Ministry of Education and Science of Ukraine
Mykolaiv National Agrarian University

ISSN 2313-092X
E-ISSN 2411-9199

Вісник аграрної науки Причорномор'я

Науковий журнал

Ukrainian Black Sea Region Agrarian Science

Scientific Journal

Том 27, № 4

Volume 27, No. 4

Year of establishment: 1997
Publication frequency: Four times a year

Mykolaiv
2023

DOI: 10.56407/2313-092X/2023-27(4)

Рекомендовано до друку та поширення
через мережу Інтернет Вченою радою
Миколаївського національного аграрного університету
(протокол № 5 від 12 грудня 2023 р.)

Свідоцтво про державну реєстрацію
друкованого засобу масової інформації
Серія: КВ № 25119-15059 ПР від 21 лютого 2022 р.

Журнал входить до переліку наукових фахових видань України категорії «Б»:

з економічних, технічних, сільськогосподарських, ветеринарних наук за спеціальностями 051 – Економіка, 071 – Облік і оподаткування, 072 – Фінанси, банківська справа та страхування, 073 – Менеджмент, 075 – Маркетинг, 076 – Підприємництво, торгівля та біржова діяльність, 181 – Харчові технології, 183 – Технології захисту навколишнього середовища, 201 – Агрономія, 202 – Захист і карантин рослин, 204 – Технологія виробництва і переробки продукції тваринництва, 205 – Лісове господарство, 207 – Водні біоресурси та аквакультура, 208 – Агроінженерія, 281 – Публічне управління та адміністрування
(Наказ Міністерства освіти і науки України від 07 травня 2019 р. № 612; від 11 липня 2019 р. № 975)

Журнал представлено у наукометричних базах даних, репозитаріях:
Google Scholar, Open Academic Journals Index,
Національна бібліотека України імені В. І. Вернадського, IJIFACTOR,
Directory of Research Journals Indexing | DRJI, Crossref,
Фахові видання України, Dimensions, AGRIS, EBSCO

Вісник аграрної науки Причорномор'я : наук. журн. / [редкол.: В. С. Шебанін (голов. ред.) та ін.]. – Миколаїв : Миколаївський національний аграрний університет, 2023. – Т. 27, № 4. – 100 с.

Адреса редакції:
Миколаївський національний аграрний університет
54008, вул. Георгія Ґонґадзе, 9, м. Миколаїв, Україна,
тел.: +38(0512) 70-93-54
E-mail: info@bsagriculture.com.ua
www: https://bsagriculture.com.ua/uk

DOI: 10.56407/2313-092X/2023-27(4)

Recommended for printing and distribution
via the Internet by the Mykolaiv National Agrarian University
(Minutes No. 5 of December 12, 2023)

Certificate of state registration of the print media
Series: KB No. 25119-15059 PR of February 21, 2022

The journal is included in the list of professional publications of Ukraine of category "B":
Economic, technical, agricultural, veterinary sciences by specialty 051 – Economics,
071 – Accounting and taxation, 072 – Finance, banking and insurance, 073 – Management, 075 – Marketing,
076 – Entrepreneurship, trade and exchange activity, 181 – Food technologies,
183 – Environmental protection technologies, 201 – Agronomy, 202 – Protection and quarantine of plants,
204 – Technology of production and processing of livestock products, 205 – Forestry,
207 – Water bioresources and aquaculture, 208 – Agricultural engineering,
281 – Public management and administration
(Order of the Ministry of Education and Science of Ukraine of May 7, 2019 No. 612; of July 11, 2019 No. 975)

The journal is presented at scientometric databases, repositories:
Google Scholar, Open Academic Journals Index,
National Library of Ukraine named after V. I. Vernadskyi, IJIFACTOR,
Directory of Research Journals Indexing | DRJI, Crossref,
Professional Editions of Ukraine, Dimensions, AGRIS, EBSCO

Ukrainian Black Sea Region Agrarian Science / Ed. by V. S. Shebanin (Editor-in-Chief) et al. Mykolaiv: Mykolaiv National Agrarian University, 2023. Vol. 27, No. 4. 100 p.

Publishing Address:
Mykolaiv National Agrarian University
54008, 9 Georgiy Gongadze Str., Mykolaiv, Ukraine
tel.: +38(0512) 70-93-54
E-mail: info@bsagriculture.com.ua
www: https://bsagriculture.com.ua/en

Редакційна колегія

Editorial Board

ЗМІСТ / CONTENTS

А. В. Дробітько, Т. В. Качанова
Агроекологічне обґрунтування технологій вирощування зернових та зернобобових культур в умовах Південного Степу України 9
A. Drobitko, T. Kachanova
Agroecological substantiation of technologies for growing grain crops in the conditions of the Southern Steppe of Ukraine 9

Д. В. Бабенко, Н. А. Доценко, О. А. Горбенко, І. В. Бацуровська
Дослідження характеру руху подрібненої маси по поверхні решіт сепаратора насіння овочевих та баштанних культур 18
D. Babenko, N. Dotsenko, O. Gorbenko, I. Batsurovska
Study of the nature of the movement of the crushed mass on the surface of the sieves of the vegetable and melon seed separator 18

М. І. Гиль, О. І. Каратєєва, М. М. Тимофіїв
Біотехнологія регуляції відтворювальних функцій порід *Bos primigenius taurus* 36
M. Gill, O. Karatieieva, M. Tymofiiv
Biotechnology of regulation of reproductive functions of *Bos primigenius taurus* 36

О. Г. Афанасьєва, Л. М. Голосна, Г. М. Лісова, А. І. Кривенко, Р. В. Соломонов
Ефективні джерела стійкості пшениці озимої в селекції на імунітет 52
O. Afanasyeva, L. Golosna, G. Lisova, A. Kryvenko, R. Solomonov
Use of effective sources of winter wheat resistance in breeding for immunity 52

О. С. Садовий, О. І. Савенков, І. М. Сидорика, Ю. Г. Щербак, А. А. Кондратьєва
Підвищення ефективності машин і механізмів агропромислового комплексу застосуванням підшипників ковзання з криволінійними твірними внутрішньої циліндричної поверхні 60
O. Sadovoy, O. Savenkov, I. Sydoryka, Yu. Shcherbak, A. Kondratieva
Increasing the efficiency of machines and mechanisms of the agro-industrial complex using sliding bearings with curvilinear generators of the internal cylindrical surface 60

В. М. Польовий, М. Г. Фурманець, О. В. Сніжок, Л. А. Ященко
Вплив побічної продукції за різних способів обробітку ґрунту на врожайність ріпаку озимого в умовах Західного Лісостепу 71
V. Poliovyi, M. Furmanets, O. Snizhok, L. Yashchenko
Influence of by-products under different methods of soil cultivation on the yield of winter rape in the Western Forest-Steppe 71

В. Б. Рябошапка, Р. Д. Лисенко
Проблеми та перспективи створення сучасних сільськогосподарських газодизелів: літературний огляд 81
V. Ryaboshapka, R. Lysenko
Problems and prospects of creating modern agricultural gas diesel engines: A literature review 81

О. І. Трембіцька, С. В. Богдан
Оцінка впливу дефекату та органічних добрив на продуктивність буряків цукрових в умовах Поділля 90
O. Trembitska, S. Bohdan
Evaluation of the effect of sugar mud and organic fertilizers on the productivity of sugar beets in the conditions of Podillia 90

UDC: 633.1(477)
DOI: 10.56407/bs.agrarian/4.2023.09

Ukrainian Black Sea Region Agrarian Science
Vol. 27, No. 4

Agroecological substantiation of technologies for growing grain crops in the conditions of the Southern Steppe of Ukraine

Antonina Drobitko
Doctor of Agriculture, Professor
Mykolaiv National Agrarian University
54008, 9 Georgiy Gongadze Str., Mykolaiv, Ukraine
https://orcid.org/0000-0002-6492-4558

Tetiana Kachanova*
PhD in Agriculture, Associate Professor
Mykolaiv National Agrarian University
54008, 9 Georgiy Gongadze Str., Mykolaiv, Ukraine
https://orcid.org/0000-0003-0032-3996

Abstract. Agroecological substantiation of cereal crops cultivation technologies becomes especially relevant in conditions of insufficient moisture, as it requires sustainable and efficient agro-production systems that ensure high yields and preserve natural resources. The aim of the study is to determine the impact of nitrogen fertilisation on the growth and development of winter wheat in an arid climate. To achieve this goal, a field study was conducted at the fields of the Educational and Research Centre of Mykolaiv National Agrarian University to study mineral nutrition and the impact of different nitrogen rates on the structure and quality of winter wheat grain yield. The study found that increasing nitrogen fertiliser rates has a positive impact on crop growth and yield. The application of higher nitrogen rates, in particular N_{60} and N_{80} in spring fertilisation, increases plant height by 3.8 and 4.6 cm, respectively, compared to N_{30}. In addition, a double increase in nitrogen fertiliser rates resulted in a 3.5% increase in the number of productive stems and a 13.6% increase in the weight of 1,000 seeds. Mineral fertilisers also had a significant impact on winter wheat yields, with $P_{30}K_{30}+N_{60}$ and $P_{30}K_{30}+N_{80}$ yielding 51.8 and 49.3 c/ha, respectively. The results of laboratory studies confirmed that nitrogen fertilizers in an increased amount lead to a decrease in the starch content in winter wheat grains, while simultaneously increasing the protein content. Correlation analysis showed a tendency to increase the yield of winter wheat with higher application of nitrogen fertilizers, however, in order to avoid deterioration of the quality of crop products, it is important to follow the recommendations. The practical significance of the obtained results lies in optimizing the cultivation of grain crops, as well as increasing their yield in conditions of limited water resources and the threat of drought

Keywords: winter wheat; fertiliser; yield; plant nutrition; dry conditions

INTRODUCTION

In today's world, agri-environmental issues are becoming increasingly relevant, as agriculture is a key sector that ensures food security and economic development. Climate change, population growth and volatile agricultural markets require the development and implementation of environmentally sustainable and

Article's History:
Received: 12.09.2023
Revised: 20.11.2023
Accepted: 12.12.2023

Suggested Citation:
Drobitko, A., & Kachanova, T. (2023). Agroecological substantiation of technologies for growing grain crops in the conditions of the Southern Steppe of Ukraine. *Ukrainian Black Sea Region Agrarian Science*, 27(4), 9-17. doi: 10.56407/bs.agrarian/4.2023.09.

*Corresponding author

productive agricultural technologies. In the Southern Steppe of Ukraine, which has significant potential for agricultural production, this relevance is most evident through the above challenges and opportunities.

Modern agriculture faces numerous challenges, such as climate change, rapid population growth, global competition and the need to ensure environmental sustainability. To address these challenges, new technologies and crop production strategies are needed. M. Ivasyk & M. Bakhmat (2023) in their study emphasise that it is important to strive for high productivity, conservation of resources and the environment, as well as to ensure product quality and access to global markets.

A number of authors, such as J. Wang *et al.* (2021) and L.N. Jørgensen *et al.* (2020), argue that the main aspects of the agroecological approach to crop production include site selection, selection of varieties and hybrids, use of efficient agronomic practices, water management, monitoring and control of negative impacts, biodiversity conservation, and promotion of environmental awareness among farmers and consumers. Macronutrients, as integral components of important physiologically active substances, help to increase the activity of enzymes in plants, improve their ability to absorb essential nutrients and increase photosynthetic productivity and assimilation activity. The addition of mineral fertilisers has a number of beneficial effects for plants and crops. It increases the resistance of plants to adverse environmental conditions and makes them less susceptible to pests and diseases. This leads to higher yields and improved grain quality (Sallam *et al.,* 2019).

The cultivation of winter wheat is crucial for its yield. The fertilisation system for this crop includes the application of various types of nutrients. This is necessary due to the fact that winter wheat requires a large amount of nutrients for its proper growth and development, and most of these nutrients are often not available to plants in the required quantities in the soil. Nutrient deficiencies in the soil can lead to reduced yields, poor seed quality and an increased risk of disease and pest infestation. Therefore, it is important to provide winter wheat with the necessary amount of nutrients by applying fertiliser in appropriate amounts and at the optimal time, as shown in study A. Ren *et al.* (2019).

Ye. Kuzmenko *et al.* (2023) believe that the scientific and agro-ecological justification of growing cereal crops in Ukraine is an important task in the context of ensuring food security, sustainable use of natural resources and biodiversity conservation. The authors pay particular attention to the Southern Steppe of Ukraine, which is an important agricultural area but also faces a number of agro-ecological challenges and constraints. This region has unique natural conditions, but at the same time is vulnerable to threats such as drought, soil erosion, waterlogging, water pollution, and others.

According to M. Solodushko *et al.* (2021), the agroecological justification of grain growing technologies also affects the conservation of nature and public health. Healthy ecosystems not only ensure sustainable agricultural production, but also provide natural balance, maintain species diversity, and regulate climate processes. Prevention of soil and water pollution also affects the quality and safety of food for the population. Thus, the agro-ecological justification of crop cultivation technologies has a deep social and environmental context and relevance, and determines the future of agriculture and the environment in the Southern Steppe of Ukraine.

V. Gamayunova *et al.* (2020) point out that grain farming in Ukraine is one of the main sectors of the agricultural complex, and its development largely determines the production of food and feed resources, as well as affects the economy as a whole. Modern grain varieties, including winter wheat, have a high potential yield of up to 7 tonnes of grain per hectare, but average yields in Ukraine remain significantly lower.

The aim of the study was to investigate the impact of mineral fertilisation on the growth and development of winter wheat in the Southern Steppe of Ukraine. To achieve this goal, the following objectives were set: to study the peculiarities of mineral nutrition of winter wheat and its fertiliser requirements, as well as to determine the impact of nitrogen fertiliser rates on the yield and quality of winter wheat.

MATERIALS AND METHODS

To determine the productivity of winter wheat, a field experiment was conducted using laboratory and field observations of the growth and development of the crop grown under different conditions of mineral fertilisation. The study was conducted in 2020-2022 on the fields of the Educational and Research Centre (ERC) of Mykolaiv National Agrarian University. The study complies with all ethical standards under The Convention on Biological Diversity (2022).

The soil of the experimental plots is southern black soil on carbonate loess, characterised by high potassium, medium phosphorus and low nitrogen content. The soil has a medium loamy texture, with a humus horizon of up to 50-65 cm and a humus content of approximately 3.5%. The content of mobile forms of phosphorus is 8.8-9.6 mg per 100 soil, easily hydrolysed nitrogen in the soil is about 0.1-0.4 mg per 100 soil, and exchangeable potassium is about 30.3 mg per 100 soil. The soil reaction of the experimental plot (pH) is 7.5.

Since climatic conditions have a great influence on the formation of winter wheat grain yield, it is important to note that the study was conducted in an area that belongs to the zone with insufficient rainfall, and all years of research were characterised by a shortage of precipitation. The experiment was replicated three times, with a total plot size of 350 m^2 and an area of 80 m^2 per plot. Perennial grasses were the predecessor of winter wheat. Winter wheat was sown between 25 and 30 September, with a seeding rate of 220 kg per 1 ha or 4.5-5 million/ha of germinating seeds.

Organic fertiliser (manure) was applied to the soil for autumn ploughing before sowing winter wheat at a rate of 25 t/ha in all experimental variants. In addition, phosphorus-potassium fertilisers were applied at a rate of $P_{30}K_{30}$ during winter ploughing, and nitrogen fertilisers were applied in spring according to the appropriate scheme: Option I – N_{30}, Option II – N_{60}, Option III – N_{80}. The method of fertilisation with nitrogen fertilisers was to apply them during early spring fertilisation on frozen soil and at the beginning of the phase of winter wheat emergence into the tube. Urea was used as a nitrogen fertiliser, potassium chloride as a potassium fertiliser, and granular superphosphate as a phosphorus fertiliser.

Correlation and regression analysis was used to confirm the reliability of the results. This method is a powerful tool for establishing relationships between different variables. In the present study, this analysis was used to determine the relationship between mineral fertiliser use, winter wheat grain yield and starch and protein content in the grain. In addition, this analysis allowed us to build a model that can predict winter wheat yields depending on the use of mineral fertilisers.

The data of winter wheat growth parameters, such as plant height, number of productive stems and weight of 1,000 seeds, were obtained by measuring, counting and weighing, and the leaf area was determined by the method of notching. The starch content of seeds was determined using a Shimadzu UV-1800 spectrophotometer (Shimadzu, Japan), and the protein content was determined by refractometric method. Winter wheat grain yield was determined manually from each plot separately. During the data analysis, statistical analysis was also performed to determine the average and relative values of the effect of the level of mineral fertilisation on the yield, and comparative analysis was performed to compare the data obtained.

All experiments were repeated three times for each variant of the experiment. To verify the reliability of the research results, the multivariate method of analysis of variance MANOVA was used, which was conducted using Microsoft Excel software and Statistica 10 software package. Differences between the results obtained were defined as statistically significant if the significance level (P) was less than or equal to 0.05 according to the Student's criterion.

RESULTS

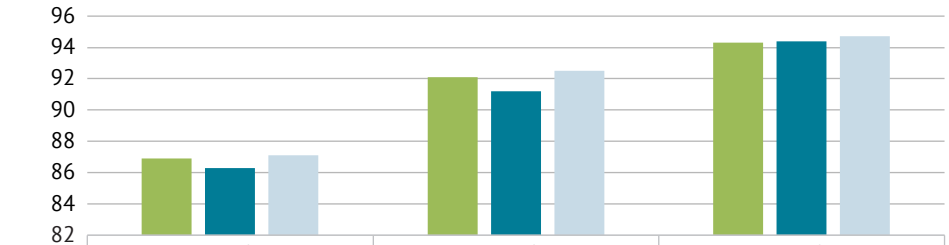
An important component of the fertilisation system for winter wheat is the application of the optimal amount of macro- and microelements required to meet the needs of the plants. To achieve this, both organic and mineral fertilisers can be used. Determining the optimal fertilisation system for winter wheat is a complex task, as it depends on numerous factors that can be difficult to control. These factors include climatic conditions, soil type, weather, plant variety, soil moisture availability, soil nutrient availability, and others. Therefore, the optimal fertilisation system may vary depending on the specific growing conditions (Serrago *et al.,* 2013).

An important aspect is the timely application of nitrogen fertilisers at different stages of plant organogenesis. This allows to effectively influence the formation of grain yield structure indicators, such as plant density and size. Phosphorus and potassium are equally important for the growth and development of winter wheat, particularly in the early stages of growth, when the root system and winter hardiness of plants are formed. The use of large doses of nitrogen fertilisers in the early stages of organogenesis can have a suppressive effect on young plants, so it is important to avoid their large application during pre-sowing cultivation and during sowing. However, a lack of nitrogen at these stages can negatively affect plant development and reduce yields.

One of the research objectives was to study the peculiarities of mineral nutrition of winter wheat and its fertiliser requirements, so it is important to note that to obtain a winter wheat yield of 1 tonne of grain per hectare, the following amounts of macronutrients should be provided: nitrogen – 30-35 kg, phosphorus – 10-13 kg, potassium – 20-25 kg (Holman *et al.,* 2023). As for the inheritance of plant height, this indicator is stable and genetically dependent, but environmental conditions, in particular stress factors, can significantly change this parameter. In addition, plant height can vary significantly depending on certain factors, including the year of cultivation, plant variety and environmental conditions. For example, under ideal conditions of soil moisture and nutrient supply, plants will be taller than under conditions of drought and insufficient soil nutrition (Ahmad *et al.,* 2022).

