7	36.2
Rb	44.3	41.6	41.3
Sr	32.7	33.2	31.1
Mo	1.2	0.7	0.6
Ag	0.4	0.3	0.3
Cd	0.4	0.3	0.3
Cs	3.1	2.9	2.7
Ba	148	144	150
Tl	0.7	0.4	0.3
Pb	12.7	12.7	13.1
Bi	0.3	0.2	0.2

soil. For instance, if in 2002 the 0–20 and 21–40-cm soil layers contained 0.141 % and 884 mg/1,000 g of general nitrogen and phosphorus, in 2014 the content of these elements almost did not change and was at the level of 0.148 % and 823 mg/1,000 g. Soil acidity was a less stable value during these years. For instance, in 1964 the pH value of the salt extract was 5.5 un., and hydrolytic acidity – 2.4 mmol/100 g of soil, in 1981 – 4.9 un. and 3.6 mmol/100 g of soil, respectively, in – 5.4 un. and 3.3 mmol/100 g of soil.

The laboratory analyses of soil samples demonstrate that the content of inorganic elements also changed during 1969, 1982, and 2014. In particular, during this period the content of Li, Mo, Tl, Be in soil decreased 2.1; 2.8; 2.3 and 2.8 times respectively, and that of Na, Cd, Ag, Bi – 1.2; 1.4 and 1.6 times, whereas other nutrients were almost at the same level (Table 2).

The study of the dynamics in humus content in soil during the studies of permanent cultivation of winter rye allowed determining that in 129 years the loss of humus in the 0–20-cm soil layer was 0.53 %, or 131.5 t/ha (Table 3).

For instance, if in 1888 the content of humus was 2.83 %, in 1900 – it was 2.63 %, 1945 – 2.30 %, 1948 – 2.15 %, 1955 – 2.54 %, 2001 – 2.47 %, 2014 – 2.28 %, 2016 – 2.30 %. It should be noted that the index of humus content in soil is not a static value for the whole spring-summer period, so it changes in absolute values as well. This is confirmed by the results of agrochemical analyses of samples, selected at different times from the 0–20 cm soil layer of the fixed plots in 2015. For instance, if in April the humus content was at the level of 2.52 %, in July this value decreased down to 2.22 %, and in September it increased to 2.6 %. These results are quite logical, as this index is affected by water and temperature regimes of the soil, which directly condition the intensity of hydrolysis and synthesis of organic matter therein. On the other hand, during different phases of development plants consume nutrients from soil with different intensity.

In recent years, there have been changes in qualitative indices of humus both in 0-20 and 21–40 cm layers of soil along with the ratio of carbon in humic and fulvic acids. For instance, if in 1964, according to the soil layer, this index was 1.15 and 1.26 un., in 1979 and 2012 – 0.93 and 1.16, and 0.93 and 0.99 un.

It is noteworthy that in absence of chemical protection the fields of winter rye were full of weeds, but during the study years the degree and prevailing species of segetal plants were changing (Table 4). The registration of weeds testifies to a considerable increase in their number: from 454 it/sq.m. on average in 2005–2007 to 607 it/sq.m. in 2008–2010. Among the dominating species of weeds there is a considerable increase in wild camomile (*Matricaria perforata Merat.*) – from 79.9 to 218.5 it/sq.m., or by 173.5 %, cornflower (*Centaurea cyanus L.*) – from 55.8 to 78.3 it/sq.m., field pansy (*Viola arvensis Murr.*) – from 30.0 to 64.3 it/sq.m. The amount of less common weeds is in the range of 9.7–21.8 it./sq.m. In general, for three years of observations, the amount of weeds in the fields of winter rye increased by 33.7 % compared against the previous three years.

