ЗЕМЛЕРОБСТВО І РОСЛИННИЦТВО

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REACTION OF LONG-LEAVED FLAX VARIETIES TO DIFFERENT DOSES OF MINERAL FERTILIZERS IN THE CONDITIONS OF THE WESTERN FOREST-STEPPE

The effectiveness of the use of different backgrounds of mineral fertilizers in the technology of growing long-leaved flax in the soil and climatic conditions of the Western Forest-Steppe has been established, which will significantly increase the productivity of coenoses and improve product quality indicators. The agrotechnological parameters of cultivation and weather conditions significantly influenced the growth and development of crop plants, which affected the indicators of structure and productivity.

The long-leaved flax varieties Miandr, Oberih (originator – Institute of Agriculture of the Carpathian Region of the National Academy of Agrarian Sciences), Usivskyi (Institute of bast cultures of the NAAS), Ivanivskyi (NSC "Institute of Agriculture of the NAAS") were studied on the variant without fertilizers and on the backgrounds of mineral fertilizer $N_{20}P_{40}K_{60}$, $N_{30}P_{60}K_{90}$, $N_{45}P_{90}K_{135}$.

During the years of research (2021–2022), fluctuations in hydrothermal indicators were noted, which affected the formation of elements of productivity of long-leaved flax varieties.

The duration of the vegetation phases of long-leaved flax plants depended on both the biological characteristics of the variety and hydrothermal conditions. In 2021, depending on the variety, it was 90–95 days. In 2022, dry vegetation conditions with elevated air temperature led to the shortening of this period for all varieties to 78–81 days.

More intense growth of plants in the "herringbone" phase was observed on the variants of applying mineral fertilizers, in particular, the height of plants of the Miandr variety, compared to unfertilized areas, increased from 6.88 to 8.96 cm, of the Oberih variety from 7.80 to 10.16 cm, Usivskyi – 8.32–8.80 cm, Ivanivskyi – 6.84–8.72 cm.

The highest seed yield (1.21 t/ha) on average in 2021–2022 was obtained on sowings of the Miandr variety with the application of mineral fertilizers at the rate of

$N_{45}P_{90}K_{135}$, the increase compared to the control variant was 0.37 t/ha or 44.05 %. The specified fertilizer option also provided the highest yield of flax straw (4.15 t/ha). The increase compared to the control was 0.46 t/ha (12.47 %).

Flax straw yield indicators on average for 2021–2022 were the most important in the Miandr variety, it varied from 3.69 t/ha (on the control version) to 4.15 t/ha (with the application of mineral fertilizers $N_{45}P_{90}K_{135}$).

Keywords: long-leaved flax, varieties, productivity, weather conditions, mineral fertilizers.

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Реакція сортів льону-довгунцю на різні дози мінеральних добрив в умовах Лісостепу Західного

Встановлено ефективність використання різних фонів мінерального удобрення в технології вирощування льону-довгунцю в ґрунтово-кліматичних умовах Лісостепу Західного, що дозволить істотно підвищити продуктивність ценозів та поліпшити показники якості продукції. Агротехнологічні параметри вирощування та погодні умови суттєво впливали на ріст і розвиток рослин культури, що позначалося на показниках структури та продуктивності.

Досліджували сорти льону-довгунцю Міандр, Оберіг (оригінатор – Інститут сільського господарства Карпатського регіону НААН), Усівський (Інститут луб'яних культур НААН), Іванівський (ННЦ "Інститут землеробства НААН") на варіанті без добрив та на фонах мінерального удобрення $N_{20}P_{40}K_{60}$, $N_{30}P_{60}K_{90}$, $N_{45}P_{90}K_{135}$.

У роки проведення досліджень (2021–2022) відзначено коливання гідротермічних показників, що вплинуло на формування елементів продуктивності сортів льону-довгунцю.

Тривалість фаз вегетації у рослин льону-довгунцю залежала як від біологічних особливостей сорту, так і гідротермічних умов. У 2021 р., залежно від сорту, вона становила 90–95 діб. У 2022 р. посушливі умови вегетації з підвищеним температурним режимом повітря зумовили скорочення цього періоду на всіх сортах до 78–81 діб.