In this study, the application of different rates of nitrogen fertilisers in winter wheat crops had a significant impact on crop height over three years. It was found that an increase in nitrogen fertiliser rates promotes higher growth of winter wheat plants. Thus,

in the variant of $P_{30}K_{30}+N_{30}$ application, the average plant height was 86.8 cm over the years of study. Improvement of the nutrition background in the variants $P_{30}K_{30}+N_{60}$ and $P_{30}K_{30}+N_{80}$ contributed to an increase in the height of winter wheat plants by 3.8 and 4.6 cm, respectively (Fig. 1).



	$P_{30}K_{30}+N_{30}$	$P_{30}K_{30}+N_{60}$	$P_{30}K_{30}+N_{80}$
2020	86.9	92.1	94.3
2021	86.3	91.2	94.4
2022	87.1	92.5	94.7

Figure 1. *Effect of fertiliser on the height of winter wheat plants, cm*
Source: *compiled by the authors*

The formation of high-yielding winter wheat crops depends on the size and photosynthetic activity of its leaf surface. Optimisation of photosynthesis and efficient use of solar energy are key factors for increasing grain yields. In the arid conditions of southern Ukraine, insufficient development of the leaf surface is the main limiting factor for achieving high crop productivity. The application of mineral fertilisers, especially nitrogen, which is part of chlorophyll, plays an important role in the formation of the leaf apparatus. By improving the nutritional regime, it is possible to increase the size and productivity of the leaf surface of plants, which affects their photosynthetic activity. According to the data obtained as a result of the study, during the growing season, winter wheat plants fertilised with higher rates of nitrogen fertilisers in the variants $P_{30}K_{30}+N_{60}$ and $P_{30}K_{30}+N_{80}$ had a larger leaf surface compared to the variant $P_{30}K_{30}+N_{30}$. The leaf surface reached its largest size at the earing stage in all experimental variants (Table 1).

Table 1. *Effect of fertilisation on the leaf area of winter wheat, thousand m^2/ha (average for 2020-2022)*

Variant of the experiment	Scheme of application of mineral fertilizers	Phase of development		
		tillering	output tube	earing
1	$P_{30}K_{30}+N_{30}$	12.3	17.2	22.4
2	$P_{30}K_{30}+N_{60}$	14.4	20.1	27.1
3	$P_{30}K_{30}+N_{80}$	14.8	23.7	29.1

Source: *compiled by the authors*

In addition, it was found that different amounts of nitrogen fertiliser in winter wheat crops affected the yield structure of the crop for three years, namely the number of productive stems and the weight of 1,000 seeds. Productive stems are those stems that develop and form ears of grain. The number of productive stalks in winter wheat can vary depending on many factors, including sowing density, fertiliser use, weather conditions and plant variety. Achieving the optimum number of productive stems helps to ensure a good winter wheat harvest and increase the efficiency of agricultural production. To increase the number of productive stems, agricultural practitioners can use various agronomic measures, including optimal sowing density, timely and rational fertilisation, selection of plant varieties with higher productivity, etc. (Bilousova *et al.*, 2021).

The study found that at the level of fertilisation of $P_{30}K_{30}+N_{60}$, the largest number of productive stems was formed, which was 561 pcs. It should also be noted that the use of mineral nutrition also affected the weight of 1,000 seeds of winter wheat, despite the fact that this is a genetically determined trait. Thus, at the level of fertilisation of $P_{30}K_{30}+N_{60}$, the highest weight of 1,000 seeds was noted – 55.3 g (Table 2). Consequently, the number of productive stems was 3.5% higher with $P_{30}K_{30}+N_{60}$ than with $P_{30}K_{30}+N_{30}$, and the weight of 1,000 seeds was 13.6% higher, respectively. Therefore, it should be noted that the increase in the structural

parameters of the winter wheat crop in the study was due to the supply of a sufficient amount of nutrients from mineral fertilisers, which influenced the growth and development of plants.

Table 2. *Number of productive stems and weight of 1,000 seeds of winter wheat (average for 2020-2022)*

Variant of the experiment	Scheme of application of mineral fertilizers	Number of productive stems, pieces/m^2	Weight of 1,000 seeds, g
1	$P_{30}K_{30}+N_{30}$	542	48.7
2	$P_{30}K_{30}+N_{60}$	561	55.3
3	$P_{30}K_{30}+N_{80}$	553	54.8

Source: *compiled by the authors*

The results of the study also showed that the application of mineral fertilisers had a significant impact on the yield of winter wheat. On average, over three years, the highest yields were formed by applying $P_{30}K_{30}+N_{30}$ and $P_{30}K_{30}+N_{80}$, and amounted to 51.8 and 49.3 c/ha, respectively, indicating that the level of mineral fertiliser supply is adequate. In particular, nitrogen fertilisers, contributes to the productivity of winter wheat (Table 3).

Table 3. *Winter wheat yield, tonnes per hectare*

Variant of the experiment	Scheme of application of mineral fertilizers	Year			Average for 2020-2022
		2020	2021	2022	
1	$P_{30}K_{30}+N_{30}$	48.6	49.1	48.9	48.9
2	$P_{30}K_{30}+N_{60}$	51.9	52.2	51.4	51.8
3	$P_{30}K_{30}+N_{80}$	49.4	48.8	49.6	49.3
$HIP_{0.05}$		1.26	1.37	1.31	1.19

Source: *compiled by the authors*

The starch and protein content of wheat seeds is important for the quality and use of this crop. In particular, starch is the main type of carbohydrate in wheat grain. The starch content affects the structure and texture of wheat products. The high starch content helps wheat grains to form a dense texture, which makes them excellent for bread making. The protein content also affects the quality of flour and other wheat products. The higher the protein content, the higher the nutritional and technological value of the grain. It has been established that the application of mineral fertilisers, in addition to the yield of winter wheat grain, has an impact on its starch and protein content. Thus, according to the data obtained in laboratory conditions, the starch content decreased with an increase in the rate of nitrogen fertiliser application, but the protein content, on the contrary, increased with the application of higher nitrogen rates (Table 4).

Table 4. *Starch content in seeds and protein in winter wheat grain, % (average for 2020-2022)*

Variant of the experiment	Scheme of application of mineral fertilizers	Starch content	Protein content
1	$N_{30}P_{40}K_{30}$	66.8	14.8
2	$P_{30}K_{30}+N_{30}$	62.6	16.4
3	$P_{30}K_{30}+N_{60}$	64.4	17.2

Source: *compiled by the authors*

Thus, according to the results obtained, the indicators of crop structure and quality characteristics of grain, as well as its yield, are significantly influenced by the rates of nitrogen fertiliser application. According to the correlation and regression analysis, there is a tendency to increase the yield and protein content of winter wheat grain with an increase in the level of mineral fertilisers. The value of reliability for yield is $R^2 = 1$, for protein content – $R^2 = 0.9643$. At the same time, a tendency to decrease the starch content in grain with an increase in nitrogen fertiliser application was found, with a reliability value of $R^2 = 1$. This means that the model accurately describes the available data (Fig. 2).

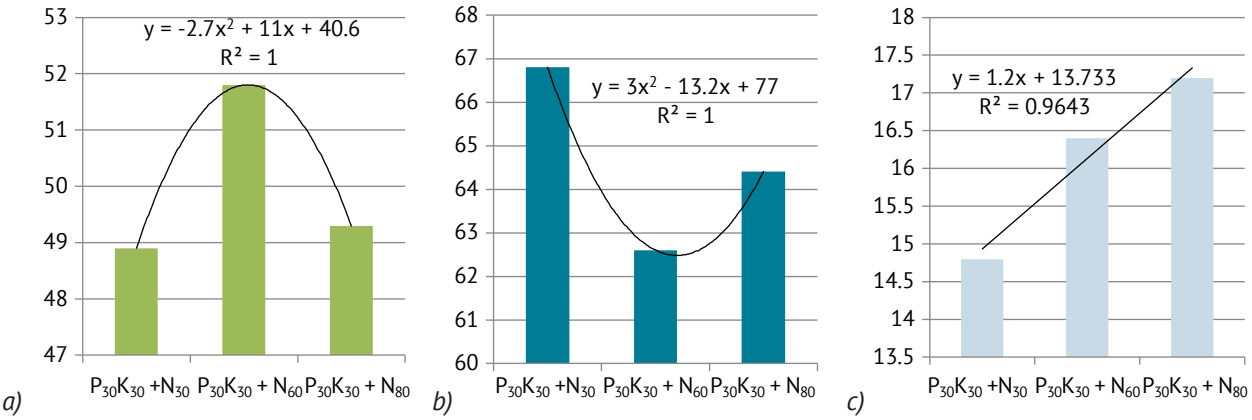


Figure 2. *Correlation and regression analysis of the effect of mineral fertilisers*
Notes: *a) grain yield of winter wheat; b) starch content in grain; c) protein content in grain*
Source: *compiled by the authors*

Thus, the study found that increasing the dose of nitrogen fertiliser can lead to an increase in the number of productive stems, plant height, leaf area, 1,000 seed weight and protein content in winter wheat grain. In addition, it has also led to increased yields, even in arid climates. Thus, it can be noted that in the conditions of insufficient moisture in the Southern Steppe of Ukraine, the methods of growing grain crops have a scientific agroecological justification.

DISCUSSION

Confirmation of the study can be found in the works of M. Solodushko *et al.* (2021), according to which the conditions of insufficient moisture supply in the Southern Steppe of Ukraine require a scientifically sound agroecological approach to grain growing technologies. This approach involves taking into account natural conditions, climatic features and water supply sources to ensure a stable harvest and preserve the environment.

The Southern Steppe region of Ukraine is characterised by a "non-flushing" water regime. This means that moisture enters the soil mainly as a result of precipitation, and there is no significant water flushing through the soil profile. The growing season of agricultural crops is characterised by a lack of moisture, and the main factor in replenishing soil moisture is autumn and winter precipitation, while in summer precipitation evaporates quickly. That is why a significant part of the moisture is retained in the surface layers of the soil, making it difficult for plants to access water. An important problem in this region is the conservation and rational use of moisture reserves to ensure crop yields (Gamayunova *et al.*, 2020).

L. Skinulienė *et al.* (2022) consider that the fertilisation system for winter wheat includes the application of different types of fertilisers with different concentrations and amounts, taking into account agronomic practices, soil type, climatic conditions and other factors. The main components of fertiliser for winter wheat include nitrogen, phosphorus, potassium and various trace elements. This integrated approach to fertilisation helps to achieve optimal results in growing the crop. Y. Su *et al.* (2021) in their research believe that organic fertilisers, unlike inorganic fertilisers, tend to decompose slowly, which allows them to gradually release nutrients into the soil over a long period of time. This ensures that winter wheat is nourished sustainably and over a long period of time, contributing to its sustainable growth and development throughout the growing season. Inorganic fertilisers, on the other hand, have a more concentrated composition and can provide a quick, intense boost to plants. They typically contain significant amounts of nitrogen, phosphorus, potassium and other essential nutrients, which can promote rapid growth and development of winter wheat. Both approaches have their advantages and disadvantages, and the choice between them usually depends on the specific growing conditions and the purpose of the agricultural production.

J. Wang *et al.* (2021) argue that integrated fertilisation has a significant effect on the gluten content of grain, which is explained by an increase in protein and reserve fractions such as prolamins and glutenins. This integrated approach helps to improve the quality of grain, in particular, by increasing the gluten content, which is an important parameter for the production of bread and other food products. Similar results were obtained in the study by M.A. Bukhari *et al.* (2021), where the authors indicate that the combined application of nitrogen fertilisers together with phosphate and potassium fertilisers leads to an increase in protein content in winter wheat grain. These results highlight the importance of integrated fertilisation to improve the quality and productivity of this crop.

However, Ye. Kuzmenko *et al.* (2023) note that it is important to consider that excessive nitrogen fertilisation can have a negative impact on plant development and crop quality. Excessive amounts of nitrogen can lead to an increase in plant height and a delay in the formation of generative organs. In addition, excessive nitrogen can lead to increased water retention in the plant and an increased risk of disease and pest spread. Therefore, it is important to follow the recommendations on the optimal doses of nitrogen fertilisers to achieve the best results in winter wheat cultivation.

The results of the study are echoed in the scientific works of L.N. Jørgensen *et al.* (2020), who argue that the fertilisation system can affect the weight of 1,000 seeds of winter wheat. The authors' research has shown that the application of phosphorus fertilisers improves the formation and development of the plant's root system, providing the necessary energy for its growth, which affects the increase in seed weight. Potassium is also an important element for the growth of winter wheat and maintaining its resistance to stressful conditions such as high or low temperatures. A lack of potassium in the soil can lead to a decrease in seed weight and overall crop yield. The results of the study confirm the importance of optimal use of these elements to achieve the best results in winter wheat cultivation.

The results of the study also coincide with the opinion of R. Vozhehova *et al.* (2021), who call for a careful consideration of mineral nutrition factors in the Southern Steppe of Ukraine. According to their data, winter wheat can achieve significant yields if the recommended mineral nutrition rates are met, which highlights the importance of proper crop care in this region. According to the authors M. Ivasyk & M. Bakhmat (2023), the application of $N_{60}P_{30}$ in autumn and additional nitrate fertilisation at N_{30} in spring ensures maximum leaf area in the tillering and earing phase for cereals, which was also confirmed in the study.

In the work of Y. Li *et al.* (2022) noted a very strong correlation between the leaf surface area in the earing phase and grain yield for cereals when using pre-sowing seed treatment with the biological product Escort-bio ($R^2 = 0.902$), as well as between the leaf surface area in the earing phase and plant height at full grain ripeness ($R^2 = 0.931$). Optimisation of the nutritional background affects the increase in the photosynthetic potential of winter wheat crops by 14-20%, as reported by S. Yue *et al.* (2012). According to the authors, the maximum values were obtained when $N_{60}P_{30}$ was applied before sowing. In addition, it was found that the net productivity of photosynthesis increased in winter wheat crops by 25-60% when the nutritional background was optimised. The maximum values of net photosynthetic productivity were achieved when $K_{30}P_{30}$ was applied before sowing and additional fertilisation with ammonium nitrate at a dose of N_{30}.

According to P. Astrauskas & G. Staugaitis (2022), mineral fertilisers and fertilisations increased the protein content of winter wheat grain from 13.5% when growing plants on unfertilised plots to 15% when optimising the nutritional background, which is also reflected in the study. O. Sydiakina & V. Dvoretskyi (2020) state that the application of mineral fertilisers at the recommended rates and the use of green manure, as well as manure feeding in the amount of 10 t/ha, led to an increase in winter wheat yields by 1.45 t/ha of grain and 1.16 t/ha of straw. Efficiency increases with the use of foliar fertilisation with complex fertilisers, in particular with the organomineral complex Organic D2-M, which additionally ensured the formation of 0.62-0.96 t/ha of grain and 0.50-0.77 t/ha of straw. Optimisation of the nutritional background also improved grain quality by increasing protein and crude gluten content, but variants using the vitamin BF-3 complex were less effective.

Considering these studies of the authors and the results of the study, it can be concluded that a scientifically based agroecological substantiation of grain crops cultivation technologies is critical in the conditions of insufficient moisture in the Southern Steppe of Ukraine. Adherence to agroecological principles and application of scientific methods contribute to increasing the drought resistance of cereals, rational use of water resources and preservation of soil and environmental quality.

CONCLUSIONS

As a result of the research, it was found that increasing the nitrogen fertilizer rates has a significant positive effect on the growth and yield of winter wheat. When applying higher nitrogen rates (options $P_{30}K_{30}+N_{60}$ and $P_{30}K_{30}+N_{80}$), plant height increased by 3.8 and 4.6 cm, respectively, compared to option $P_{30}K_{30}+N_{30}$. In addition, doubling the rates of nitrogen fertilizers helped to increase the number of productive stems by 3.5% and the weight of 1,000 seeds by 13.6%. The application of mineral fertilizers also had an effect on the yield of winter wheat. Thus, when applying $P_{30}K_{30}+N_{60}$ and $P_{30}K_{30}+N_{80}$, the grain yield exceeded the option of applying $P_{30}K_{30}+N_{60}$ and $P_{30}K_{30}+N_{30}$ by 2.9 and 0.4 t/ha, respectively. This testifies to the important role of nitrogen fertilizers in ensuring high productivity of winter wheat. Laboratory studies have confirmed that increasing the rates of nitrogen fertilizers helps to reduce the starch content in winter wheat grain, but to increase the protein content, which can affect the quality and

use of wheat grain in products. Therefore, increasing the doses of mineral fertilizers can have a positive effect on the yield structure of winter wheat and provide an additional harvest even in the arid conditions of the Southern Steppe of Ukraine. However, it is important to follow the recommendations for applying fertilizers in order not to deteriorate the quality of the products.

In general, science-based agro-ecological approaches to the cultivation of grain crops not only increase the efficiency of agricultural production, but also contribute to the sustainable development of the agricultural sector and the preservation of natural resources in conditions of insufficient moisture. The results of the study help to optimize the cultivation of grain crops, increase their yield and improve the quality of products in arid climate conditions, which will contribute to the sustainability of agricultural enterprises. The conducted analysis revealed a correlation between the increase in the application of nitrogen mineral fertilizers and the increase in the yield of winter wheat. This means that future studies can consider further increases in fertilizer rates of each individual macronutrient, as well as their combined effects on yield structure and crop quality of this crop.

ACKNOWLEDGEMENTS

None.

CONFLICT OF INTEREST

None.

REFERENCES

[1] Ahmad, A., Aslam, Z., Javed, T., Hussain, S., Raza, A., Shabbir, R., ... Tauseef, M. (2022). Screening of wheat (*Triticum aestivum* L.) genotypes for drought tolerance through agronomic and physiological response. *Agronomy*, 12(2), 287. doi: 10.3390/agronomy12020287.

[2] Astrauskas, P., & Staugaitis, G. (2022). Digital technologies determination effectiveness for the productivity of organic winter wheat production in low soil performance indicator. *Agriculture*, 12(4), 474. doi: 10.3390/agriculture12040474.

[3] Bilousova, Z., Klipakova, Y., & Keneva, V. (2021). Features of the pigment complex of winter wheat plants depending on the method of fertilisation. *Plant and Soil Science*, 12(3), 7-16. doi: 10.31548/agr2021.03.0007.

[4] Bukhari, M.A., Shah, A.N., Fahad, S., Iqbal, J., Nawaz, F., Manan, A., & Baloch, M.S. (2021). Screening of wheat (*Triticum aestivum* L.) genotypes for drought tolerance using polyethylene glycol. *Arabian Journal of Geosciences*, 14, 2808. doi: 10.1007/s12517-021-09073-0.

[5] Gamayunova, V., Panfilova, A., Baklanova, T., Kuvshinova, A., Kasatkina, T., & Nagirniy, V. (2020). The increase of grain production in Ukrainian Steppe area by means of barley cultivation and its nutrition optimisation. *Scientific Horizons*, 2(87), 15-23. doi: 10.33249/2663-2144-2020-87-02-15-23.

[6] Holman, J.D., Obour, A.K., & Assefa, Y. (2023). Forage sorghum grown in a conventional wheat-grain sorghum-fallow rotation increased cropping system productivity and profitability. *Canadian Journal of Plant Science*, 103(1), 61-72. doi: 10.1139/cjps-2022-0171.