The observations proved the disappearance of a number of weeds, common for the late 19th century,

Table 3. Humus content of a soil plot in conditions of permanent cultivation of winter rye

Index	Year					
	1964		1979		2012	
	Soil layer, cm					
	0–20	21–40	0–20	21–40	0–20	21–40
Content of humus, %	2.35	1.76	2.26	1.84	2.33	1.81
Organic carbon in soil	1.47	1.02	1.30	1.97	1.42	1.19
Carbon in 0.1 n. H_2SO_4	0.066	0.056	0.095	0.072	0.088	0.069
Carbon in $Na_4P_2O_3$ + NaOH	0.659	0.465	0.599	0.486	0.613	0.472
Carbon in humic acids	0.353	0.258	0.288	0.261	0.307	0.234
Carbon in fulvic acids	0.306	0.210	0.311	0.225	0.329	0.236
The ratio of carbon in humic acids to carbon in fulvic acids	1.15	1.26	0.930	1.16	0.930	0.990

Table 4. Species composition of weeds, dominating in conditions of permanent cultivation of winter rye

Name of species	Distribution in years, %					
	2005	2006	2007	2008	2009	2010
Wild garlic *Allium ursinum* L.	16.5	31.5	13.2	0	13.0	19.4
Wild camomile *Matricaria perforata Merat.*	21.0	25.5	6.3	35.3	47.6	25.1
Cow vetch *Vicia cracca* L.	9.3	12.4	8.5	7.7	5.9	4.5
Cornflower *Centaurea cyanus* L.	1.2	4.5	31.3	16.0	3.7	19.0
Hoary cress *Lepidium draba* L.	2.6	3.4	5.8	1.6	1.2	0.8
Forking larkspur *Delphinium consolida* L.	1.7	6.9	11.3	9.0	0.3	5.5
Field pennycress *Thlaspi arvense* L.	18.2	4.3	0.5	4.0	0.5	6.3
Field pansy *Viola arvensis Murr.*	7.9	1.7	10.2	13.6	7.8	10.8
Shepherd's purse *Capsella bursa-pastoris* L. Med.	13.2	0	0.8	1.5	3.0	0.3
Other species	8.4	9.8	11.7	11.1	16.7	8.2
Total amount of weeds per 1 sq.m.	418	580	364	543	640	638

from the fields of permanent winter rye, including common corn-cockle *(Agrostemma githago* L.) and salsola (*Salsola* L.). At the same time the number of such weeds as cow vetch *(Vicia cracca* L.*)*, field pennycress (*Thlaspi arvense* L.), cornflower *(Centaurea cyanus* L.*)*, field pansy *(Viola arvensis Murr.)* decreased with the simultaneous slight increase in the amount of strict forget-me-not *(Myosotis micrantha Pall.)*, Forking larkspur *(Delphinium consolida* L.) and cleavers *(Galium aparine* L.).

CONCLUSIONS

The Poltava long-term experiment in permanent cultivation of winter rye at the fixed plot for 132 years has surely not lost its relevance from the scientific point of view even nowadays. The results of such long-term studies are often used in solving the fundamental issues of agriculture, in deep complex studies, in the demonstration of the role of the main factors and conditions of vegetative life.

In conditions of long-term permanent cultivation of winter rye, there are considerable changes in segetal vegetation both in quantitative terms and species composition. During three years of observations (2008–2010), the amount of weeds in the winter rye field increased by 33.7 % compared to the previous three years (2005–2007). The dominating weeds in the fields are as follows: field pansy (*Viola arvensis*) – 10.7 % from the total amount of present species composition of weeds, wild camomile (*Matricaria perforata*) – 36.0 %, cornflower (*Centaurea cyanus*) – 12.9 %.

The average yield of winter rye grain in the experiment for 132 years of studies was 1.19 t/ha. The highest yield of winter rye – 2.38 t/ha – was obtained in 1887 (Probstneynske variety), and the minimal yield – 0.15 t/ha (Petkuske variety) in 1954 and in 2016 – 0.16 t/ha (Khamarka variety). The level of performance of the crop depends on the level of favorable weather conditions of the year, the quality of soil preparation, and the content of productive moisture in the cultivated soil layer during sowing, as well as the amount of weeds in the field during the experiment.