Більш інтенсивний ріст рослин у фазі "ялинка" спостерігали на варіантах внесення мінеральних добрив, зокрема висота рослин сорту Міандр порівняно з неудобреними ділянками збільшилася від 6,88 до 8,96 см, сорту Оберіг – від 7,80 до 10,16 см, Усівський – 8,32–8,80 см, Іванівський – 6,84–8,72 см.

Найвищу врожайність насіння (1,21 т/га) в середньому за 2021–2022 рр. одержали на посівах сорту Міандр за внесення мінеральних добрив з розрахунку $N_{45}P_{90}K_{135}$, приріст до контрольного варіанта становив 0,37 т/га, або 44,05 %. Зазначений варіант удобрення забезпечив також найбільший врожай льоносоломи (4,15 т/га). Приріст до контролю становив 0,46 т/га (12,47 %).

Показники врожайності льносоломи в середньому за 2021–2022 рр. найбільше значення мали в сорту Міандр, вона варіювала від 3,69 т/га (на

контрольному варіанті) до 4,15 т/га (за внесення мінеральних добрив $N_{45}P_{90}K_{135}$).

Ключові слова: льон-довгунець, сорти, продуктивність, погодні умови, мінеральні добрива.

Introduction. The main use of long-leaved flax is as a raw material for the textile industry. In the textile industry of Ukraine, flax occupied 41.9 % (cotton – 49.3 %, wool – 7.9 % and silk 1.0 %). The profitability of flax growing in farms was up to 200 %. Flax growing gave up to 60 % of profits in crop production [1, 12, 25, 27, 29, 31, 36].

A powerful base for the processing of raw flax was created in Ukraine. In 1995, 46 flax mills with a total production capacity of 130,000 tons of fiber per year were operating in Ukraine. The profitability of the work of flax factories, taking into account state subsidies, was 30–35 %, and that of the textile industry was up to 100 % [2, 12, 15, 23]. Flax fibers obtained from long-leaved flax and curly flax were used in textile production for the manufacture of interior, clothing, footwear, technical textile materials and products, linen cotton, cotton wool, paper and cardboard, cords and ropes, as well as composite materials for various purposes. Heat-insulating building materials were produced from the tar obtained during the processing of flax. Heat- and sound-insulating materials for construction, cleaning materials and other technical materials were produced from non-spinning waste of linen production [21, 26, 30].

In the State register of plants suitable for distribution in Ukraine for the year 2023 [5, 8, 9, 35], 23 varieties of long-leaved flax are registered, of which 17 are varieties of Ukrainian selection, including four varieties of selection of IACR NAAS: Oberih, Miandr, Kameniar, Zoria-87 and six foreign varieties.

However, this time-consuming culture has become a niche [14]. The main areas of flax are mainly concentrated in the North-Western region, the area of its cultivation has narrowed to the Zhytomyr, Chernihiv, and Sumy regions [6, 7, 13, 17, 18, 23, 32, 34].

Long-leaved flax shows a high reaction to the application of fertilizers, which is explained by the insufficient physiological activity of its root system, the high removal of nutrients by the harvest and the short growing season, the unevenness of their assimilation during the growing season [4, 10, 16, 19, 20, 24, 28].

From germination to the beginning of the “herringbone” phase, the total nutrient requirement of flax plants is very small, because the stem grows slowly and bast fibers are just beginning to form [22]. However, the root system develops rapidly in this phase.

Regarding nitrogen, the critical period is between the “herringbone” and budding phases. The largest amount of phosphorus is assimilated in the first days, from germination to the formation of 10–12 leaves. Lack of potassium in the first three weeks of growth (during the formation of elementary fibers) and in the phase of budding and flowering negatively affects seed yield and fiber quality.

The weather conditions of the Western Forest-Steppe zone are favorable for the cultivation of long-leaved flax. However, questions regarding the reaction of flax varieties of different ecotypes to doses of mineral fertilizers in the soil and climatic conditions of this region have not yet been sufficiently studied.