[7] Ivasyk, M., & Bakhmat, M. (2023). Increasing the performance of soybean grain in the conditions of Podillia. *Podilian Bulletin: Agriculture, Engineering, Economics*, 2(37), 51-57. doi: 10.37406/2706-9052-2022-2-8.

[8] Jørgensen, L.N., Matzen, N., Ficke, A., Nielsen, G.C., Jalli, M., Ronis, A., ... Djurle, A. (2020). Validation of risk models for control of leaf blotch diseases in wheat in the Nordic and Baltic countries. *European Journal of Plant Pathology*, 157(3), 599-613. doi: 10.1007/s10658-020-02025-6.

[9] Kuzmenko, Ye., Fedorenko, M., Pirych, A., & Blyzniuk, R. (2023). Ecological plasticity and stability of promising lines of spring wheat (*Triticum aestivum* L.) in terms of yield. *Plant Varieties Studying and Protection*, 18(4), 242-250. doi: 10.21498/2518-1017.18.4.2022.273985.

[10] Li, Y., Miao, Y., Zhang, J., Cammarano, D., Li, S., Liu, X., ... Cao, Q. (2022). Improving estimation of winter wheat nitrogen status using random forest by integrating multi-source data across different agro-ecological zones. *Frontiers in Plant Science*, 13, 890892. doi: 10.3389/fpls.2022.890892.

[11] Ren, A., Sun, M., Xue, L., Deng, Y., Wang, P., Lei, M., ... Gao, Z. (2019). Spatio-temporal dynamics in soil water storage reveals effects of nitrogen inputs on soil water consumption at different growth stages of winter wheat. *Agricultural Water Management*, 216, 379-389. doi: 10.1016/j.agwat.2019.01.023.

[12] Sallam, A., Alqudah, A.M., Dawood, M.F.A., Baenziger, P.S., & Börner, A. (2019). Drought stress tolerance in wheat and barley: Advances in physiology, breeding and genetics research. *International Journal of Molecular Sciences*, 20(13), 3137. doi: 10.3390/ijms20133137.

[13] Serrago, R.A., Alzueta, I., Savin, R., & Slafer, G.A. (2013). Understanding grain yield responses to source-sink ratios during grain filling in wheat and barley under contrasting environments. *Field Crops Research*, 150, 2-51. doi: 10.1016/j.fcr.2013.05.016.

[14] Skinulienė, L., Marcinkevičienė, A., Butkevičienė, L.M., Steponavičienė, V., Petrauskas, E., & Bogužas, V. (2022). Residual effects of 50-year-term different rotations and continued bare fallow on soil CO_2 emission, earthworms, and fertility for wheat crops. *Plants*, 11(10), 1279. doi: 10.3390/plants11101279.
[15] Solodushko, M., Gasanova, I., Pedash, O., Yaroshenko, S., Drumova, O., Astakhova, Ya., ... Zavalypich, N. (2021). Effect of mineral nutrition on winter wheat yield after sunflower in Ukrainian Steppe zone. *Ukrainian Journal of Ecology*, 11(7), 179-184. doi: 10.15421/2021_256.
[16] Su, Y., Gabrielle, B., & Makowski, D. (2021). A global dataset for crop production under conventional tillage and no tillage systems. *Scientific Data*, 8(1), 33. doi: 10.1038/s41597-021-00817-x.
[17] Sydiakina, O., & Dvoretskyi, V. (2020). Productivity of winter wheat depending on food backgrounds in the conditions of Western Polissia. *Scientific Horizons*, 7(92), 45-52. doi: 10.33249/2663-2144-2020-92-7-45-52.
[18] The Convention on Biological Diversity. (2022). Retrieved from https://www.cbd.int/convention/.
[19] Vozhehova, R., Kokovikhin, S., Drobitko, A., & Naidonov, V. (2021). The influence of agricultural practices on the efficiency of using photosynthetic active radiation and moisture by soybean under the conditions of the South of Ukraine. *Taurida Scientific Herald. Series: Rural Sciences*, 117, 22-28. doi: 10.32851/2226-0099.2021.117.4.
[20] Wang, J., Zhang, S., Saimju, U.M., Ghimire, R., & Zhao, F. (2021). A meta-analysis on cover crop impact on soil water storage, succeeding crop yield, and water-use efficiency. *Agricultural Water Management*, 256, 107085. doi: 10.1016/j.agwat.2021.107085.
[21] Yue, S., Meng, Q., Zhao, R., Li, F., Chen, X., Zhang, F., & Cui, Z. (2012). Critical nitrogen dilution curve for optimizing nitrogen management of winter wheat production in the North China plain. *Agronomy Journal*, 104(2), 523-529. doi: 10.2134/agronj2011.0258.

Агроекологічне обґрунтування технологій вирощування зернових культур в умовах Південного Степу України

Антоніна Вікторівна Дробітько
Доктор сільськогосподарських наук, професор
Миколаївський національний аграрний університет
54008, вул. Георгія Ґонґадзе, 9, м. Миколаїв, Україна
https://orcid.org/0000-0002-6492-4558
Тетяна Володимирівна Качанова
Кандидат сільськогосподарських наук, доцент
Миколаївський національний аграрний університет
54008, вул. Георгія Ґонґадзе, 9, м. Миколаїв, Україна
https://orcid.org/0000-0003-0032-3996

Анотація. Агроекологічне обґрунтування технологій вирощування зернових культур стає особливо актуальним в умовах недостатнього зволоження, оскільки вимагає стійких та ефективних агропродукційних систем, що забезпечують високу врожайність та зберігають природні ресурси. Мета дослідження – визначити вплив внесення азотних мінеральних добрив на ріст і розвиток озимої пшениці в умовах посушливого клімату. Для досягнення цієї мети проведено польове дослідження на полях Навчально-науково-практичного центру Миколаївського національного аграрного університету із вивчення мінерального живлення та впливу різних норм азоту на структуру та якість врожайності зерна озимої пшениці. Результатами дослідження встановлено, що підвищення норм азотних добрив позитивно впливає на ріст та врожайність культури. Внесення вищих норм азоту, зокрема N_{60} та N_{80} у підживлення навесні, впливає на збільшення висоти рослин на 3,8 см і 4,6 см відповідно, порівняно внесення N_{30}. Крім того, подвійне збільшення норм азотних добрив призвело до зростання кількості продуктивних стебел на 3,5 % та маси 1000 насінин на 13,6 %. Мінеральні добрива також суттєво вплинули на врожайність озимої пшениці, так при застосуванні $P_{30}K_{30}+N_{60}$ і $P_{30}K_{30}+N_{80}$ урожайність зерна становила відповідно 51,8 ц/га та 49,3 ц/га. Результати лабораторних досліджень підтвердили, що азотні добрива у збільшеній кількості призводять до зниження вмісту крохмалю в зерні озимої пшениці, одночасно збільшуючи вміст білка. Кореляційний аналіз засвідчив тенденцію до зростання врожайності озимої пшениці при більшому внесенні норм азотних добрив, проте задля уникнення погіршення якості продукції культури, важливо дотримуватися рекомендацій. Практичне значення отриманих результатів полягає в оптимізації вирощування зернових культур, а також збільшенні їх врожаю в умовах обмежених водних ресурсів і загрози посухи

Ключові слова: озима пшениця; добриво; врожайність; живлення рослин; посушливі умови

UDC: 631.361.81
DOI: 10.56407/bs.agrarian/4.2023.18

Ukrainian Black Sea Region Agrarian Science
Vol. 27, No. 4

Study of the nature of the movement of the crushed mass on the surface of the sieves of the vegetable and melon seed separator

Dmytro Babenko*
PhD in Technical Sciences, Professor
Mykolaiv National Agrarian University
54008, 9 Georgiy Gongadze Str., Mykolaiv, Ukraine
https://orcid.org/0000-0003-2239-4832

Nataliia Dotsenko
Doctor of Pedagogical Sciences, Associate Professor
Mykolaiv National Agrarian University
54008, 9 Georgiy Gongadze Str., Mykolaiv, Ukraine
https://orcid.org/0000-0003-1050-8193

Olena Gorbenko
PhD in Technical Sciences, Associate Professor
Mykolaiv National Agrarian University
54008, 9 Georgiy Gongadze Str., Mykolaiv, Ukraine
https://orcid.org/0000-0001-6006-6931

Ilona Batsurovska
Doctor of Pedagogical Sciences, Associate Professor
Mykolaiv National Agrarian University
54008, 9 Georgiy Gongadze Str., Mykolaiv, Ukraine
https://orcid.org/0000-0002-8407-4984

Abstract. Improvement of equipment for processing vegetable and melon crops requires research on the nature of the movement of the crushed mass to reduce material damage and obtain high-quality seeds, which will bring the vegetable and melon industry to a new level of development. The aim of the study is to analyse the movement of the crushed mass on the surface of the sieves of the vegetable and melon seed separator. The nature of the movement of the crushed mass on the surface of the sieves of the proposed design solution was substantiated on the basis of the use of methods of physics, theoretical mechanics and analysis and study of the physical and mechanical characteristics of the technological mass. As a basic design for the study, a vegetable and melon separator were used, the feature of which is the use of a two-screen system of sieves. In this system, the upper sieve separates the peel, and the lower sieve separates the seeds and pulp; the pulp and juice are the final product of the second sieve. The sieve, which performs inertial motion, helps to remove the seeds associated with the peel. As a result of the research, the functional dependence of the amplitude of oscillations on the frequency of oscillations for different operating modes of the separator is presented. To determine the average speed of material movement in the technological zone of the separator, formulas are provided for the upper screen operating in the inertial separator mode and for the lower screen operating in the vibration

Article's History:
Received: 23.08.2023
Revised: 19.11.2023
Accepted: 12.12.2023

Suggested Citation:
Babenko, D., Dotsenko, N., Gorbenko, O., & Batsurovska, I. (2023). Study of the nature of the movement of the crushed mass on the surface of the sieves of the vegetable and melon seed separator. *Ukrainian Black Sea Region Agrarian Science*, 27(4), 18-35. doi: 10.56407/bs.agrarian/4.2023.18.

*Corresponding author

separator mode. In the context of the above-mentioned features of the proposed design solution, the nature of the movement of the crushed mass along the surface of the inertial and vibrating screens was studied. In the course of theoretical calculations, dependencies were obtained to determine the average particle velocity in the working area of these sieves. On the basis of the theoretical analysis, a methodology for calculating the main parameters of a double-screen separator was developed. The mechanical and technological properties of vegetable and melon seeds separated by the proposed design solution were determined. In laboratory conditions, the composition of the components of the separated seed mass was studied and analysed, which indicates the feasibility of using the proposed design solution for the separator of vegetable and melon crops and the practical application of the obtained theoretical dependencies for regulating its technological parameters

Keywords: inertial separator; vibrating separator; mechanical and technological properties; particle motion

INTRODUCTION

The transition to the cultivation of vegetable and melon crops in private households has led to an increase in the gap between the real producer and the achievements of the latest technologies and has significantly limited the opportunities for the development of this industry and the production of quality seeds. There is a need to develop equipment for the production of vegetable and melon seeds that can be adapted to the conditions of small farms. To create and design machines and equipment for the processing of vegetable and melon seeds, it is necessary to theoretically substantiate the nature of the movement of seeds along the moving parts of the machine in order to prevent their injury and increase germination.

Considerable attention has been paid to research on the cultivation of vegetable and melon crops and constructive solutions for seed extraction. In order to meet the needs of modern agriculture, it is essential to obtain high-quality seeds of vegetable and melon crops in order to reduce costs and eliminate the need to purchase them from third-party producers (Mukhopadhyay *et al.*, 2021). Yield estimation of new varieties of hybrid watermelons was paid attention to by researchers A. Wahyudi *et al.* (2022). It was proved that the production of watermelon seeds within an agricultural enterprise can increase the production and income of watermelon farmers. Seed evaluation and selection are important steps in a plant breeding programme.

The influence of the mechanical and technological parameters of vegetable and melon seeds on the subsequent seed quality was studied by S. Kale *et al.* (2020), and K. Fayzullaev *et al.* (2021) presented the development of a machine for sowing vegetable and melon crops. Tests have shown that the developed machine reliably performs the specified technological process, and its performance fully meets the requirements. D. Tlevlessova *et al.* (2023) noted that the transition to cultivation in households and small farms has led to the need to introduce scientific advances and the latest technologies for obtaining high-quality seeds. The authors emphasised that one of the key problems of industrial pumpkin production is the transition of production from large agricultural enterprises to small private farms, which currently account for more than 90% of the total. At the same time, the transfer of production to the private sector brings additional income to small producers and may be their only source of income. The current situation shows that private peasant farms are more adapted to the specifics of market relations.

C. Osuji *et al.* (2023) conducted a comparative study between mechanised and manual seed hulling of vegetable and melon crops. The seeds were peeled manually and mechanically using a mechanical melon peeler and a press machine. The efficiency of seed extraction using these machines was evaluated. The huller was the most efficient of the mechanised processes. The cleaned seeds were evaluated by mechanical and technological parameters. The study showed that the choice of a suitable variety, seed separator and packaging material is crucial for the overall efficiency and high-quality production of vegetable and melon seeds.

Studies of the probability of seed passage through the sieve holes indicate that by changing the geometric dimensions of the sieve holes it is impossible to achieve a separation level of more than 53…58%. In order to improve the quality of separation, it is necessary to study and theoretically substantiate the kinematic mode of operation of the sieve in order to determine the range of optimal speeds at which the content of impurities in the mass of freshly separated seeds is minimal with the maximum percentage of conditioned seeds that have passed through the sieve holes. At the same time, an increase in the relative speed of the separator sieves above 0.23…0.24 m/s negatively affects the operation of separation mechanisms due to the movement of the technological mass beyond the working surface. In view of this, there is a need to conduct theoretical studies to substantiate the process of separating seeds from

the crushed crust and pulp obtained during the grinding of seed fruits. The kinematic scheme of horizontally oscillating separators is almost identical. The quality of separation is influenced by the degree of seed fruit grinding, seed shape, shape of sieve holes, type of separator, and the nature of sieve movement. The literature does not contain enough specific recommendations on the design schemes of vegetable and melon crop separators, their kinematic modes, which allow intensifying the process of separating seeds from organic impurities. Therefore, the purpose of the article was to identify the factors that have the greatest impact on the quality of the technological process.

LITERATURE REVIEW

The literature review provides an important analytical overview of aspects of the entire cycle of cultivation and processing: from a thorough study of melon cultivation parameters to research on improving technologies to obtain high-quality seeds. For example, Erniati *et al*. (2022) studied the cultivation of melons and the optimal parameters for obtaining high-quality material. Particular attention was paid to the growing parameters, the study focused on monitoring such indicators as air temperature, relative humidity, radiometric sunlight intensity, plant age, leaf area, plant height to predict leaf area and plant height for the next two days. The author W. Nascimento (2002) noted that seed preparation and improvement can be a good option to increase the survival rate of melon crops. Primed seeds demonstrate better performance during germination, especially at low temperatures. The author discusses some aspects related to seed preparation and its impact on melon seed germination and yield formation.

In the context of the study of the full cycle of vegetable and melon crops cultivation and seed production, experiments on improving the environment for growing vegetable crops were conducted by P. Mazuela & M. Urrestarazu (2009), who noted that there is a need to increase the number of producers of vegetable and melon seeds. Obtaining high-quality seeds helps to increase yields, and grafting technology is also highly effective in reducing seed injury and, consequently, yield losses. The issue of automation of machinery for growing vegetable crops was addressed by J.M. Lee *et al*. (2010). Ukrainian scientists A.O. Lymar & V.A. Lymar (2012) paid attention to the issues of melon growing in Ukraine, who in their monograph described the technical, technological and agronomic aspects of melon growing in Ukraine. M. Zayachuk (2012) analysed the territorial differentiation of production of major vegetable crops in the regions of Ukraine. Research on melon varieties that can be grown in Ukraine was conducted by O.S. Shablya & O.G. Kholodnyak (2022). They present a device for classifying quality watermelon fruits using microwave technology. This device converts radio frequency to DC so that the voltage of mature fruits is higher than that of immature ones. The experiment of K. Kuchakorn *et al*. (2021) shows good separation of unripe and ripe watermelons. The study paid attention to determining the ripeness of fruits using specialised equipment and its suitability for further seed extraction. The properties of melon seeds as a food additive were also investigated by B. Gutyj *et al*. (2017).

Studies have also been conducted on the processing of vegetable and melon seeds. O.V. Tsurkan *et al*. (2015) highlighted the hydrodynamics of the process of filtration dehydration of freshly cleaned seeds with vibration activation. The authors studied the effect of pressure drop and mainly vertical vibrations on the intensity of dehydration, and compared the calculated and experimental values. O.V. Stanislavchuk *et al*. (2017) also presented the kinetic features of vibration and filtration dehydration of freshly peeled pumpkin seeds. On the basis of the constructed graphical dependence, the drying coefficients depending on the main parameters of the process of vibration of freshly peeled pumpkin seeds and combined dehydration, as well as the coefficient of relative drying, were determined. The dependencies for calculating moisture and dehydration time in the studied range of changes in the parameters of the drying process are presented. G. Kaletnik *et al*. (2020) investigated the determination of the kinetics of the process of vibratory convective seed drying. The research is driven by the need to solve the problem of fast and high-quality post-harvest processing at minimal cost. Existing technologies and equipment do not provide high productivity of the drying process in the post-harvest period or carry it out with significant time and resources. The main objective of the study was to determine the rational parameters of the process and equipment for drying pumpkin seeds. The results of the study of the intensification of vibration impact indicate a direct correlation between the vibration frequency of the drying chamber and the drying duration: the higher the frequency, the greater the intensity of vibroconvection drying, as well as the reduction in drying time with an increase in vibration amplitude. The determination of the parameters and operating modes of the structures of new solar collectors for drying grain and plant materials by active ventilation was carried out by B. Kotov *et al*. (2019). The article presents the results of experimental studies of the efficiency of air heating in solar collectors with different surface shapes, developed to justify their use in agricultural equipment. The authors also analyse the technological parameters

of a vibration centrifugal mixer and their influence on the kinetics of the process of preparing bulk solids. The analysis of the obtained experimental data made it possible to establish the rational operating parameters of the experimental vibrating machine, provided that the energy consumption for the organisation of the studied process is reduced (Kaletnik & Yanovych, 2017). Considering bulk or individual units of agricultural material, it is important to have an accurate estimate of the shape, size, volume, density, specific gravity, surface area and other mechanical characteristics that can be considered as design parameters for food production. Measurement techniques allow for the calculation of these parameters, which can provide information on the impact of processing (Dobrzanski & Stepniewski, 2013). Studies have also been conducted on the physical properties of vegetable crops (Tang *et al.,* 2014). Thus, the study of physical properties of vegetable crops and methods of their measurement is an integral part of the field of food production and agricultural technology.

MATERIALS AND METHODS

The study used the methods of physics (Lerner & Trigg, 1991), theoretical mechanics and analysis (Lanczos, 1986), and the study of the physical and mechanical characteristics of the technological mass (State Standard of Ukraine DSTU 8439:2015, 2015). In the course of analysing the movement of the crushed mass on the surface of the sieves of the vegetable and melon seed separator, a stepwise integration method was used, which allows more precisely determining the moments of transition of particles from one separation mode to another, from one direction of movement to the opposite. On the basis of the theoretical analysis, in accordance with the assumptions made, mathematical dependencies were established that allow determining the main structural and kinematic parameters of the vibrations of a sieve separating seeds, pulp and pulp from the crust. The theoretical study of the movement of seeds, pulp and hull along a sieve moving in a vibrating mode allowed to obtain formulas for determining the acceleration, speed and movement of the separated mass in the technological zone of the separating device. The greatest influence on the quality of the technological process was found to be the angle of inclination of the sieve, the frequency of oscillations, the amplitude of oscillations and the angle of additional forced oscillations. These factors were taken into account during the experimental studies.