The humus content in the 0–20 cm soil layer on the plot of permanent cultivation of winter rye in 1884–2016 decreased by 0.53 % (the content in 1888 – 2.83 %, in 2016 – 2.30 %), so its loss in the soil was 131.5 t/ha.

Унікальний дослід світового землеробства на Полтавщині – беззмінне вирощування жита озимого

А. В. Кохан [1], Л. Д. Глущенко [1], В. В. Гангур [2], О. А. Самойленко [1], О. І. Лень [1], Р. В. Олепір [1], С. М. Калініченко [1], Л. В. Кавалір [1]

e-mail: v.gangur@rambler.ru

[1] Полтавська державна сільськогосподарська дослідна станція імені М. І. Вавилова Інституту свинарства і агропромислового виробництва НААН України
Вул. Шведська, 86, Полтава, Україна, 36014

[2]Інститут свинарства і агропромислового виробництва НААН України
Вул. Шведська Могила, 1, Полтава, Україна, 36013

Мета. Визначити вплив тривалої дії комплексу факторів (антропогенних, кліматичних) на родючість ґрунту, зміну фітоценозу бур'янів та продуктивності жита озимого за беззмінного вирощування. **Методи**. Вміст азоту у ґрунті визначали за Корнфілдом; фосфор і калій – за Чириковим; вміст неорганічних хімічних елементів у ґрунті – методом мас-спектрометрії з індуктивно-зв'язаною плазмою (ІЗП-МС) на емісійному мас-спектрометрі Agilent-7700× (США). **Результати.** Показано, що середня врожайність жита озимого за 1884–2016 рр. становить 1,19 т/га, однак рівень продуктивності культури змінювався залежно від сприятливості погодних умов року, якості підготовки ґрунту та вмісту продуктивної вологи в посівному шарі ґрунту на час сівби, ступеня забур'яненості посіву в досліді. **Висновки.** Результати досліджень можна використовувати для вирішення фундаментальних питань землеробства, для глибоких комплексних досліджень, демонстрації ролі основних факторів і умов життя рослин.

Ключові слова: жито, беззмінний посів, сорт, урожайність, гумус, забур'яненість.

Уникальный опыт мирового земледелия на Полтавщине – бессменное возделывание ржи озимой

А. В. Кохан [1], Л. Д. Глущенко [1], В. В. Гангур [2], Е. А. Самойленко [1], А. И. Лень [1], Р. В. Олепир [1], С. М. Калиниченко [1], Л. В. Кавалир [1]

e-mail: v.gangur@rambler.ru

[1] Полтавская государственная сельскохозяйственная опытная станция имени Н. И. Вавилова Института свиноводства и агропромышленного производства НААН Украины
Ул. Шведская, 86, Полтава, Украина, 36014

[2] Институт свиноводства и агропромышленного производства НААН Украины
Ул. Шведская Могила, 1, Полтава, Украина, 36013

Цель. Определить влияние длительного действия комплекса факторов (антропогенных, климатических) на плодородие почвы, изменение фитоценоза сорняков и продуктивность ржи озимой при бессменном возделывании. **Методы.** Содержание азота в почве определяли по Корнфилду; фосфор и калий – по Чирикову; содержание неорганических химических элементов в почве – методом масс-спектрометрии с индуктивно-связанной плазмой (ИСП-МС) на эмиссионном масс-спектрометре Agilent-7700× (США). **Результаты.** Определено, что средняя урожайность ржи озимой за 1884–2016 гг. составляет 1,19 т/га, тем не менее уровень продуктивности культуры изменялся в зависимости от благоприятности погодных условий года, качества подготовки почвы и содержания продуктивной влаги в посевном слое почвы на время посева, степени засоренности бурьянами посева в опыте. **Выводы.** Результаты исследований можно использовать для решения фундаментальных вопросов земледелия, для глубоких комплексных исследований, демонстрации роли основных факторов и условий жизни растений.

Ключевые слова: рожь, бессменный посев, сорт, урожайность, гумус, засоренность.

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