The purpose of the work was to investigate the regularities of the formation of the productivity of long-leaved flax plants depending on the application of improved agrotechnological techniques, which will allow to significantly increase the realization of the genetic potential of domestic breeding varieties in the soil and climatic conditions of the Western Forest-Steppe and ensure the production of environmentally safe products, establish their resistance to abiotic factors and potential of their productivity.

Materials and methods. The study of varieties of different ecotypes of long-leaved flax (*Linum usitatissimum* L.) was conducted during 2021–2022 on gray forestal surface-gleyed soils. The arable layer (0–20 cm) of the soil was characterized by the following agrochemical parameters: humus – 1.6–1.7 %, pH (saline) – 5.9–6.0, alkaline hydrolyzed nitrogen – 96–105 mg/kg of soil, mobile phosphorus – 111–116, exchangeable potassium – 102–107 mg/kg of soil [3, 11, 33].

The varieties of long-leaved flax Miandr (IACR), Oberih (IACR), Usivskyi (Institute of bast cultures), Ivanivskyi (NSC “Institute of Agriculture”) were studied on plots without mineral fertilizers and with the application of $N_{20}P_{40}K_{60}$; $N_{30}P_{60}K_{90}$; $N_{45}P_{90}K_{135}$.

Agricultural cultivation techniques were generally accepted for the conditions of the Western Forest-Steppe. Sowing was carried out in the generally defined terms for the Western Forest-Steppe zone (1st–3rd decade of April) at a soil temperature of 7–8 °C at a depth of 10 cm, with a SL-16 seeder in a narrow-row method (7.5 cm) with a seeding rate of 22 million germinated seeds per hectare. The depth of seed wrapping – 1.0–1.5 cm. Sown area of the plot 36 m^2; accounting area – 25 m^2. The experiment was repeated four times. Predecessor – cereal ears. Mineral fertilizers were applied under the pre-sowing cultivation according to the scheme of the experiment. The following mineral fertilizers were used: ammonium nitrate, granulated superphosphate, calimagnesia.

Phenological observations were carried out according to the method of M. O. Maisurian, Yu. V. Shelestov, structural and technological analysis according to the method of V. M. Kabanets. Statistical processing of research results was carried out using the method of dispersion analysis (Ushkarenko V. O., 2015).

Care of the crops during the onset of the phase of full growth of the long-leaved flax consisted in the fight against the flax flea (*Aphthona euphorbiae Schrk*) in the presence of EPS (pest population density exceeds 10–15 beetles per 1 m^2), by spraying with insecticide karate zeon 050 CS, mc. S. (0.15 l/ha). Agritox (1.0 l/ha) and oreol maxi (1.25 l/ha) herbicides were applied in the "herringbone" phase to control weeds.

Results and discussion. In recent years, there has been a trend of sharp temperature drops, significant warming in certain periods and an extremely uneven regime of moisture, which causes physiological stress in plants during the growing season, which has a particularly negative effect during the period of initial growth of long-leaved flax plants, the formation and ripening of seeds and fibers.

The meteorological conditions of the 2021–2022 vegetation year differed from the average long-term values (Table 1) by fluctuations in the main hydrothermal indicators (heat, moisture), which affected the growth and development of plants, the formation of productivity elements, and the yield of flax.

1. Meteorological data for the years of research (2021–2022)

Indicators	Months					
	March	April	May	June	July	August
2021						
Air temp, ºC	2,0	6,2	13,0	18,8	21,9	17,7
Norm, ºC	0,5	7,4	12,9	16,3	17,5	16,9
Precipitation, mm	43,1	39,9	55,4	97,3	94,2	112,8
Norm, mm	44,0	51,0	85,0	93,0	102,0	82,0
2022						
Air temp, ºC	2,6	6,5	13,9	19,7	19,5	20,3
Norm, ºC	0,5	7,4	12,9	16,3	17,5	16,9
Precipitation, mm	17,3	82,0	24,3	31,3	85,8	72,5
Norm, mm	44,0	51,0	85,0	93,0	102,0	82,0

* Hydrometeorological post of IACR NAAS, observation point – Obroshyne.