Using the expression that characterises the mode of operation of sieve oscillations, the dependencies for determining the amplitude A and frequency of its oscillations ω and the angle of additional forced oscillations β were derived. To carry out engineering calculations, formulas were obtained that allow to calculate the average speed v_{cp} of the movement of particles of the crushed mass in the working space of the proposed design, productivity Q and drive power N. The determination of the mechanical and technological properties of vegetable and melon seeds separated by the proposed design solution was carried out using statistical analysis methods. During the study of mechanical and technological properties, the mass after the grinding device was considered. The determination of the percentage of suspended components of the crushed mass of seeds entering the separation was based on the following calculation:

$$C_i = \left(\frac{m_i}{\sum_{i=1}^{n} m_i}\right) \cdot 100\%, \quad (1)$$

where C_i, m_i – percentage and weight of the i-th fraction.

The interdependence of the fraction components was determined by the formula:

$$C_j = \left(\frac{m_j}{\sum_{j=1}^{k} m_i}\right) \cdot 100\%, \quad (2)$$

where C_j, m_j – percentage and weight of the i-th component

The methodology for determining the size and weight, physical and mechanical parameters of seeds and fruit elements is based on specific conditions of experiments with the development and manufacture of the necessary instruments and devices. Statistical methods of research and mathematical processing are used to distinguish natural changes from random indicators. Selective statistical observation was used to characterise the general population (all seeds of the studied varieties) by discrete variation traits. The extreme values of each observation are denoted as X_{min} AND X_{max}. The total number of samples n for each trait was taken as at least 50. At the same time:

$$n = \sum_{i=1}^{n} l(i). \quad (3)$$

The statistical series of the feature X was divided into a number of classes $N_k = 10$ at $n \geqslant 50$. In this case, the class step:

$$t = \frac{X_{max} - X_{min}}{N_k}. \quad (4)$$

The lower limit of the class:

$$X_{k-1} = X_{min}. \quad (5)$$

The upper limit of the class:

$$X_k = X_{k-1} + t. \quad (6)$$

Relative frequency of observations from any *k*-th class

$$P_k = \frac{n_k}{n}, \quad (7)$$

where n_k – number of variants falling into the *k*-th class.

The results were checked by the expression:

$$\sum_{k=1}^{N} P_k = 1. \quad (8)$$

The average arithmetic value of a feature by class:

$$X_{k.aver} = \frac{(X_{k-1}+X_k)}{2}. \quad (9)$$

The statistical distribution of discrete values was determined:

$$X_a = \sum_{k=1}^{N} X_{k.aver} \cdot P_k. \quad (10)$$

The estimate of the scatter (dispersion) of the values of the random variable *X* around the average statistical value Ha was determined by the formula for the mean square of the deviation (variance) *S*:

$$S = \sum_{k=1}^{N} (X_{k.ch} - X_a)^2 \cdot P_k. \quad (11)$$

To compare the spread of values near the centre of the distribution and a random variable, the standard deviation is calculated σ:

$$\sigma = \sqrt{S}, \quad (12)$$

as well as the coefficient of variation or variability of the trait v:

$$v = (\sigma / X_{aver}) \cdot 100\%. \quad (13)$$

The experience error rate should not exceed 4.0% :

$$\rho = \pm \frac{\sigma}{X_a \cdot \sqrt{n}} \cdot 100\%. \quad (14)$$

In order to determine the dynamic and kinematic parameters of the proposed design solution for a vegetable and melon seed separator, such indicators as the dependence of seed deformation on the applied force, the dependence of elongated testis lengths on the average transverse size, and the dependence of fruit deformation on the applied static and dynamic force are of interest.

For the mathematical description of the studied dependencies, the least squares method was used, followed by a check of the obtained functional dependence for adequacy using Fisher's criterion. The functional dependence $y = f(x)$ of the studied trait was determined at *j* fixed values of the argument, with $j \geq 4$. The repetition of the experiment at each point of the fixed argument value was $n = 5$. Based on the results of the experiments, the average value of the function at each point was calculated, i.e:

$$Y_j = \frac{1}{n} \cdot \sum_{i=1}^{n} Y_{ij}. \quad (15)$$

After that, the Cochrane criterion was determined, which confirms the accuracy of the results. At the next stage of processing the experimental data, it was assumed that the obtained dependence could be described by a first-degree function:

$$Y = ax + b. \quad (16)$$

After that, the adequacy was checked by Fisher's criterion F_k. If the condition $F_{tabl} \geq F_k$ is met, with a given number of degrees of freedom, the hypothesis of adequacy of the description of the studied dependence by the function of the form (92) is accepted with the level of significance recommended for research in agriculture of 0.95. If $F_k \geq F_{tabl}$ the hypothesis of the linear nature of the studied dependence was rejected, its description by the following expression was used with a repeated check of adequacy:

$$Y = a \cdot X^2 + b \cdot X + C \text{ or } Y = a \cdot X^3 + b \cdot X^2 + c \cdot X + d. \quad (17)$$

RESULTS

Figure 1 shows the proposed design solution for a vegetable and melon seed separator. The final cleaning of seeds from impurities is carried out on separate machines that are part of the technological chain after the seed separators.

The technological process of the proposed design solution of the vegetable and melon crop separator is as follows: the fruits are loaded into the hopper 2 of the chopper 3 by a special conveyor. The material crushed by drums 4-5 falls into the screen 10. Seeds, pulp and small equal-sized particles of peel (subgrade product) fall on the surface of the sieve of the second screen 11. Seeds with impurities on its surface are subjected to final cleaning, while other components are sent to the pump 4. The presented design solution provides for the following adjustments: the rotational speed of the cranks and, consequently, the frequency of the screen oscillations was changed by V-belt variators 19-20; the angle of inclination of the sieves was changed by adjusting the lengths of the hinge suspensions 12-13; partitions were made to change the length of the working part of the sieve.

The separator is a system consisting of two screens. The upper screen separates the coarse fraction of the crushed peel, while the lower screen separates the seeds. The remaining fractions, such as pulp, pulp particles and juice, fall into the tray. To reduce seed losses in

the peel fraction, it is advisable to use the inertial separator mode. Additional friction of the material against the edges of the holes in the peel fraction reduces the seed content. The mode of the vibrating conveyor for the second sieve is used to increase the passage of the pulp through the sieve holes.

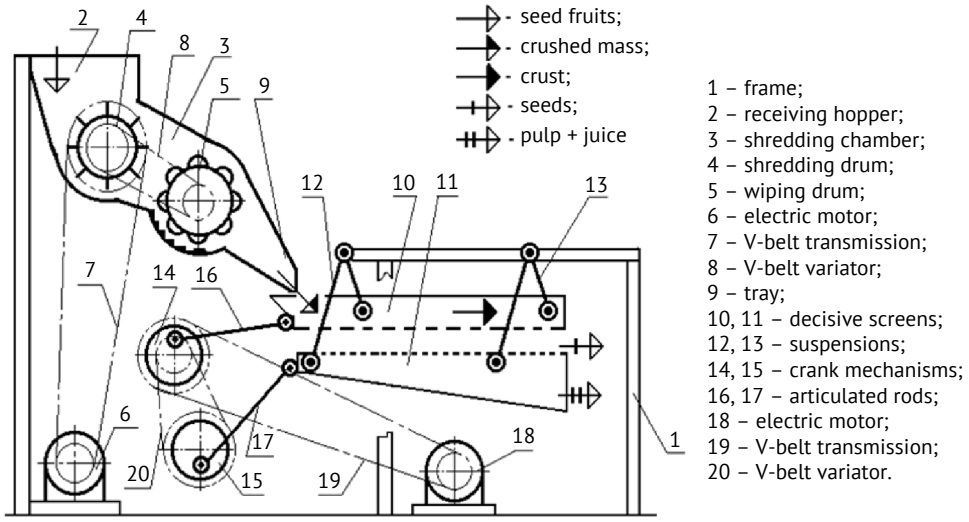


Figure 1. *Proposed design solution for a vegetable and melon crop separator*
Source: *developed by the authors*

To study the nature of the movement of the crushed mass on the surface of the sieves of the vegetable and melon seed separator, it is necessary to analyse the nature of the material movement on sieves that perform inertial and vibratory movement. In the context of analysing the movement of material along an inertial sieve of a separator, Figure 2 shows a general case of seed movement along an inclined plane. The angle of inclination of the sieve plane to the horizon α and the angle of inclination of the vibrations to the sieve plane β are within the limits:

$$\begin{cases} -\frac{1}{2}\cdot\pi \le \alpha \le \frac{1}{2}\cdot\pi \\ 0 \le \beta \le \frac{1}{2}\cdot\pi. \end{cases} \quad (18)$$

Projections of sieve movement $\tilde{\xi}; \tilde{\eta}$ described by the system:

$$\begin{cases} \tilde{\xi} = A\cdot Cos\beta\cdot Sin\omega t \\ \tilde{\eta} = A\cdot Sin\beta\cdot Sin\omega t, \end{cases} \quad (19)$$

where A and ω – oscillation amplitude and frequency.

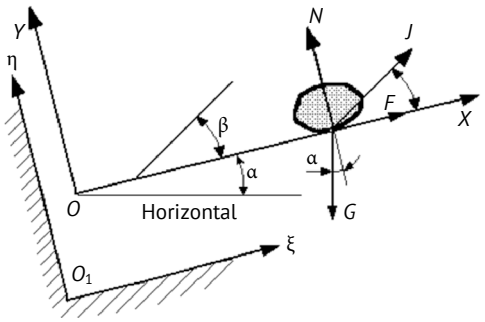


Figure 2. *General case of seed movement on an inclined plane*
Source: *developed by the authors on the basis of theoretical mechanics (Maas, 2017)*

Relative material movement in projections on moving axes:

$$\begin{cases} m\cdot x'' = -m\cdot\xi'' - m\cdot g\cdot Sin\alpha + F \\ m\cdot y'' = -m\cdot\eta'' - m\cdot g\cdot Cos\alpha + N \end{cases}. \quad (20)$$

Substituting into the system of equations the expressions for the projections of the force of inertia *-m ξ"* and *-m η"*, obtained after double differentiation in t equations, the system has the form:

$$\begin{cases} m\cdot x'' = m\cdot A\cdot\omega^2\cdot Cos\beta\cdot Sin\omega t - m\cdot g\cdot Sin\alpha + F \\ m\cdot y'' = m\cdot A\cdot\omega^2\cdot Sin\beta\cdot Sin\omega t - m\cdot g\cdot Cos\alpha + N. \end{cases} \quad (21)$$

The normal reaction is determined:

$$N = N(t) = m \cdot g \cdot Cos\alpha - m \cdot A \cdot \omega^2 \cdot Sin\beta \cdot Sin\omega t. \quad (22)$$

Condition $N(t) > 0$ transforms:

$$Sin\omega t < \frac{g \cdot Cos\alpha}{A \cdot \omega^2 \cdot Sin\beta} = Z_0, \quad (23)$$

or, using the concept of the operating mode factor:

$$G = \frac{A \cdot \omega^2 \cdot Sin\beta}{g \cdot Cos\alpha} \leq 1. \quad (24)$$

The relative equilibrium equation is as follows:

$$F^{(0)} = F^{(0)}(t) = m \cdot g \cdot Sin\alpha - m \cdot A \cdot \omega^2 \cdot Cos\beta \cdot Sin\omega t. \quad (25)$$

The condition of relative calm is represented by:

$$-f_1 \cdot N(t) < F^{(0)}(t) < f_1 \cdot N(t). \quad (26)$$

Transforming the first equation of system (21), the equation of motion of a particle on the sieve surface is obtained:

$$x'' = \frac{d^2x}{dt^2} = -g \cdot \frac{Sin(\alpha \pm \rho)}{Cos\rho} + \\ + A \cdot \omega^2 \cdot \frac{Cos(\beta \mp \rho)}{Cos\rho} \cdot Sin\omega t. \quad (27)$$

Substituting the values of $N(t)$ from (22) and the value of $F^{(0)}(t)$ from (25), is determined along the axis ωt the boundary of the sub-interval of the particle staying on the sieve surface in relative rest:

$$Sin\omega t > Z_{1+}; \quad (28)$$

$$\sigma_1 \cdot (Z_{1-} - Sin\omega t) > 0, \quad (29)$$

where the following designations are introduced:

$$Z_{1\pm} = \frac{g \cdot Sin(\alpha \pm \rho_1)}{A \cdot \omega^2 \cdot Cos(\beta \mp \rho_1)}; \quad (30)$$

$$\sigma_1 = Sign\left[\frac{\pi}{2} - (\beta + \rho_1)\right] = \\ = \begin{cases} 1 & at \quad \beta + \rho_1 < \pi/2 \\ -1 & at \quad \beta + \rho_1 > \frac{\pi}{2}. \end{cases} \quad (31)$$

Then the time limits for the intervals $t = t_+^k$ ($k = 0, 1, 2, ...$) can be determined from the equations:

$$Sin\omega t_+^k = \text{Sin}\delta_+^k = Z_+; \quad (32)$$

$$Sin\omega t_-^k = \text{Sin}\delta_-^k = Z_-, \quad (33)$$

and the condition of continuous motion of the particle on the sieve surface is:

$$Sin\omega t > \frac{g \cdot Cos\alpha}{A \cdot \omega^2 \cdot Sin\beta} = Z_0 > 1. \quad (34)$$

The time limits of the intervals of continuous movement of particles on the surface of the separator sieve are defined as:

$$Sin\omega t_0^k = \text{Sin}\delta_0^k = Z_0. \quad (35)$$

In the following δ_0, δ_+ i δ_- denote the roots of the equations defined by the relations:

$$\begin{cases} \delta_0 = arcSinZ_0 \\ \delta_+ = arcSinZ_+ \\ \delta_- = \begin{cases} \pi - arcSinZ_- & at\ \sigma_1 = 1 \quad i.e.\ at \quad \beta + \rho_1 < \pi/2 \\ arcSinZ_- & at\ \sigma_1 = -1\ i.e.\ at \quad \beta + \rho_1 > \pi/2, \end{cases} \end{cases} \quad (36)$$

where *arcSinZ* means the main value of the function lying in the interval -0.5π...+0.5π. The differential equation is transformed into a more convenient form for further calculations:

$$x'' = \frac{d^2x}{dt^2} = A \cdot \omega^2 \cdot \frac{Cos(\beta \mp \rho)}{Cos\rho} \cdot \\ \cdot \left[Sin\omega t - \frac{g \cdot Sin(\alpha \pm \rho)}{A \cdot \omega^2 \cdot Cos(\beta \mp \rho)}\right], \quad (37)$$

by entering the following notation:

$$\delta = \omega t; \quad (38)$$

$$a_\pm = A \cdot \omega^2 \cdot \frac{Cos(\beta \mp \rho)}{Cos\rho}; \quad (39)$$

$$Z_{1\pm} = \frac{g \cdot Sin(\alpha \pm \rho_1)}{A \cdot \omega^2 \cdot Cos(\beta \mp \rho_1)}. \quad (40)$$

Equation (37) will have the following form:

$$x'' = \frac{d^2x}{dt^2} = a_\pm \cdot (Sin\delta - Z_\pm). \quad (41)$$

The values of sums and angle differences are limited to: $-0.5\pi \leqslant (\alpha \pm \rho) \leqslant 0.5\pi$ and $-0.5\pi \leqslant (\beta \mp \rho) \leqslant 0.5\pi$. Since condition (28) was accepted, the values of the terms of equation (41) will also be limited: $a_\pm > 0$; $Z_+ > 0$; $Z_- < 0$. For positive and negative direction, the phase angles are δ_+' and δ_-', and the phase angles of the end of these motions are respectively δ_+^* and δ_-^*. The particle will slide in the positive direction if the acceleration $x'' = \frac{d^2x}{dt^2} > 0$, i.e. at

$$Sin\delta'_{+} \geqslant Z_{+}, \tag{42}$$

and its sliding in the opposite (negative) direction when the condition:

$$Sin\delta'_{-} \leqslant Z_{-}. \tag{43}$$

The conditions for starting a slip are indicated by:

$$Sin\delta_{0+} = Z_{+} = \frac{g \cdot Sin(\alpha+\rho)}{A \cdot \omega^2 \cdot Cos(\beta-\rho)}; \tag{44}$$

$$Sin\delta_{0-} = Z_{-} = \frac{g \cdot Sin(\alpha-\rho)}{A \cdot \omega^2 \cdot Cos(\beta+\rho)}. \tag{45}$$

If to each of the angles δ_{0+} and δ_{0-} the share was at a relative standstill, meaning that the previous slide had already ended, therefore $\delta'_{+} = \delta_{0+}$ and $\delta'_{-} = \delta_{0-}$. To fulfil this condition, it is necessary that the projections of velocities on the *X*-axis are equal to 0. By integrating the equations of relative motion, the phase angles are determined δ_{0+} and δ_{0-}, the corresponding stopping points for each of the displacements. When integrating, the following relations should be taken into account:

$$\begin{gathered} \delta = \omega t;\ d\delta = \omega \cdot dt; \\ x'' = \frac{d^2x}{dt^2};\ \frac{dx}{dt} = \omega \cdot \frac{dx}{d\delta}. \end{gathered} \tag{46}$$

The first integrals of the equation for the intervals of relative motion of the particle in the positive and negative directions are respectively:

$$\begin{gathered} x' = \frac{dx}{dt} = \frac{a_{+}}{\omega} \cdot \\ \cdot [(Cos\delta_{0+} - Cos\delta) - Z_{+} \cdot (\delta - \delta_{0+})]; \end{gathered} \tag{47}$$

$$\begin{gathered} x' = \frac{dx}{dt} = \frac{a_{-}}{\omega} \cdot \\ \cdot [(Cos\delta_{0-} - Cos\delta) - Z_{-} \cdot (\delta - \delta_{0-})]. \end{gathered} \tag{48}$$

The right-hand sides of these equations go to zero when the sliding stops, i.e., when the angles of δ take the values δ^*_{+} and δ^*_{-}. Therefore,

$$Cos\delta_{0+} - Cos\delta^*_{+} = Z_{+} \cdot (\delta - \delta_{0+}); \tag{49}$$

$$Cos\delta_{0-} - Cos\delta^*_{-} = Z_{-} \cdot (\delta - \delta_{0-}). \tag{50}$$

By solving the transcendental equations, the values of the phase angles δ^*_{+} and δ^*_{-} corresponding to the stopping of the particle when it moves in the positive and negative directions of the *X*-axis are determined. Then for this mode it can be written as:

$$\begin{cases} \delta'_{-} = \delta^*_{+} \\ \delta^*_{-} = 2\pi + \delta'_{-}. \end{cases} \tag{51}$$

Integrating the differential equation (41) within the limits of $x'_0 = 0$:

$$\begin{gathered} x' = \frac{dx}{dt} = \frac{a_{+}}{\omega} \cdot \\ \cdot [(Cos\delta'_{+} - Cos\delta) - Z_{+} \cdot (\delta - \delta'_{+})]. \end{gathered} \tag{52}$$

For the negative direction of motion of the particle, equation (41) is integrated from δ'_{-} to δ:

$$\begin{gathered} x' = \frac{dx}{dt} = \frac{a_{-}}{\omega} \cdot \\ \cdot [(Cos\delta'_{-} - Cos\delta) - Z_{-} \cdot (\delta - \delta'_{-})]. \end{gathered} \tag{53}$$

The moment the slide stops $x'_0 = \frac{dx}{dt} = 0$, the angles δ in equations (52; 53) take, respectively, the values δ and $\delta = \delta^*_{-}$. After substituting these values into equations (52; 53), the equality is obtained:

$$Cos\delta'_{+} - Cos\delta^*_{+} = Z_{+} \cdot (\delta^*_{+} - \delta'_{+}); \tag{54}$$

$$Cos\delta'_{-} - Cos\delta^*_{-} = Z_{-} \cdot (\delta^*_{-} - \delta'_{-}). \tag{55}$$

After substituting the values of δ'_{-} and δ^*_{-} from system (35), the equality is obtained:

$$Cos\delta'_{+} - Cos(2\pi + \delta'_{+}) = Z_{-} \cdot (2\pi + \delta'_{+} - \delta^*_{+}), \tag{56}$$

which in transformed form can be written as follows:

$$Cos\delta'_{+} - Cos\delta^*_{+} = Z_{-} \cdot [(\delta^*_{+} - \delta'_{+}) - 2\pi]. \tag{57}$$

Equating the right-hand sides of equations (38) and (41), the formula is obtained:

$$\delta^*_{+} - \delta' = 2\pi \cdot \frac{\gamma}{\gamma - 1}, \tag{58}$$

where γ is defined by the expression:

$$\gamma = \frac{Z_{-}}{Z_{+}} = \frac{Sin(\alpha-\rho) \cdot Cos(\beta-\rho)}{Cos(\beta+\rho) \cdot Sin(\alpha+\rho)}. \tag{59}$$

The following notation has been introduced:

$$\varepsilon = \frac{\delta^*_{+} - \delta'_{+}}{2} = \pi \cdot \frac{\gamma}{\gamma - 1}. \tag{60}$$

Converting the left-hand side of equation (58) with the expression (60), the following is obtained:

$$2 \cdot Sin\left(\frac{\delta^*_{+} - \delta'_{+}}{2}\right) \cdot Sin\varepsilon = Z_{+} \cdot \varepsilon; \tag{61}$$

$$\frac{\delta^*_{+} - \delta'_{+}}{2} = arcSin\left(\frac{\varepsilon \cdot Z_{+}}{Sin\varepsilon}\right). \tag{62}$$

Provided that $\frac{\delta^*_{+} - \delta'_{+}}{2}$ is an acute angle, then:

$$\frac{\delta^*_{+} - \delta'_{+}}{2} = \pi - arcSin\left(\frac{\varepsilon \cdot Z_{+}}{Sin\varepsilon}\right). \tag{63}$$

Grouping equations (61; 63) into a system and solving it, there will be formulas for determining the phase angles of the beginning and end of the particle's motion in the positive direction along the axis *OX*:

$$\delta'_+ = \left(\pi - arcSin\frac{\varepsilon Z_+}{Sin\varepsilon}\right) - \varepsilon; \quad (64)$$

$$\delta^*_+ = \left(\pi - arcSin\frac{\varepsilon Z_+}{Sin\varepsilon}\right) + \varepsilon. \quad (65)$$

Based on the formulas, the following ratios were formed:

$$Sin\delta'_+ = \frac{\varepsilon \cdot Z_+}{tg\varepsilon} + \sqrt{Sin^2\varepsilon - (\varepsilon \cdot Z_+)^2}; \quad (66)$$

$$Sin\delta^*_+ = \frac{\varepsilon \cdot Z_+}{tg\varepsilon} - \sqrt{Sin^2\varepsilon - (\varepsilon \cdot Z_+)^2}. \quad (67)$$

To determine the magnitude of the particle displacements in the positive and negative directions along the axis *OX* for one period of oscillation, it is necessary to integrate equation (52) in the range from δ'_+ to δ^*_+ and equation (53) within $\delta'_- = \delta^*_+$ to $\delta^*_- = 2 \cdot \pi + \delta'_+$. It is necessary to take into account the relationship (46).

$$x_+ = \frac{a_+}{\omega^2} \cdot \left[(Cos\delta'_+ + Z_+ \cdot \delta'_+) \cdot (\delta^*_+ - \delta'_+) - (Sin\delta'_+ - Sin\delta^*_+) - Z_+ \cdot \frac{(\delta^*_+ - \delta'_+)^2}{2}\right]; \quad (68)$$

$$x_- = \frac{a_-}{\omega^2} \cdot \left[(Cos\delta^*_+ + Z_- \cdot \delta^*_+) \cdot (2\pi + \delta'_+ - \delta^*_+) - (Sin\delta'_+ - Sin\delta^*_+) - Z_- \cdot \frac{(2\pi + \delta'_+ - \delta^*_+)^2}{2}\right]. \quad (69)$$

Taking into account the formulas (23; 24; 41; 44; 47-50), it is determined:

$$x_+ = 2A \cdot \frac{Cos(\beta - \rho)}{Cos\rho} \cdot \left(1 - \frac{\varepsilon}{tg\varepsilon}\right) \cdot \cdot \sqrt{Sin^2\varepsilon - (\varepsilon \cdot Z_+)^2}; \quad (70)$$

$$x_- = 2A \cdot \frac{Cos(\beta + \rho)}{Cos\rho} \cdot \left(1 + \frac{\pi - \varepsilon}{tg\varepsilon}\right) \cdot \cdot \sqrt{Sin^2\varepsilon - (\varepsilon \cdot Z_+)^2}. \quad (71)$$

Average particle velocity:

$$x'_{avr} = \frac{1}{2\pi} \cdot \left(\int_{\delta'_+}^{\delta^*_+} x' d\delta + \int_{\delta'_-}^{\delta^*_-} x' d\delta\right), \quad (72)$$

$$or\ v_{avr} = \frac{x_+ + x_-}{T}, \quad (73)$$

where $T = 2\pi/\omega$.

Substituting (70; 71) into (73), the equation of the average velocity of a particle on an inertial sieve is obtained after transformations:

$$v_{avr} = A \cdot \omega \cdot Cos\beta \cdot Cos\varepsilon \cdot \cdot \left[\frac{2}{\pi} \cdot tg\rho \cdot tg\beta \cdot (tg\varepsilon - \varepsilon + \frac{\pi}{2} - 1\right] \sqrt{1 - \left(\frac{\varepsilon \cdot Z_+}{Sin\varepsilon}\right)}. \quad (74)$$

The theoretical study of the nature of the movement of the crushed mass on the surface of the sieve of a vegetable and melon seed separator can be based on various hypotheses about the impact interaction of a particle with a vibrating working surface: the impact can be considered inelastic, partially elastic, or absolutely elastic. Interactions in the tangential direction can be expressed by the coefficient of instantaneous friction, which is taken from one of the following relations. Usually, the relationship between the velocities before and after the impact of a particle with a vibrating surface is taken from one of the following relations:

$$v_{x+} = \left(\frac{dx}{dt}\right)_+ = (1 - \lambda) \cdot v_{x-} \text{ at } |v_{x-}| < < \left|\frac{f \cdot (v_{y+} - v_{y-})}{\lambda}\right|, (0 \le \lambda \le 1), \quad (75)$$

where v_{x-}; v_{x+} – projection of the particle velocity onto the axis of the *OX,* respectively, before and after the impact; v_{y-}; v_{y+} – projection of the particle velocity on the axis *OY*, respectively, before and after the impact; λ – instantaneous friction coefficient equal to the sliding friction coefficient *f*.

$$v_{x+} = \left(\frac{dx}{dt}\right)_+ = v_{x-} - f' \cdot \cdot \left(v_{y+} - v_{y-}\right) \cdot sign(v_{x-}) \text{ at } |v_{x-}| > > \left|\frac{f \cdot (v_{y+} - v_{y-})}{\lambda}\right|, \quad (76)$$

where f' – impact friction coefficient equal to the sliding friction coefficient.

At the same time, the recovery rate of seeds when they hit the metal surface of the sieve is numerically equal to $R = -\frac{v_{y+}}{v_{y-}}$. In further theoretical analysis, the relation between the particle velocities relative to the sieve plane in the tangential and normal directions is assumed to be λ hypothesis (75).

The differential equations of particle separation at $F \equiv 0$; $N \equiv 0$.

$$x'' = \frac{d^2x}{dt^2} = A \cdot \omega^2 \cdot Cos\beta \cdot Sin\omega t - g \cdot Sin\alpha; \quad (77)$$

$$y'' = \frac{d^2y}{dt^2} = A \cdot \omega^2 \cdot Sin\beta \cdot Cos\omega t - g \cdot Cos\alpha. \quad (78)$$

To obtain a complete system of relations defining the motion of a particle, equations (77) and (78) should be supplemented by equations (75) and (76) defining the law of change of the relative velocity of a particle when it collides with a surface. Since in the steady-state motion the particle systematically hits the vibrating plane, when integrating equations (77) and (78), it is sufficient to assume the initial value of the coordinate

Y is zero, i.e., to consider the flight of the particle starting from the vibrating plane. By placing the origin at the point of the plane from which the particle flight begins $t = t_0^*$, it can be assumed that the *X* coordinate at the training moment is also equal to zero. As a result of integrating equations (77; 78), taking as initial conditions:

$$x(t_0^*) = 0;\ v_{x0}^* = x'(t_0^*) = 0;\ y(t_0^*) = 0;\ v_{y0_y}^* = y'(t_0^*) = 0, \quad (79)$$

where v_{x0}^*; v_{y0}^* – projections of the particle velocity, respectively, on the axes *OX* and *OY*, at the moment of its detachment from the plane at $t = t_0^*$.

The movement of a particle when it is detached:

$$v(t)_x = \frac{dx}{dt} = -A \cdot \omega \cdot Cos\beta \cdot (Cos\omega t - Cos\omega t_0^*) - g \cdot \cdot (t - t_0^*) \cdot Sin\alpha + v_{x0}^* + 1; \quad (80)$$

$$x(t) = -A \cdot Cos\beta \cdot (Sin\omega t - Sin\omega t_0^*) - 0.5 \cdot g \cdot Sin\alpha \cdot \cdot (t - t_0^*)^2 + A \cdot \omega \cdot (t - t_0^*) \cdot Cos\beta \cdot Cos\omega t_0^* + v_{x0}^* \cdot (t - t_0^*); \quad (81)$$

$$v(t)_y = \frac{dy}{dt} = -A \cdot \omega \cdot Sin\beta \cdot (Cos\omega t - Cos\omega t_0^*) - g \cdot \cdot (t - t_0^*) \cdot Cos\alpha + v_{y0}^*; \quad (82)$$

$$y(t) = -A \cdot Sin\beta \cdot (Sin\omega t - Sin\omega t_0^*) - 0.5 \cdot g \cdot Cos\alpha \cdot \cdot (t - t_0^*)^2 + A \cdot \omega \cdot (t - t_0^*) \cdot Sin\beta \cdot Cos\omega t_0^* + v_{y0}^* \cdot (t - t_0^*). \quad (83)$$

It is assumed that when a particle falls on the sieve, both a completely inelastic ($R = 0$) and an elastic impact ($0 \leqslant R \leqslant 1$) are present, and that the particle can be detached from the plane at time t_0^*, which is determined from the condition:

$$Sin\omega t_0 = Z_0 = \frac{g \cdot Cos\alpha}{A \cdot \omega^2 \cdot Sin\beta}, \quad (84)$$

and the moment of particle impact on the plane can belong to any period of oscillations of the plane, depending on the values of the system parameters and the initial conditions of motion. The moment of fall of a particle is determined by:

$$y(t_f) = -A \cdot Sin\beta \cdot (Sin\omega t_f - Sin\omega t_0^*) - 0.5 \cdot g \cdot Cos\alpha \cdot \cdot (t_f - t_0^*) \cdot Sin\beta \cdot Cos\omega t_0^* + v_{y0}^* \cdot (t_f - t_0^*), \quad (85)$$

by converting which can be written as:

$$\frac{Z_0 \cdot (\phi_f - \delta_0^*)^2}{2} + (Sin\phi_f - Sin\delta_0^*) - (\phi_f - \delta_0^*) \cdot (Cos\delta_0^* + \psi) = 0. \quad (86)$$

The following notations are used in the equation:

$$\psi = \frac{v(y_0^*)}{A \cdot \omega \cdot Sin\beta};\ \omega \cdot t_0^* = \delta_0^*;\ \omega \cdot t_f = \phi_f. \quad (87)$$

This equation is transcendental. To solve it graphically, it is necessary to plot in the coordinates $\{\phi = \omega \cdot t;\ O^*;\ y\}$ sinusoid $y = Sin\phi$ and a parabola described by the expression: $y = F(\varphi) = -\frac{Z_0 \cdot (\varphi - \delta_0^*)^2}{2} + (Cos\delta_0^* + \psi) \cdot (\varphi - \delta_0^*) + Sin\delta_0^*$. The root of equation (85) is the abscissa of the intersection of the curves. Conducting transformations of equations (80; 81), similar to the transformations carried out in the derivation of the formulas, an expression for determining the average speed of a particle on the sieve of a separator of vegetable and melon seeds can be obtained:

$$v_{avr} \cong A \cdot \omega \cdot \left(Cos\beta - \frac{2-\lambda}{\lambda} \cdot Sin\beta \cdot tg\alpha\right). \quad (88)$$

Figure 3 shows the interpretation of the detachment of a particle of material from the sieve.

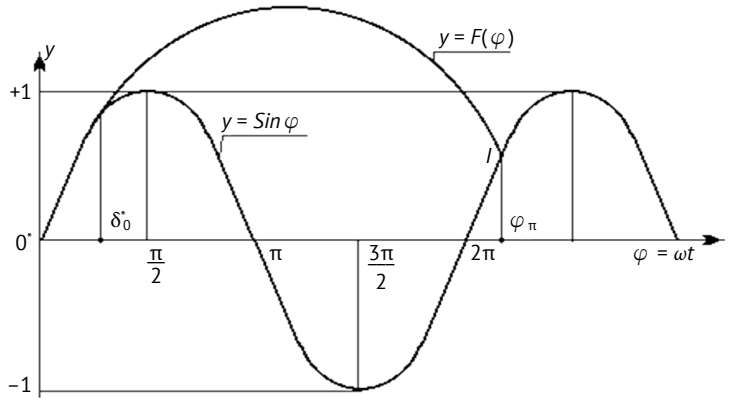


Figure 3. *Interpretation of material particle detachment from the sieve*
Source: *developed by the authors on the basis of theoretical mechanics (Hand & Finch, 2008)*

To determine the kinematic modes of the upper sieve, on which seeds, pulp and pulp are separated from the crust, the expression is transformed to determine the operating mode coefficient and the solution is performed sequentially with respect to *A*; ω; α and β. Taking the operating mode coefficient $G = 0.5$, it turns out:

$$A = \frac{G \cdot g \cdot Cos\alpha}{\omega^2 \cdot Sin\beta};\ \omega = \sqrt{\frac{G \cdot g \cdot Cos\alpha}{A \cdot Sin\beta}};$$
$$\beta = arcSin\left(\frac{G \cdot g \cdot Cos}{A \cdot \omega^2}\alpha\right). \quad (89)$$

Based on the analysis of the mechanical and technological properties of the crushed seed mass (Bortz & Schuster, 2010), analytical dependencies are presented that can be used for practical application. The graphical dependence $A = F(\omega)$ for different modes of operation at different angles of application of forced oscillations β is shown in Figure 4. The region of existence of the mode of particle motion without detachment from the separator surface lies to the left of curves I and II. As can be seen from the graphs, at the angle of force application $\beta = 10°$, the screen oscillation frequency should be at least 25 1/s. Reducing the oscillation frequency less than this value leads to an unjustified increase in the oscillation amplitude and complication of the drive mechanism. In the kinematic mode at an angle of $\beta = 30°$, the oscillation frequency can be in the range of 15...20 1/s, while the oscillation amplitude will not exceed 100 mm.

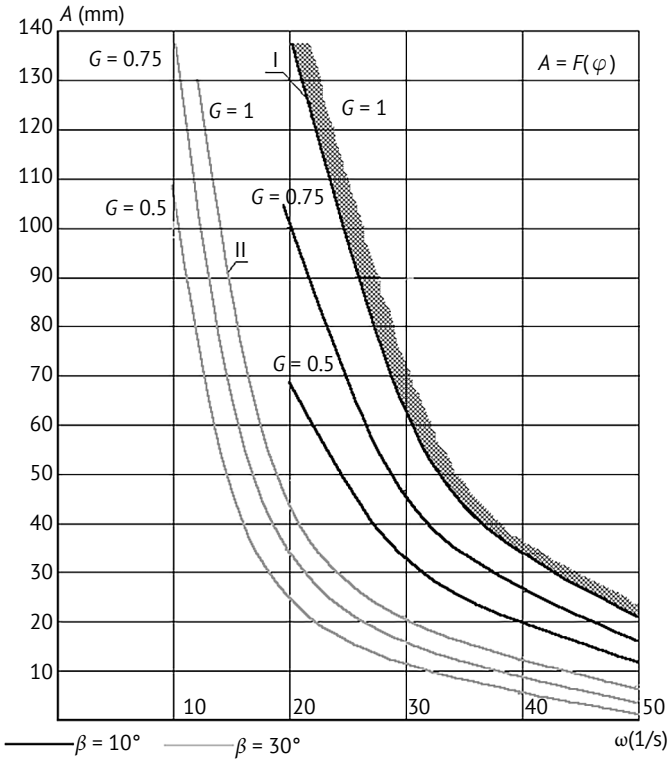


Figure 4. *Functional dependence of oscillation amplitude on oscillation frequency for different separator operating modes*
Source: *developed by the authors*

It is necessary to strive to reduce the amplitude and frequency of oscillations. This reduces the dynamic loads on the drive elements and simplifies the design of the separator. The authors recommend determining the frequency and amplitude of oscillations not separately, but investigating the relationship $A \cdot \omega^2 = F(\beta)$ or:

$$A \cdot \omega^2 = \frac{G \cdot g \cdot Cos\alpha}{Sin\beta}. \quad (90)$$

The graphical interpretation of expression (90) is shown in Figure 5. The zone of existence of the mode of sliding particles without detachment from the plane will also lie to the left of curve I. To determine the average speed of material movement in the technological zone of the separator, use formulas (74) for the upper screen operating in the inertial separator mode and (88) for the lower screen operating in the vibrating separator mode.

The separator capacity is determined by the formula:

$$Q = 3600 \cdot F_0 \cdot \psi\ \ v_{aver} \cdot \gamma, \quad (91)$$

where F_0 – cross-sectional area of the rumble plate; γ – bulk mass of the material; ψ – filling factor.

The drive power for an inertial separator is calculated using the empirical expression:

$$N \approx \frac{4 \cdot 10^{-4} \cdot Q \cdot L}{\eta \cdot tg\beta} \cdot \left(6 \cdot 10^{-4} \cdot \frac{A \cdot \omega^2}{f} + 1\right), \quad (92)$$

and the drive power of the vibrating screen by the formula:

$$N \approx \frac{C \cdot Q}{10^3 \cdot \eta} \cdot k_3 \cdot L, \quad (93)$$

where L – length of the sieve; η – efficiency; C – transportability coefficient; k_3 – coefficient of specific power consumption.