In 2021, a late recovery of vegetation and a rapid increase in positive air temperatures were observed (Table 1). Average daily air temperatures of the 1st and 2nd decades of March were 0.5 and 1.7 ºC and exceeded the norm by 2.2 and 1.6 ºC, respectively. The beginning of the third decade

(21–23.03) was characterized by low temperatures, which were lower than the climatic index (3.1 ºC) by 0.8 ºC, the minimum on 21.03 was 7.3 ºC. Flax sowing in 2021 was carried out on April 21.

April was characterized by a slow increase in heat. The average monthly air temperature in April was 6.2 ºC with an annual average of 7.4 ºC. The first decade was colder than the norm by 1.2 ºC, in particular, the average daily air temperature at the beginning of April did not exceed the mark of 4.9 ºC with a norm of 6.1 ºC. Lower than the average daily values by 0.3 and 2.0 ºC were also observed in the II and III decades April. In the first decade of May, the temperature was also lower than normal (11.5 ºC) by 0.7 ºC. An increase in temperature indicators was observed in the II and III decades of May. In the II decade of May and the I–III decades of June, the temperature background exceeded the norm by 0.8–2.10 ºC. In June, the average monthly air temperature exceeded the annual average by 2.5 ºC, in July by 4.4 ºC, and in August by 0.8 ºC.

In March, the amount of precipitation was 97 % of the norm. A little less precipitation was recorded in April as well – 78 % of the norm (51.0 mm), moreover, more of them fell in the second decade (24.5 mm), and in the first decade the least amount of precipitation fell (6.5 mm), which had a certain negative effect on the similarity of early spring crops.

In May, the amount of precipitation was also lower – 55.4 mm, compared to the norm of 85.0 mm (65 % of the long-term average). In the first decade of June, 29 % of the long-term norm fell, and in the second – 166 %. Average monthly precipitation in June was close to the norm (97.3 mm against the norm of 93.0 mm). Dry conditions were noted at the end of July, 11.2 mm, with a long-term average of 37.0 mm. During August, precipitation fell by 30.8 mm more than the average long-term indicator, which was 82.0 mm.

April 2022 was characterized by a slow increase in heat. The average monthly air temperature in April was 6.5 ºC with a long-term average of 7.4 ºC. The first decade was colder than the norm by 0.9 ºC, in particular, the average daily air temperature at the beginning of April did not exceed the mark of 5.2 ºC against the norm of 6.1 ºC. Lower than the daily average by 1.5 and 0.1 ºC was also observed in II and III decades of April. Sowing of long-leaved flax in 2022 was carried out on April 14.

The temperature in May was in the range of 13.1–14.6 ºC, the average monthly indicator exceeded the norm by 1.0 ºC.

In June, the average monthly air temperature exceeded the long-term average by 3.4 ºC, in July by 2.0 ºC, in August by 3.4 ºC.

In April, the amount of precipitation was 82.0 mm, which is 31.0 mm higher than the average long-term norm. Moreover, more of them fell in the first and third decade of the month (31.0 mm and 44.9 mm), precipitation in the third decade of April contributed to the production of friendly seedlings.

In May, the amount of precipitation was less – by 60.7 mm compared to the norm of 85.0 mm (up to the long-term average).

Long-leaved flax needs a good supply of moisture at the beginning of the growing season. During May – June (2022), there was no precipitation, which negatively affected crop productivity. The reserves of productive soil moisture as of May 3, 2022 were 47.7–48.3 mm in the 0–20 cm soil horizon, 51.4–55.9 mm in the 20–40 cm horizon. The amount of moisture on 14.06.2022 – 13.3 mm in the 0–20 cm soil horizon, 5.5 mm in the 20–40 cm horizon, and 12.5 mm in the 0–20 cm soil horizon on June 21, 2022.

In the first decade of June 11.0 mm of precipitation, in the second – 14.4 mm, in the third – 5.7 mm from the long-term norm of 30.0–33.0 mm, which negatively affected the growth of flax plants. Lack of moisture (66.34 % in June) and high temperature regime in May and June shortened the interphase periods of growth and development of flax, affected the overall height of the plants. During July, 85.8 mm of precipitation fell, compared to the long-term average of 102.0 mm. In August, precipitation was 9.5 mm less than the long-term average of 82.0 mm.