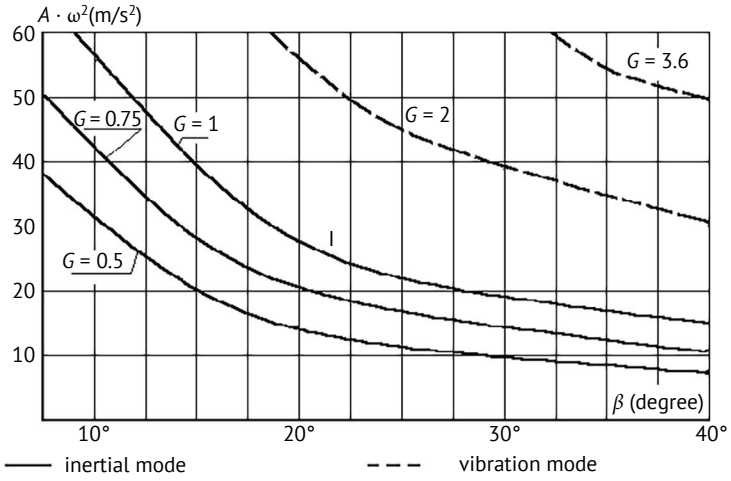


Figure 5. *Dependency graphs*

Source: *developed by the authors*

Based on the theoretical analysis, a methodology was developed for calculating the kinematic and structural parameters of the proposed design solution. The calculation sequence is as follows:

- according to the graph (Fig. 5), the values of the amplitude A and the oscillation frequency ω of the screen and the angle β are selected, with an arbitrary choice of the sieve angle α;
- phase angles of transition δ from one mode of motion to another or from one direction to the opposite are determined;
- determine the maximum speed for each mode, determine the force of interaction between the seeds and the sieve surface;
- calculate the average speed v_{aver}; find the productivity Q, determine the drive power N;
- if the separator capacity Q is specified by regulatory documents (technical specifications or initial requirements for development), the cross-sectional area of the screen F_0 and then its width is determined.

To confirm the effectiveness of the proposed design solution and the feasibility of using the presented analytical dependencies, the selected seeds and peel with pulp were weighed alternately (State Standard of Ukraine DSTU 7160:2020, 2020). The percentage of each component of the crushed mass was determined according to the following dependencies:

$$C = \left(\frac{m_s}{m}\right) \cdot 100\%; \quad C_c = \left(\frac{m_c}{m}\right) \cdot 100\%; \quad C_p = 100\% - (C_s + C_c), \quad (94)$$

where C_s, C_c, C_p – percentage of seeds, crust with pulp and pulp in the obtained material; m_s, m_c – weight of seeds and the weight of crust with pulp in the crushed mass; m is the total weight of crushed seeds. The results are presented in Table 1.

Table 1. *Components of the process mass*

Name of the crop	Components of the process mass, %		
	peel + pulp	seeds	pulp + juice
Cucumber "Konrurent"	41.2	3.8	55.0
Watermelon "Vognyk"	35.0	2.3	62.7
Melon "Kolkhoznitsa"	53.6	3.5	42.9

Source: *developed by the authors on the basis of experimental research*

The percentage of peel in the crushed mass was determined by size group: up to 10 mm, 10-50 mm and over 50 mm using the following formulas:

$$C_{10} = \left(\frac{m_{10}}{m_c}\right) \cdot 100\%; \quad (95)$$

$$C_{50} = \left(\frac{m_{10}}{m_c}\right) \cdot 100\%; \quad (96)$$

$$C_{70} = \left(\frac{m_{10}}{m_c}\right) \cdot 100\%; \quad (97)$$

where m_{10}, m_{50}, m_{70} – mass of peel and pulp of each size group contained in the heap; m_c – total mass of the shredded peel. The results of the study of the components of each of the fractions of the crushed mass are presented in Table 2.

Table 2. *Indicators of the crushed process mass*

Culture	Crushed peel, %			The seed bound to the pulp and crust, %	Injured seeds, %	Seeds, %
	till 10 mm	10-70 mm	more than 70 mm			
Cucumber	12	37	21	7.5	0.5	92.0
Melon	11	53	36	2.4	0.35	97.25
Watermelon	11	57	32	6.6	0.4	93.0

Source: *developed by the authors on the basis of experimental research*

In the process of studying the mechanical and technological properties of the crushed mass of seeds, the friction properties of the peel of vegetable and melon crops were also studied. The values of the friction angles of the peel on the following three surfaces were determined: rubber, metal and sieve plates. Rubber, metal and sieve plates were chosen as friction surfaces. When studying the sliding friction of crushed crust particles, the latter were placed on an inclined plane of the device with a sample of the material under study fixed on it. The inclined plane was raised to the an , at which the particles began to move. The sliding friction coefficient f was determined by the formula:

$$f = tg(\varphi). \quad (98)$$

The replication of the experiments for cucumber variety "Konkurent", watermelon variety "Ogonyok", melon variety "Kolkhoznitsa" was a hundred times, the angles and sliding coefficients of the peel particles from the studied materials are presented in Table 3.

Table 3. *Sliding angles and coefficients of friction of crushed peel*

Friction surface material	Variety of crops under study					
	Cucumber		Melon		Watermelon	
	friction angle	friction coefficient	friction angle	friction coefficient	friction angle	friction coefficient
Rubber plate	24°78'	0.53	22°16'	0.41	22° 59'	0.42
Metal plate	18°46'	0.34	19°57'	0.36	19°29'	0.35
Sieve cloth	19°41'	0.36	21°17'	0.39	21°22'	0.37

Source: *developed by the authors on the basis of experimental research*

The presented research results indicate that the mechanical and technological parameters of the components of the crushed technological mass, namely the ratio of the components of the crushed mass and the indicators of the crushed technological mass, are within the normal range. The use of the proposed design solution and regulation of its modes in accordance with the presented dependences of the amplitude of oscillations on the frequency of oscillations for different modes of operation of the separator and determination of the average speed of material movement in the technological zone of the separator for the upper screen operating in the mode of an inertial separator and for the lower screen operating in the mode of a vibrating separator is advisable.

DISCUSSION

The development of vegetable and melon seed production requires the introduction of industrial models of machines designed for complex mechanisation and automation of production processes. Improvement and development of the seed production industry will help to ensure that agricultural production is supplied with seeds of its own production, which will significantly reduce costs and increase productivity in the industry. Producers of melons and gourds will be able to reduce the cost of production of these crops if they produce their own seeds.

Vibrating machines are widely used to separate seeds of vegetable and melon crops. The study of modelling the sieving of crops at different vibration amplitudes, frequencies and angles is presented (Chen & Yan, 2019). The results show that the angle of deviation of the vibration direction has little effect on the sieving efficiency. Under the influence of other parameters, the sieving efficiency first increases and then decreases. After comparing the data, the best combination of sieving parameters was obtained with an amplitude of 4 mm, a

vibration frequency of 13 Hz, a sieve angle of 8° and a vibration direction angle (angle between the vibration line and the *Z*-axis) of 0°. The combination of vibration and inertial motion, as in the case of the proposed design solution, has a positive effect on the quantitative and qualitative indicators of seed separation.

A study has been conducted on the practical application of unbalanced vibration drives in adjustable drives of vibrating sieves (Despotovic *et al.,* 2019). For synchronous operation of vibration drives, frequency control of their exciting force is required, as well as operation of vibrating screens in the so-called "superresonant" mode. This study presents an experiment to determine the amplitude-frequency characteristics of vibrating screens, as well as the most important experimental results obtained under real operating conditions. The design solution proposed by the authors and the use of graphs to optimise its design and operating parameters allow increasing the seed yield and reducing its losses.

Z. Kaliniewicz *et al*. (2021) evaluated the relationships between the main physical properties of seeds of selected species for seed sorting purposes. Physical properties were measured in seeds of five species, and the existence of relationships between these traits was determined using correlation and regression analyses. Seeds should be separated on a sieve equipped with at least two mesh screens with holes. The study emphasises the need for technical means for post-harvest processing on farms, with vibration equipment being particularly effective. The use of the proposed design solution provides not only the use of the properties of vibrating machines, but also additional work in the inertial mode, which ensures high quality seed separation.

The authors M. Ohienko *et al*. (2010) proposed the design of an inclined rotary separator with an irrigation device located on the axis of rotation of the drum. The inclined rotary separator for refining the technological seed mass of vegetable and melon crops consists of a frame, an electric motor, a worm gearbox, a cylindrical mesh drum, a sprinkler, a loading and unloading tray, which differs in that to improve the process of passing seeds through the holes of the drum and removing them outside the machine, it has an irrigation device mounted in the axis of rotation of the drum. The purpose of the utility model is to further separate the seeds on the rotary separator during the passage of the crushed mass along the inner surface of the rotating mesh drum. The peculiarity of the separator is that it can be used as the first in the flow line for refining the processed mass. The proposed design solution is an independent machine for the main operation of separating seeds of vegetable and melon crops, and not as a machine for refining.

The methodology for modelling the technology of processing the seed mass of vegetable and melon crops can be used to determine the optimal values of the design and operating parameters of seed separators (Shebanin *et al.,* 2019). The researchers presented a solution to the problem of predicting seed characteristics using the tested method. The optimisation criteria were seed loss and purity of the resulting material. However, the machine used for the experiment was a pressurising machine, which has a lower quality of seed separation compared to vibrating equipment. In addition, mathematical modelling of the technological process is time-consuming and allows modelling only for a certain sample of varieties of vegetable and melon crops and does not allow predicting the results, unlike the proposed study of the movement of the technological mass of vegetable and melon seeds, which makes it possible to predict the results to some extent and choose the optimal operating modes of the separator using the proposed graphs.

The analysis of trends in the models and types of equipment used for different breeding volumes of vegetable and melon seed production in the southern region of Ukraine shows that the existing equipment for seed selection of vegetable and melon crops in Ukraine is energy inefficient. Significant amounts of seeds are damaged or lost during the selection process. When obtaining seeds of vegetable and melon crops, there are no methods of their analysis, synthesis and optimisation adapted to the systems of complex mechanisation. A. Pastushenko (2021) proposed the analysis and optimisation of technical systems for the integrated mechanisation of vegetable and melon seeds production using graph theory methods, constructed information and flow charts and incident matrices for a prototype production line for processing fruit seeds and producing vegetable and melon seeds. By varying the schematic solutions and/or different variants of the layout of system elements, structural elements and the distance between them, it is possible to determine the optimal technological line, in accordance with a pre-selected optimisation criterion. An algorithm for optimising the system is proposed, which establishes the procedure for calculating mathematical models and its individual elements. The efficiency criteria can be economic, energy, technological or other characteristics of the system. The proposed methodology is effective for determining the optimal combination of equipment for a technological line, but it is not adapted to determine the operating parameters of specific samples and equipment that complete the technological line. It has been determined that the disadvantages of vegetable and melon separators include a significant percentage

of injured seeds and loss of conditioned seeds, which can be avoided by predicting the technological process and adjusting the equipment. It can also be noted that there is a need to improve the methods of optimising the mechanisation of this technological process.

The experimental studies in this article allowed to optimise the sieve angle α, the amplitude A and frequency of oscillations ω, the length L and the angle of application of forced oscillations β. The surface of the material has a negligible effect on the sliding friction coefficient. The advantage of using the proposed design solution of the separator is the combination of inertial and vibrational motion of the sieves, as evidenced by the experimental data obtained on the basis of the mechanical and technological properties of the selected samples.

CONCLUSIONS

Theoretical studies have made it possible to identify the main factors influencing the technological process and to obtain analytical dependencies for calculating the amplitude, oscillation frequency, angle of forced oscillations, material movement speed, drive performance and power. The graph-analytical method of studying kinematic modes made it possible to determine the zones of existence of different modes of inertial and vibratory separator screens. Laboratory studies of the mechanical and technological properties of the technological mass made it possible to conclude that it is expedient to separate seeds using the proposed design solution. As a result of statistical data processing, it was determined that the percentage composition of the components of the technological mass depends on the crop and variety. The optimal values of the content of seeds, pulp, peel and juice are presented. The values of the coefficients of friction of the crushed peel can be used in further calculations of the modes of technological equipment.

The obtained theoretical dependences fully characterise the technological process of seed cleaning from pulp, pulp and hull on a two-screen separator with different kinematic modes of each sieve. However, it is necessary to take into account the value of the friction coefficient (friction angle) for both the crust and the freshly separated seeds, the data on the value of which are not available. The absence of data on the mechanical and technological characteristics of seeds and crushed mass does not allow using the obtained dependencies in further practical engineering calculations. To determine their values, it is necessary to conduct additional experimental studies of the physical and mechanical characteristics and dimensional and mass parameters of various components of the crushed mass of seed fruits.

Determination of the size and weight characteristics of seed fruits of a particular crop does not affect the degree of crushing and the mechanical and technological parameters of the crushed mass. The degree of grinding depends only on the design of the impactor and the crop being processed. The size and weight characteristics of the seeds allow to conclude that they can be separated from impurities by the principle of differentiation by seed length. However, it is not possible to use the same type of sieves for all studied crops. Therefore, the prospects for further research are to determine the geometry of the sieve openings and seed resistance to static and dynamic (impact) loads and the effect of the kinematic parameters of the separator on the seed injury parameter.

ACKNOWLEDGEMENTS

None.

CONFLICT OF INTEREST

None.

REFERENCES

[1] Bortz, J., & Schuster, C. (2010). *Statistics for human and social scientists*. Retrieved from https://link.springer.com/book/10.1007/978-3-642-12770-0.

[2] Chen, G., & Yan, J. (2019). Study on sieving efficiency of wet corn granules in linear vibration mode. In *2019 International conference on artificial intelligence and advanced manufacturing (AIAM)* (pp. 583-587). doi: 10.1109/AIAM48774.2019.00121.

[3] Despotovic, Z.V., Pavlovic, A.M., & Ivanic, D. (2019). Exciting force frequency control of unbalanced vibratory actuators. In *2019 20th International symposium on power electronics (Ee)* (pp.1-6). doi:10.1109/PEE.2019.8923574.

[4] Dobrzanski, B., & Stepniewski, A. (2013). Physical properties of seeds in technological processes. In S. Grundas, & A. Stepniewski (Eds.), *Advances in agrophysical research*. London: IntechOpen. doi: 10.5772/56874.

[5] Erniati, Suhardiyanto, H., Hasbullah, R., & Supriyanto. (2022). Artificial neural network models to estimate growth of melon (Cucumis melo L.) at vegetative phase in greenhouse with evaporative cooling. *IOP Conference Series: Earth and Environmental Science*, 1038, 012011. doi: 10.1088/1755-1315/1038/1/012011.

[6] Fayzullaev, K., Mamatov, F., Mirzaev, B., Irgashev, D., Mustapakulov, S., & Sodikov, A. (2021). Study on mechanisms of tillage for melon cultivation under the film. *E3S Web of Conferences*, 304, 03012. doi: 10.1051/e3sconf/202130403012.

[7] Gutyj, B., Hachak, Y., Vavrysevych, J., & Nagovska, V. (2017). The influence of cryopowder "Garbuz" on the technology of curds of different fat content. *Eastern-European Journal of Enterprise Technologies*, 2(10(86)), 20-24. doi: 10.15587/1729-4061.2017.98194.
[8] Hand, L.N., & Finch, J.D. (2008). *Analytical mechanics*. Cambridge: Cambridge University Press. Retrieved from http://assets.cambridge.org/97805215/73276/frontmatter/9780521573276_frontmatter.pdf.
[9] Kale, S., Matthäus, B., Aljuhaimi, F., Ahmed, I.A.M., Özcan, M.M., Ghafoor, K., ... Alqah, H.A.S. (2020). A comparative study of the properties of 10 variety melon seeds and seed oils. *Journal of Food Processing and Preservation*, 44(6), e14463. doi: 10.1111/jfpp.14463.
[10] Kaletnik, G., Tsurkan, O., Rimar, T., & Stanislavchuk, O. (2020). Determination of the kinetics of the process of pumpkin seeds vibrational convective drying. *Eastern-European Journal of Enterprise Technologies*, 1(8(103)), 50-57. doi: 10.15587/1729-4061.2020.195203.
[11] Kaletnik, G.M., & Yanovych, V.P. (2017). Justification of operating parameters of the vibrating machine for mixing loose masses. *Design, Production and Operation of Agricultural Machines*, 47(1), 91-98. Retrieved from http://dspace.kntu.kr.ua/jspui/bitstream/123456789/7635/1/Z_47_1_2017-91-98.pdf.
[12] Kaliniewicz, Z., Anders, A., Markowski, P., Tylek, P., & Owoc, D. (2021). Analysis of the physical properties of spindle seeds for seed sorting operations. *Scientific Reports*, 11, 13625. doi: 10.1038/s41598-021-93166-z.
[13] Kotov, B., Spirin, A., Kalinichenko, R., Bandura, V., Polievoda, Y., & Tverdokhlib, I. (2019). Determination the parameters and modes of new heliocollectors constructions work for drying grain and vegetable raw material by active ventilation. *Research in Agricultural Engineering*, 65(1), 20-24. doi: 10.17221/73/2017-RAE.
[14] Kuchakorn, K., Phopirom, C., & Yoiyod, P. (2021). Watermelon meter for classifying mature fruit. In *2021 9th International electrical engineering congress (iEECON)* (pp. 1-3). doi: 10.1109/iEECON51072.2021.9440234.
[15] Lanczos, C. (1986). *The variational principles of mechanics* (4th ed.). New York: Dover Publications Inc.
[16] Lee, J.M., Kubota, C., Tsao, S.J., Bie, Z., Echevarria, P.H., Morra, L., & Oda, M. (2010). Current status of vegetable grafting: Diffusion grafting techniques automation. *Scientia Horticulturae*, 127(2), 93-105. doi: 10.1016/j.scienta.2010.08.003.
[17] Lerner, R.G., & Trigg, G.L. (1991). *Encyclopedia of physics* (2nd ed.). Weinheim: VHC publishers. Retrieved from https://www.abebooks.com/Encyclopedia-Physics-2nd-Edition-Lerner-Rita/59462375/bd.
[18] Lymar, A.O., & Lymar, V.A. (2012). *Vegetable growing of Ukraine*. Mykolaiv: Mykolaiv National Agrarian University.
[19] Maas, A. (2017). *Theoretical mechanics. Lecture in WS 2016/17 at the KFU Graz*. Retrieved from https://www.academia.edu/35573618/Theoretical_Mechanics_Lecture_in_WS_2016_17_at_the_KFU_Graz.
[20] Mazuela, P., & Urrestarazu, M. (2009). The effect of amendment of vegetable waste compost used as substrate in soilless culture on yield and quality of melon crops. *Compost Science & Utilization*, 17, 103-107. doi: 10.1080/1065657X.2009.10702408.
[21] Mukhopadhyay, K., Paramanik, S.J., Samanta, M.K., Debnath, M., Kundu, M.K., Saha, S., ... Datta, A. (2021). *Organic vegetable seed production*. doi: 10.13140/RG.2.2.24563.45601.
[22] Nascimento, W.M. (2002). Primed melon seeds: Are they worth using? *Horticultura Brasileira*, 20(2), 133-135. Retrieved from https://www.researchgate.net/publication/262555584_Primed_melon_seeds_are_they_worth_using.
[23] Ohienko, M.M., Pastushenko, S.I., Horbenko, O.A., & Dumenko, K.M. (2010). *Inclined rotary separator for final treatment of technological seed mass of vegetable and melon crops. Patent No. 55613*. Retrieved from https://uapatents.com/2-55613-pokhilijj-rotornijj-separator-dlya-dorobki-tekhnologichno-nasinnehvo-masi-ovoche-bashtannikh-kultur.html.
[24] Osuji, C., Uche, C., Iheagwara, M., Ofoedu, C., Omeire, G., Nwakaudu, A., & Ozumba, I. (2023). The effect of mechanized shelling and packaging on the quality of melon seeds. *Potravinarstvo Slovak Journal of Food Sciences*, 17, 565-580. doi: 10.5219/1884.
[25] Pastushenko, A.S. (2021). Fundamentals of line analysis and optimization to obtain seeds of melons. *Engineering of Nature Management*, 1(19), 48-56. doi: 10.37700/enm.2021.1(19).48.
[26] Shablya, O.S., & Kholodnyak, O.G. (2022). Marketing principles for promoting varieties of melon crops in Ukraine. *Vegetable and Melon Growing*, 70, 125-135. doi: 10.32717/0131-0062-2021-70-125-135.
[27] Shebanin, V., Atamanyuk, I., Gorbenko, O., Kondratenko, Y., & Dotsenko, N. (2019). Mathematical modelling of the technology of processing the seed mass of vegetables and melons. *Food Science and Technology*, 13(3), 118-126. doi: 10.15673/fst.v13i3.1480.

[28] Stanislavchuk, O.V., Tsurkan, O.V., Gerasimov, O.O., Polyevoda, Y.A., Tverdokhlib, I.V., & Rimar, T.I. (2017). Kinetic features of vibrating and filtration dewatering of fresh-peeled pumpkin seeds. *INMATEH - Agricultural Engineering*, 52(2), 69-76. Retrieved from https://sci.ldubgd.edu.ua/handle/123456789/4429.

[29] State Standard of Ukraine DSTU 7160:2020 "Seeds of vegetable, melon, fodder and spice and aromatic crops. Varietal and sowing qualities. Technical specifications". (2020, July). Retrieved from http://online.budstandart.com/ua/catalog/doc-page.html?id_doc=90394.

[30] State Standard of Ukraine DSTU 8439:2015 "Seeds of vegetable and melon plants and fodder roots. Documentation". (2015, September). Retrieved from http://online.budstandart.com/ua/catalog/doc-page?id_doc=80194.

[31] Tang, M., Zhu, J.-H., Ren, J., Shi, X.-F., & Peng, J.-G. (2014). Primary study on physical properties of some vegetable seeds. In *2014 IEEE workshop on advanced research and technology in industry applications (WARTIA)* (pp. 806-808). doi: 10.1109/WARTIA.2014.6976394.

[32] Tlevlessova, D., Medvedkov, Y., Kairbayeva, A., & Nazymbekova, A. (2023). Mechanisation of the primary processing of watermelons without destroying the rind. *Food Science and Technology*, 43, e86622. doi: 10.1590/fst.86622.

[33] Tsurkan, O.V., Gerasimov, O.O., Polyevoda, Y.A., Ryman, T.I., & Stanislavchuk, O.V. (2015). Generalisation of the kinetics of the first period of filtration dehydration of freshly peeled pumpkin seeds with vibration-pneumatic activation. *Scientific Papers of the National University of Food Technologies*, 21(2), 151-159. Retrieved from http://www.irbis-nbuv.gov.ua/.

[34] Wahyudi, A., Nazirwan, Kartahadimaja, J., Setyawan, A.B., Mustakim, N.A., Askhary, F.A., & Katfar, B.J. (2022). Evaluation of yields on new varieties of hybrid watermelon. *IOP Conference Series: Earth and Environmental Science*, 1012, 012070. doi: 10.1088/1755-1315/1012/1/012070.

[35] Zayachuk, M. (2012). *The current state and prospects for the development of vegetable growing in Ukraine*. Retrieved from https://www.researchgate.net/publication/354653238_SUCASNIJ_STAN_TA_PERSPEKTIVI_ROZVITKU_OVOCIVNICTVA_V_UKRAINI.

Дослідження характеру руху подрібненої маси по поверхні решіт сепаратора насіння овочевих та баштанних культур

Дмитро Володимирович Бабенко
Кандидат технічних наук, професор
Миколаївський національний аграрний університет
54008, вул. Георгія Ґонґадзе, 9, м. Миколаїв, Україна
https://orcid.org/0000-0003-2239-4832

Наталія Андріївна Доценко
Доктор педагогічних наук, доцент
Миколаївський національний аграрний університет
54008, вул. Георгія Ґонґадзе, 9, м. Миколаїв, Україна
https://orcid.org/0000-0003-1050-8193

Олена Андріївна Горбенко
Кандидат технічних наук, доцент
Миколаївський національний аграрний університет
54008, вул. Георгія Ґонґадзе, 9, м. Миколаїв, Україна
https://orcid.org/0000-0001-6006-6931

Ілона Вікторівна Бацуровська
Доктор педагогічних наук, доцент
Миколаївський національний аграрний університет
54008, вул. Георгія Ґонґадзе, 9, м. Миколаїв, Україна
https://orcid.org/0000-0002-8407-4984

Анотація. Вдосконалення обладнання для переробки овочевої та баштанної культур потребує проведення досліджень характеру руху подрібненої маси для зменшення травмування матеріалу та отримання якісного насіння, що дозволить перевести галузь овоче-баштанництва на новий рівень розвитку. Метою дослідження є аналіз характеру руху подрібненої маси по поверхні решіт сепаратора насіння овочевих та баштанних культур. Обґрунтування характеру руху подрібненої маси по поверхні решіт запропонованого конструктивного рішення виконувалося на базі використання методів фізики, теоретичної механіки та аналізу і дослідження фізико-механічних характеристик технологічної маси. В якості базової конструкції для дослідження використовувався сепаратор овочевих та баштанних культур, особливістю якого є застосування двогрохотної системи решіт. В наведеній системі верхнє решето виконує виділення кірки, а нижнє – насіння та мезги; м'якоть і сік будуть підґратним продуктом другого решета. Решето, що виконує інерційний рух, сприяє вилученню пов'язаного з кіркою насіння. В результаті досліджень представлена функціональна залежність амплітуди коливань від частоти коливань для різних режимів роботи сепаратора. Для визначення середньої швидкості руху матеріалу в технологічній зоні сепаратора надані формули для верхнього грохоту, що працює в режимі інерційного сепаратора і для нижнього грохоту, який працює в режимі вібросепаратора. В контексті вищевказаних особливостей запропонованого конструктивного рішення проведене дослідження характеру руху подрібненої маси по поверхні інерційного та вібраційного решіт. В ході теоретичних розрахунків отримано залежності для визначення середньої швидкості частинки в робочій зоні зазначених решіт. На підставі теоретичного аналізу була розроблена методика розрахунку основних параметрів двогрохотного сепаратора. Здійснено визначення механіко-технологічних властивостей насіння овочевих та баштанних культур виділеного за допомогою запропонованого конструктивного рішення. В лабораторних умовах було проведено дослідження складу компонентів виділеної насіннєвої маси і їх аналіз, який свідчить про доцільність застосування запропонованого конструктивного рішення сепаратора овочевих та баштанних культур та застосування на практиці отриманих теоретичних залежностей для регулювання його технологічних параметрів

Ключові слова: інерційний сепаратор; вібраційний сепаратор; механіко-технологічні властивості; рух частинки

UDC: 60:636.2-027.36
DOI: 10.56407/bs.agrarian/4.2023.36

Ukrainian Black Sea Region Agrarian Science
Vol. 27, No. 4

Biotechnology of regulation of reproductive functions of *Bos primigenius taurus*

Michael Gill*
Doctor of Agriculture, Professor
Mykolaiv National Agrarian University
54008, 9 Georgiy Gongadze Str., Mykolaiv, Ukraine
https://orcid.org/0000-0001-7353-9865

Olena Karatieieva
PhD in Agriculture, Associate Professor
Mykolaiv National Agrarian University
54008, 9 Georgiy Gongadze Str., Mykolaiv, Ukraine
https://orcid.org/0000-0002-0652-1240

Mykhailo Tymofiiv
Senior Lecturer
Mykolaiv National Agrarian University
54008, 9 Georgiy Gongadze Str., Mykolaiv, Ukraine
https://orcid.org/0009-0001-5920-9971

Abstract. Since cattle are biologically capable of giving birth to only one calf per year, they are considered a single-fruited animal species. One of the cardinal methods of solving the problem of accelerated reproduction of livestock is biotechnological regulation of reproductive function in cows and synchronisation of their sexual activity. The aim of the study is to investigate the peculiarities of the reproductive function of Red Steppe cows under the influence of various methods of its regulation using modern hormonal agents. To evaluate the reproductive function of cows, generally accepted zootechnical methods were used, methods of variation statistics were used to calculate data, and biotechnological methods were used to regulate sexual activity in cows. Based on the analysis of the state of reproduction of the cattle herd, it was established that 164-187 cows and 85-96 heifers are artificially inseminated annually, which ensures the yield of calves per 100 cows of 89-91 heads and the annual introduction of 36 to 40 first-born calves per 100 cows. The shortened service period contributes to both a higher calf yield and an increase in milk yield, which is a desirable production effect. However, calving to conception interval, necessary to prepare the cow's body for a new insemination, can be reduced to at least 30 days. Insemination of heifers with artificial insemination devices should be started when they reach a live weight of 314 ± 6.5 kg, which will allow to obtain fertility from the first insemination at the level of 73.7-77.8% and thereby prevent obesity of heifers, which mainly reduces the percentage of fertility from the first insemination. It is necessary to establish obstetric and gynaecological examinations and treatment of problematic replacement heifers and cows, and it is advisable to use prostaglandin $F_{2\alpha}$ analogues in combination with vitamins or biologically active drugs to stimulate the sexual function of cows and heifers. The

Article's History:
Received: 20.08.2023
Revised: 29.10.2023
Accepted: 12.12.2023

Suggested Citation:
Gill, M., Karatieieva, O., & Tymofiiv, M. (2023). Biotechnology of regulation of reproductive functions of *Bos primigenius taurust. Ukrainian Black Sea Region Agrarian Science*, 27(4), 36-51. doi: 10.56407/bs.agrarian/4.2023.36.

*Corresponding author

use of prophylactic drugs will help to synchronise the heifers' sexual desire and increase their fertility during insemination. And the organisation of cattle reproduction and the proposed biotechnological ways to improve artificial insemination of the red steppe breed breeding stock will significantly improve their reproductive status, which will increase the overall economic efficiency of the industry

Keywords: prostaglandins; sexual desire; service period; insemination index; dry period; artificial insemination

INTRODUCTION

Modern livestock farming, including cattle breeding, requires intensive reproduction, which is impossible without stimulating and synchronising the sexual function of heifers and cows for the full operation of the industry, i.e. obtaining one calf per year and planned predictable artificial insemination. Therefore, improving methods to maximise the reproductive potential of females requires a comprehensive understanding of the processes that control follicle development (Melnik *et al.*, 2022).

Various strategies and biotechnological techniques are used to achieve optimal reproductive function or reproductive health management. Although exogenous agonists of human chorionic gonadotropin (HCG) and gonadotropin-releasing hormone (GnRH) (A) are commonly used to trigger ovulation during estrous cycle synchronisation, little is known about their effects on the ovarian follicle (Ziecik *et al.*, 2021).

According to A. Abbara *et al.* (2018a), even an accurate estrus timing does not compensate for the variability of the interval between its onset and the actual time of ovulation. Hormonal treatment has been used by the authors in various studies to control the reproductive functions of cows and heifers, which allows overcoming this problem and synchronising ovulation. Follicle recruitment and atresia are important processes associated with the rate of ovulation in cattle. Follicle-stimulating hormone (FSH) regulates the distribution, differentiation and steroidogenic function of granulosa cells and thus has a significant impact on follicle growth and development. Although local factors such as growth factors and steroid hormones can regulate follicular development by controlling gonadotropin receptor expression or modulating other related processes, the dominant role of FSH cannot be ignored (Abbara *et al.*, 2018b).

According to M. Besbaci *et al.* (2020), one of the strategies to improve bovine fertility is the administration of GnRH or hCG during the luteal phase, which increases progesterone (P4) secretion and slows luteolysis. P4 insufficiency is associated with a decrease in the number of pregnancies per AI (P/AI), abnormally early embryo development, and reduced maternal pregnancy recognition signalling. The authors also found that by inducing luteolysis in cows with PG $F_{2\alpha}$-sensitive CL and subsequent treatment with exogenous P4 at subluteal concentrations, treatments 2 and 3 induced follicular persistence in a large proportion of cyclical cows.

Programmes for hormonal control of the estrous cycle of cattle were used by R.C. Bonacker *et al.* (2020) for the widespread use of reproductive technologies such as fixed-time artificial insemination (FTAI) in beef and dairy cattle. For example, scientists demonstrate an approach to stimulating follicular maturity by administering PG $F_{2\alpha}$ and treating with a CIDR insert for seven days before GnRH administration. Similar studies were conducted by E.M. Cabrera *et al.* (2021). Holstein cows during lactation were subjected to a double diagnosis (DO) procedure for the first artificial insemination (TAI) after an independence period of 73 days. The researchers concluded that administration of a dose of hCG ⩾ 2000 IU induced a greater ovulatory response in lactating Holstein cows than 100 μg GnRH or 1000 IU hCG and resulted in the greatest quantitative increase in plasma P4 concentration between 7 and 14 days.

Therefore, the purpose of the research was to use biotechnological methods to regulate the reproductive function of *Bos primigenius taurus* females using new generation hormonal drugs, which will have a positive impact on reproduction management in lactating dairy cows and will allow artificial insemination at a certain time of ovulation and eliminate the need to detect estrus.

LITERATURE REVIEW

The difficult economic and social situation in the livestock sector poses great challenges for agricultural workers to further ensure a sustainable increase in livestock production (Gonchar & Sotnichenko, 2015; Pidpala *et al.*, 2018). One of the aspects of such tasks is the use of biotechnological solutions to increase the reproductive capacity of animals (Bezuhlyi, 2002; Kamenska, 2013; Kruglyak, 2016).

According to M.P. Zhuravel & M.V. Davydenko (2005), in order to obtain calves from cows every 10.5 months and thus have a yield of 110-115 calves per 100 cows, it is necessary to use the potential fertility of animals wisely – with the use of biotechnological solutions – to ensure high organisation of their reproduction. Such

intensification of reproduction allows to increase calf yield by at least 10-15%, increase milk productivity of each cow by an average of 250-300 kg of milk per year, and extend the life of animals, which is confirmed by a number of scientists (Ponomarenko, 2005; Ugnivenko & Demchuk, 2018; Fedorovych, 2019).

According to I.V. Ponomarenko (2005), the constant growth of livestock and animal productivity is closely related to the state of the reproductive function of the breeding stock. The presence of pathological processes both in the reproductive apparatus and in the whole organism complicates the fertilisation processes, leads to changes in the reproductive function of animals, an increase in infertility, and the percentage of infertile cows in the structure of the animal herd, which reduces the level of profitability of milk production, increases milk production costs, and increases its cost (Ostashko, 1995; Zvierieva *et al.*, 2001).

According to V.F. Stakhovsky (2009) and O.V. Kruglyak (2016), the main task in cow reproduction is to intensify the reproductive function of cows, including biotechnological solutions, prevention and elimination of infertility. Improvement of breeding decisions in the use of biotechnological products is also reflected in the studies of V.M. Chukhriy *et al.* (1998), V.M. Nadtochiy *et al.* (2011), G.P. Gryshchuk (2012). At the same time, the use of artificial insemination of the breeding stock of cows is proposed by V.V. Vechorka (2010).

To intensify and restore the reproductive function of cows, a variety of methods and means are successfully used in practice (Bushtruk, 1998; Pabat & Vinnychuk, 2001; Guntik, 2003). And, as a number of scientists point out, stimulation and synchronisation of reproductive function is one of the links in the complex system of prevention and elimination of infertility and increase of reproductive function of cows (Yablonskyi, 1995; Yablonskyi *et al.*, 2011; Bobryk, 2020).

The use of biotechnological techniques in synchronising estrus in cows has been reported by a number of American scientists. For example, J.R. Pursley *et al.* (1995) reported synchronisation of ovulation time in cattle using GnRH and PG $F_{2\alpha}$. Lactating dairy cows aged 36 to 280 days after calving and young heifers aged 14 to 16 months were injected intramuscularly with 100 µg of GnRH at a random stage of the estrous cycle. Seven days later, cattle received PG $F_{2\alpha}$ for corpus luteum (CL) regression. Lactating cows and heifers received a second injection of 100 µg GnRH 48 and 24 hours later, respectively. The lactating cows were artificially inseminated 24 hours after the second GnRH injection. All cows and heifers ovulated with a newly formed dominant follicle between 24 and 32 hours after the second GnRH injection. Ten of the 20 cows were ready for timely artificial insemination. Therefore, the studies confirmed a great impact on reproduction management in lactating dairy cows and allow artificial insemination at a certain time of ovulation and eliminate the need to detect estrus.

Thus, timely detection of cows in heat, regulation of estrus with biotechnological products and elimination of negative factors affecting cow fertility will help develop appropriate measures to improve the reproductive capacity of dairy cows, increase the frequency of pregnancy during the first artificial insemination and, as a result, determine the economic efficiency of the industry.

MATERIALS AND METHODS

The research was conducted in the period from 2018 to 2020 in the conditions of the Additional Liability Company (ALC) Pivdennyi Kolos of the Novo Odesa district of the Mykolaiv region on cows of the red steppe breed in compliance with the technological standards of use and maintenance of farm animals (Ostashko, 1995; Bezuhlyi, 2002; Zhuravel & Davydenko, 2005). Also, all ethical standards of animal treatment were observed in accordance with the Code of practice... (2014) and Law of Ukraine No. 3447-IV (2006). The development of the livestock industry was analysed according to the documentation of zooveterinary and breeding records. The results of obstetric and gynaecological examination of 195 cows were used in the work. An analysis of the reasons for the shortfall in calf production in 2018-2020 was carried out in accordance with the Order of the Ministry of Agrarian Policy of Ukraine No. 230 (2001). The research used a technician's calendar and a stand for the physiological state of cow reproduction on the farm. During artificial insemination of cows and heifers, the rectocervical method of sperm injection into the genital tract at the animal housing facilities and in the artificial insemination arena was used, which is in accordance with Order of the Ministry of Agrarian Policy of Ukraine No. 230 (2001).

Semen was used in uncoated granules and paiets, stored at -196^{0}C in liquid nitrogen and delivered from the private enterprise Genetics and Selection (Kyiv). The reproductive function of cows was studied according to the following traits and indicators: postpartum period; fertility from the 1st insemination; calving to conception interval (CCI), insemination index. To study the effectiveness of insemination of cows depending on the period after calving (index period), all cows were divided into 4 groups with different terms of coming into heat and insemination according to the insemination period after calving: Group I – up to 30 days; Group II – 31-60 days; Group III – 61-90 days; Group IV – 91 days and more.