During the research years, the growing season of long-leaved flax changed significantly under the influence of weather conditions. In 2021, its duration, depending on the variety, was 90–95 days (Table 2). In 2022, dry vegetation conditions with elevated air temperature led to the shortening of this period for all varieties to 78–81 days.

2. Duration of the growing season of long-leaved flax (2021–2022)

Nutrition background	Date				Duration of the growing season, days		
	sowing		full ripening (75 %)				
	years		years		years		
	2021	2022	2021	2022	2021	2022	average
1	2	3	4	5	6	7	8
Miandr							
Control	21.04	14.04	22.07	09.07	92	80	86,0
$N_{20}P_{40}K_{60}$	21.04	14.04	22.07	09.07	92	80	86,0
$N_{30}P_{60}K_{90}$	21.04	14.04	23.07	09.07	93	80	86,5
$N_{45}P_{90}K_{135}$	21.04	14.04	23.07	09.07	93	80	86,5
Oberih							
Control	21.04	14.04	24.07	09.07	94	80	87,0

1	2	3	4	5	6	7	8
$N_{20}P_{40}K_{60}$	21.04	14.04	24.07	09.07	94	80	87,0
$N_{30}P_{60}K_{90}$	21.04	14.04	25.07	09.07	95	80	87,5
$N_{45}P_{90}K_{135}$	21.04	14.04	25.07	09.07	95	80	87,5
Usivskyi							
Control	21.04	14.04	20.07	07.07	90	78	84,0
$N_{20}P_{40}K_{60}$	21.04	14.04	20.07	07.07	90	78	84,0
$N_{30}P_{60}K_{90}$	21.04	14.04	21.07	07.07	91	78	84,5
$N_{45}P_{90}K_{135}$	21.04	14.04	21.07	07.07	91	78	84,5
Ivanivskyi							
Control	21.04	14.04	23.07	10.07	93	81	87,0
$N_{20}P_{40}K_{60}$	21.04	14.04	23.07	10.07	93	81	87,0
$N_{30}P_{60}K_{90}$	21.04	14.04	24.07	10.07	94	81	87,5
$N_{45}P_{90}K_{135}$	21.04	14.04	24.07	10.07	94	81	87,5

On average, over the years of research, the shortest duration of the growing season was in the Usivskyi variety – 84 days, in the Miandr variety it was 86 days, in the Oberih and Ivanivskyi varieties – 87 days.

The introduction of mineral fertilizers led to a slight (by 1 day) increase in the duration of the vegetation period of flax plants in 2021 for each of the studied varieties. In 2022, when a deficit of soil moisture was observed in the summer months, no such dependence was detected.

As research data showed, the rate of passage of individual phases of long-leaved flax depended on the biological characteristics of the variety and the hydrothermal conditions of the growing season.

The accumulation of air-dry mass of long-leaved flax plants in the "herringbone" phase varied depending on the fertilization background. With an increase in the rate of application of mineral fertilizers, this indicator increased, in particular, in the Miandr variety from 0.87 g on unfertilized crops to 1.27 g with the application of $N_{45}P_{90}K_{135}$, in the Oberih variety, according to 1.85 g (on control – 1.12 g) , Usivskyi – up to 1.35 g (1.14 g on the control), Ivanivskyi – up to 1.45 g (1.0 g on the control).

On the variants of applying mineral fertilizers, a more intense growth of plants in the "herringbone" phase was noted compared to the control plots without fertilizer, so the height of the plants of the Miandr variety increased from 6.88 to 8.96 cm, the Oberih variety from 7.80 to 10.16 cm, Usivskyi – 8.32–8.80 cm, Ivanivskyi – 6.84–8.72 cm.

With the introduction of mineral fertilizers, the increase in productivity of all varieties of long-leaved flax was noted (Table 3). The yield increase of flax straw in the Miandr variety was 0.29–0.46 t/ha (7.86–12.47 %), Oberih – 0.11–0.54 t/ha (3.06–15.04 %), Usivskyi – 0.13–0.33 t/ha (3.49–8.85 %), Ivanivskyi – 0.32–0.53 t/ha (9.01–14.93 %).

3. Analysis of the productivity of long-leaved flax varieties, on average for 2021–2022 (t/ha)

Fertilizer	Harvest of flax straw, t/ha	Deviation from control		Harvest of seeds, t/ha	Deviation from control	
		t/ha	%		t/ha	%
Miandr						
Control	3,69	–	–	0,84	–	–
$N_{20}P_{40}K_{60}$	3,98	0,29	7,86	0,90	0,06	7,14
$N_{30}P_{60}K_{90}$	4,09	0,4	10,84	0,97	0,13	15,48
$N_{45}P_{90}K_{135}$	4,15	0,46	12,47	1,21	0,37	44,05
Oberih						
Control	3,59	–	–	0,64	–	–
$N_{20}P_{40}K_{60}$	3,70	0,11	3,06	0,76	0,12	18,75
$N_{30}P_{60}K_{90}$	4,07	0,48	13,37	0,88	0,24	37,50
$N_{45}P_{90}K_{135}$	4,13	0,54	15,04	0,94	0,3	46,88
Usivskyi						
Control	3,73	–	–	0,75	–	–
$N_{20}P_{40}K_{60}$	3,86	0,13	3,49	0,83	0,08	10,67
$N_{30}P_{60}K_{90}$	4,06	0,33	8,85	0,89	0,14	18,67
$N_{45}P_{90}K_{135}$	4,04	0,31	8,31	0,91	0,16	21,33
Ivanivskyi						
Control	3,55	–	–	0,77	–	–
$N_{20}P_{40}K_{60}$	3,87	0,32	9,01	0,80	0,03	3,90
$N_{30}P_{60}K_{90}$	4,08	0,53	14,93	0,81	0,04	5,19
$N_{45}P_{90}K_{135}$	4,07	0,52	14,65	0,82	0,05	6,49

The highest yield of flax straw on average for 2021–2022 was noted in the Miandr variety, it varied from 3.69 t/ha (on the control version) to 4.15 t/ha (after the application of mineral fertilizers $N_{45}P_{90}K_{135}$). The increase to control was 0.46 t/ha (12.47 %).

The Miandr variety prevailed also in terms of seed yield, on average in 2021–2022, the best variant ($N_{45}P_{90}K_{135}$) yielded 1.21 t/ha. The control yield was 0.84 t/ha, the increase in seed yield was 0.37 t/ha (44.05 %).

The seed yield of the Oberih variety in the control was the lowest among the studied varieties – 0.64 t/ha, however, the application of mineral fertilizers led to an increase in seed yield by 0.12–0.3 t/ha or by 18.75–46.88 % and on the $N_{45}P_{90}K_{135}$ fertilizer option 0.94 t/ha was obtained.

The Usivskyi variety with application of $N_{45}P_{90}K_{135}$ ensured a seed yield of 0.91 t/ha, the increase compared to the variant without fertilizers was 0.16 t/ha.

The smallest increase in seed yield after the application of mineral fertilizers (0.03–0.05 t/ha) was obtained in the Ivanivsky variety. Seed yield on the $N_{45}P_{90}K_{135}$ fertilizer variant exceeded this indicator compared to the control by only 6.49 % and amounted to 0.82 t/ha.

Conclusions. In the soil-climatic conditions of the Western Forest-Steppe, sowing of long-leaved flax of the Miandr variety on the background of mineral fertilizer $N_{45}P_{90}K_{135}$ provided the highest yield of flax straw (4.15 t/ha) and seeds (1.21 t/ha). The increase compared to the control was 0.46 and 0.37 t/ha, respectively.

The introduction of mineral fertilizers contributed to the more intensive growth of plants in the “herringbone” phase compared to the control plots without fertilizers, so the height of the plants of the Miandr variety increased from 6.88 to 8.96 cm, the Oberih variety from 7.80 to 10.16 cm, Usivskyi – 8.32–8.80 cm, Ivanivskyi – 6.84–8.72 cm.

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