To study the effect of reproductive capacity on cow milk production, 53 cows were selected, and four groups were formed according to the year of birth and the serial number of their lactation in 2018, 2019 and 2020. For each animal in these groups, as well as for the whole farm, the following milk yield traits were determined and analysed: milk days, lactation yield, average daily yield, fat content and amount of milk fat. The cows were also studied for signs of reproductive capacity: the number of dry days, the yield and sex of the offspring, and the duration of the calving to conception interval (CCI).

In the production environment of Pivdennyi Kolos, the sexual activity is determined visually by the "immobility reflex" when observing animals in the herd during a walk and before morning and evening milking. Determine the sexual activity at least three times during the daylight hours: at 6-9 am, 2-3 pm and 5-7 pm. When the "immobility reflex" is established, animals are separated from the herd to special places for standing, where they are kept before insemination and afterwards until the signs of sexual desire cease.

The biometric analysis of the data was carried out in accordance with accepted methods of analysis (Povod *et al.*, 2015). The correlation analysis of the relationship between the milk production of cows of different groups and their reproductive capacity was carried out by the following characteristics: "dry days ↔ milk yield", "milk yield (lactation) ↔ calf yield", "average daily milk yield ↔ calf yield", "calving to conception interval ↔ calf yield", "calving to conception interval ↔ milk yield", "milk yield for I-VI lactation ↔ calf yield", using the formula:

$$r = \frac{\sum xy - \frac{\sum x \times \sum y}{n}}{\sqrt{(\sum x^2 \times \frac{(\sum x)^2}{n}) \times (\sum y^2 \times \frac{(\sum y)^2}{n})}}, \quad (1)$$

where r – the correlation coefficient, x – the first of the indicators between which the correlation is determined, y – the second of the indicators. For the calculation, computer equipment with the Microsoft Excel application was used.

To study the issue of regulation and synchronisation of sexual desire of repair heifers using an analogue of prastaglandin $F_{2\alpha}$ – Estrophan and its use in combination with the drugs Tetravit and Catozal, three groups of 18 heifers were formed; after their treatment with the drugs, insemination was carried out. During the study of the effect of live weight of repair heifers on their fertility, seven groups were formed by weight categories, and to study the effect of the age of first insemination on fertility, five groups were formed, after insemination, the results of fertilisation from the first insemination were calculated. The comparative evaluation of animals of different groups in terms of the development of the trait under analysis was carried out by determining the absolute difference (d) between the mean values and their errors (S_d), and the level of probability of this difference (p) was determined by the standard values of the Student's t-test (Kravchenko, 1973). On the basis of the research and the results obtained, the relevant conclusions are drawn and specific proposals for production are provided.

RESULTS AND DISCUSSION

Stable reproduction is a prerequisite for ensuring the efficiency of cattle breeding. Milk production depends on this to the greatest extent, as lactation activity is inextricably linked to the full functioning of the reproductive function and the production of offspring (Motta *et al.*, 2020). The distinctive features of red steppe cattle are their strong constitution, satisfactory milk production, good fattening and meat qualities, and high adaptability to harsh natural and climatic conditions. At the same time, the animals are highly resistant to leukaemia, tuberculosis and limb diseases. Deviations in reproductive function in red steppe animals are somewhat less common than in black-and-white cattle. However, under conditions of industrial technology, they often have problems with reproduction. Due to the disturbance of the hormonal balance of the body and, above all, the gonadotropic function of the pituitary gland, the susceptibility to functional disorders of the reproductive organs increases (Fricke & Wiltbank, 1999).

An analysis of the state of reproduction of the cow population is given in Table 1, which shows that over the years studied, there has been an increase in the number of cows. Thus, in 2018 there were 175 cows, in 2019 there were 185 cows, and in 2020 there were 195 cows. Every year, 96-98% of them are inseminated, but the yield of calves is not stable and was 89 calves per 100 cows in 2018, 91 calves in 2019, and 90 calves in 2020, respectively. In this regard, the reasons for the shortfall in calf yield over the past three years were investigated.

Table 1. *The state of reproduction of the cow population in the conditions of Pivdennyi Kolos*

Index	The research year					
	2018		2019		2020	
	heads	%	heads	%	heads	%
Availability of cows as of 01.01.	175	100	185	100	195	100
Inseminated cows	164	94	180	97	187	97

Table 1, Continued

Index	The research year					
	2018		2019		2020	
	heads	%	heads	%	heads	%
Cows were lodged	145	83	161	87	167	86
Inseminated heifers	85	-	92	-	96	-
Heifers were lodged	66	-	84	-	90	-
The first calf was introduced to the herd	64	-	81	-	86	-
including per 100 cows	36	-	43	-	44	-
Calf yield per 100 cows	89	-	91	-	90	-
Aborted cows	2	1.1	3	1.6	4	2.0
Stillborn calves	2	1.4	4	2.5	5	2.9
Cows lost in the first quarter	14	8.0	9	4.8	8	4.1
Incalvers which dropped out	3	1.8	2	1.1	3	1.6
Barn cows and cows, which calved IV qr., but were inseminated in II qr. next year	9	5.1	6	2.2	8	4.1
Calves not received	30	17.1	24	13.0	26	13.3

Source: *authors' own development*

The research revealed that 80 calves were lost in just three years. The main reason for this in 2018-2020 was the death of 31 cows, and the second reason for culling was cow fatness or the extension of the calving to conception interval – 23 cows. In addition, eight pregnant cows were culled for various reasons: disease, injury, forced slaughter, etc. An important role in the prevention of postpartum diseases and infertility is played by obstetric and gynaecological examination, a set of diagnostic, preventive and therapeutic measures aimed at ensuring the normal course of pregnancy, childbirth and the postpartum period in cows, and preserving the viability of the young animals born to them.

K. Moore & W.W. Thatcher (2006) in their research came to a similar conclusion, namely, that existing intensive commercial systems for keeping lactating dairy cows require careful management of breeding, treatment and preventive measures even before the introduction of follicular waves, CL regression and ovulation induction in programming, which will solve the problem of increasing the reproductive efficiency of high-yielding dairy cows. The analysis of Table 2 shows that the number of pregnant cows on the farm on the day of the inspection was 106 heads or 54%, which corresponds to the norm, while 15 heads or 7.7% of problem cows were identified, which is slightly below the norm and convincingly confirms the existence of an established obstetric and gynaecological examination and prevention and treatment of problem cows.

Table 2. *The results of obstetric and gynaecological examination of cows in the conditions of Pivdennyi Kolos in June 2020*

Index	Name of cow service operators (milkmaids)				
	O.M. Sirova	O.P. Moroz	H.K. Bobchuk	I.V. Yefimova	O.V. Manko
Number of cows, heads	35	42	39	41	38
Incalvers, heads	23	18	25	21	19
Cows after calving, heads	4	3	5	8	6
Inseminated cows, heads	10	11	8	9	10
Problem cows (heads) through:					
ovarian hypofunction	1	-	1	1	-
persistent yellow body	-	1	1	-	-
ovarian cyst	-	-	1	1	1
endometritis	1	1	1	1	1
abortion	1	-	-	-	1

Source: *authors' own development*

It is worth noting that at the time of the herd examination, there was an increase in the number of cows after insemination – 48 heads, which is 24.6%, which can be considered conditionally pregnant, respectively, which will increase the percentage of pregnant cows in the farm. In the course of the research, it should be noted that the gynaecological examination of cows combines diagnostic, preventive and therapeutic

measures, which, in turn, are aimed at timely detection of postpartum complications, infertility and restoration of reproductive capacity.

In their research, R.B. Walsh *et al*. (2007) also point out that there are many factors that affect the time to first ovulation and whether normal estrus and ovulation cycles will be maintained, including cow breed, parity, season, BCS (Body Condition Scoring), postpartum illness and different types of feeding. The authors' attention was focused on the link between postpartum negative energy balance and the restoration of cyclicity in dairy cows. Scientists emphasise the important link between perinatal health and reproductive function and performance.

Similar results were obtained by J. Denis-Robichaud *et al*. (2018). Prolonged postpartum anovulation is a problem because it is associated with increased time to first insemination and reduced risk of conception and usually affects 20% of cows in dairy herds and is caused by various gynaecological diseases. An analysis of the work of artificial insemination technicians in 2018-2020 found that 57-64% of cows and 64-70% of heifers conceive from the first insemination (Table 3).

Table 3. *Performance of artificial insemination technicians in 2018-2020*

Index	2018 year				2019 year				2020 year			
	cows		heifers		cows		heifers		cows		heifers	
	heads	%	heads	%	heads	%	heads	%	heads	%	heads	%
Inseminated	164	100	85	100	180	100	92	100	187	100	96	100
Fertilized from insemination: ➥ the first	108	65.8	54	63.5	124	68.9	71	77.2	125	66.8	58	60.4
➥ the second	25	15.2	12	14.1	24	13.3	13	14.1	27	14.4	18	18.8
➥ the third	12	7.4	-	-	13	7.2	-	-	15	8.1	14	14.6
Calved	145	88.4	66	77.6	161	89.4	84	91.3	167	89.3	90	93.8
Not Inseminated	19	11.6	19	22.4	19	10.6	8	8.7	20	10.7	6	6.2

Source: *authors' own development*

Thus, it was found that thanks to these biotechnologies, 36 to 40 first-born calves per 100 cows are introduced into the main herd annually. At the time of the study, the farm used bull semen frozen in the form of open pellets or straws (paietas). The artificial insemination technician at the base farm also takes into account additional signs of the stage of sexual cycle excitation, which most often precede heat – general anxiety, desire for other animals, poor appetite and reduced milk production, back bending, increased reaction to his voice or the milker, rubbing of the tail root, traces of mucus on the tail and hind limbs, and the manifestation of a hugging reflex to other cows. In addition, the artificial insemination technician has rectal diagnostics of the degree of follicle maturation, accurately determines the time and frequency of insemination, the course of estrus and the duration of heat.

Thus, the main factors that ensure high fertility of animals with the rectocervical method of insemination are the massage of the genitals during their examination and insemination of the animal, which increases uterine motility, promotes the movement of sperm through the oviducts and accelerates ovulation. The use of disposable sterile plastic instruments allows insemination to be performed under aseptic conditions and requires little time for instrument processing. In addition, the deep insertion of sperm into the cervical canal prevents its backflow into the vagina, promotes faster sperm movement and maintains a high fertilisation rate. And examination of the internal genitalia before insemination makes it possible to monitor the development of follicles, identify sick animals and prescribe timely treatment. It is particularly important to note that this reproduction biotechnology allows for one-time insemination of cows and heifers in one heat, which increases the efficiency and economic feasibility of artificial insemination.

However, the analysis of herd reproduction that was carried out does not fully reveal the reasons for the decline in calf yield, so the impact of the period of time of arrival at the first heat after calving (independence period) on the effectiveness of insemination of cows, the impact of the number of inseminations (insemination index) on the reproductive capacity of cows was investigated, the analysis of which is presented in Table 4.

Table 4. *Insemination efficiency of cows depending on the period of insemination after calving*

Lines of insemination of cows after calving	Number of cows		Independence period, days	Fertilization from the 1st insemination, %	Service period, days	Insemination index
	heads	%				
Till 30 days	197	35.5	28.6 ± 2.14	49.7	65.1 ± 3.15	1.6 ± 0.12
31-60 days	215	38.7	54.3 ± 5.18	61.5	88.5 ± 4.72	1.8 ± 0.34
61-90 days	125	22.5	78.6 ± 8.01	73.3	103.1 ± 8.51	2.1 ± 0.27
91 and more	18	3.3	120.4 ± 16.31	58.8	118.2 ± 9.11	3.2 ± 0.45
On the farm	555	100.0	54.1 ± 7.38	60.7	85.5 ± 6.17	1.9 ± 0.30

Source: *authors' own development*

The calculated data indicate that the average independence period in cows was 54.1 ± 7.38 days, the lowest in group 1 – 28.6 ± 2.14 days, the highest in group 4 – 120.4 ± 16.31 days, respectively. Therefore, the calving to conception interval was the highest in the 4th group of cows – 118.2 ± 9.11 days, and the lowest in the 1st group – 65.1 ± 3.15 days, while the average calving to conception interval on the farm was 85.5 ± 6.17 days, which is slightly higher than optimal.

The fertility from the 1st insemination averaged 60.7%, which is a normal indicator. The analysis shows that the highest insemination efficiency was after 61-90 days after calving and was 73.3%, respectively. In addition, there is a straightforward proportional relationship between the independence and calving to conception interval and the insemination index. Cows that were inseminated in the first month after childbirth had the lowest insemination index – 1.6 ± 0.12 with a minimum independence period of 28.3 ± 2.15 days and a calving to conception interval of 65.1 ± 3, 15 days, and in cows inseminated after the 91st day, the insemination index is the highest – 3.2 ± 0.45 with a maximum independence period of 120.4 ± 16.31 and calving to conception interval of 118.2 ± 9.11 days.

In the scientific literature, there are ambiguous statements regarding cow fertility and how much it depends on the length of the calving to conception interval. Thus, F. López-Gatius (2012) points out that the reasons for the decline in fertility are multifactorial and cannot be attributed solely to increased milk production. In fact, by improving feeding and housing practices, individual milk production can be positively related to high fertility, but heat stress, the sire bull and the artificial insemination operator remain the main factors that negatively affect herd fertility. And the latter does not depend on the duration of the period from launch to calving.

At the same time, B. Tadesse *et al.* (2022) obtained the opposite results. Thus, the authors point out that 37% of cows that did not conceive during the first artificial insemination are associated with a large number of days of stall housing and with reproductive processing. At the same time, scientists link the length of the calving to conception interval to the season of the year. Based on the season of artificial insemination, a significant difference in insemination in winter and spring was found in 13% of animals. Cows that did not conceive during the first insemination but conceived during the 2nd and 3rd inseminations had an average interval between calving and insemination of 45.04 days longer than cows that were conceived during the first insemination.

On the farm, the artificial insemination technician practices a single insemination of cows during heat by establishing the optimal insemination time according to the degree of follicle maturation during rectal examination. However, it is necessary to take into account the survival rate of sperm in the genital tract, which is almost impossible. In this regard, according to the instruction Order of the Ministry of Agrarian Policy of Ukraine No. 230 (2001), it is recommended to inseminate twice in one heat with an interval of 12 hours. Thus, single insemination of cows in a farm may be one of the reasons for the decrease in cow fertility. Therefore, the effect of the number of inseminations on the reproductive capacity of cows was studied (Table 5).

Table 5. *Relationship between cow reproductive capacity and insemination index (2018-2020)*

Index	Number	Insemination index				
		1	2	3	4	5 and more
Calving is taken into account, in %	658 100	385 58.5	186 28.3	51 7.8	24 3.6	12 1.8
Average service period, days	-	74.3± 3.51	95.1± 4.12	114.7± 6.28	128.7± 11.13	146.3± 21.31

Source: *authors' own development*

Thus, it was found that the insemination index – "1", the duration of the calving to conception interval is 74.3 ± 3.51 days and with its increase, an increase in the calving to conception interval is observed. And, in turn, cows that were not inseminated after the fifth or more inseminations had a calving to conception interval of 146.3 ± 21.31 days, respectively, i.e. these cows were problematic and were subject to rectal gynaecological examination, or treatment and stimulation, as well as culling for reproductive system problems.

The effectiveness of the use of artificial insemination and synchronisation of estrus is also indicated by M.F. Sá Filho *et al.* (2013). Thus, the authors note that the comparison of the reproductive efficiency of breeding programmes that used natural service (NS), artificial insemination after detection of estrus (ED) and timed artificial insemination (TAI). The researchers concluded that the inclusion of TAI programmes at an early stage of estrus increased the reproductive capacity of beef and dairy cows and reduced the number of artificial inseminations per cow, i.e. the insemination index was at an optimal level.

C.M. Tippenhauer *et al.* (2021) indicate that the number of inseminations of cows is influenced not only by the period of insemination, but also by the type of semen. Specifically, when artificial insemination of cows was used between 1 and 18 hours after peak estrus activity, the effectiveness was highest regardless of the type of semen (fresh or frozen). Cows inseminated within six hours before the peak estrus activity with frozen semen had a higher insemination rate compared to cows inseminated with fresh semen and inseminated with 1-2 inseminations. Cows inseminated with fresh semen within five hours before peak activity had a higher efficiency compared to cows inseminated with frozen semen; they were inseminated with 2-3 inseminations. And cows inseminated with frozen semen in the period from 13 to 18 hours after peak activity had higher fertilisation efficiency compared to cows inseminated with fresh semen, and it took 3-4 insemination procedures to inseminate them.

During the experiment, the influence of reproductive capacity on the milk production of Red Steppe cows and the dynamics of this relationship depending on the calendar year was determined. The research has established (Table 6) that there is a negative correlation between the duration of the period from launch to calving and subsequent milk yield during the study period.

Table 6. *The relationship between the reproductive capacity of cows and their milk production for the period 2018-2020*

Signs that the relationship is defined between	Index coefficient of correlation by years		
	2018	2019	2020
Dry days ↔ Milk yelds	-0.23	-0.10	-0.32
Milk yelds for lactation ↔ Release of calves	+0.07	+0.19	+0.11
Average daily milk yield of calves ↔ Release of calves	+0.03	+0.10	+0.07
Service period ↔ Release of calves	-0.01	+0.10	-0.12
Service period ↔ Milk yelds	-0.12	-0.19	-0.09
Milk yelds for I lactation ↔ Release of calves	+0.07	+0.08	+0.10
Milk yelds for II lactation ↔ Release of calves	+0.10	+0.05	+0.06
Milk yelds for III lactation ↔ Release of calves	+0.21	+0.29	+0.19

Source: *authors' own development*

The reason for this phenomenon is that early cow start-up leads to a shortfall in milk production. Then the duration of the period from launch to calving was brought to the optimum value of 45-60 days. There was some difference between years in this indicator: the lowest value of the negative correlation was in 2017, which, as previously established, was the most favourable for the animals on this farm.

When determining the relationship between milk yield per lactation and calf yield, a positive correlation was found. It was particularly high in 2019, due to high milk yields and a sufficient level of reproduction shown by the cows on the farm that year. It has been established that a higher number of offspring born helps to increase the milk production of cows, i.e. these two most indicative parameters have a mutual positive influence on each other, which is certainly effective for the operation of a dairy farm.

It is worth noting that a similar trend is observed when identifying the relationship between average daily milk yield in cows and calf yield: a positive correlation between these indicators with a similar trend, which confirms the above conclusion about the relationship between the number of calves and the amount

of milk produced. There is a weak positive correlation between the length of the calving to conception interval and calf yield, which was only established in 2019; in all other years, the correlation was negative. This is due to the fact that a shorter calving to conception interval indicates a faster recovery of the cow after calving and her greater readiness for the next pregnancy.

In addition, the relationship between the duration of the period from launch to calving and milk yield in cows was investigated. Based on this, a negative correlation was found regardless of the year under study. This confirms the conclusion made earlier that reducing the period from launch to calving from an excessively long 82-90 days to an optimal 30-60 days is likely to increase the milk yield of the farm's cows. When studying the relationship between reproductive capacity and milk production of Red Steppe cows for a certain lactation, a mutual positive influence of these traits was established. The highest correlation coefficients were found between the traits "milk yield for the third lactation" and "calf yield" obtained from cows at this time.

Many hypotheses regarding the relationship between the level of milk production and the reproductive capacity of cows have been described by world scientists. For example, a number of scientists (Patton *et al.*, 2007) do not link the level of cow milk yield with their fertility. The relationship between the components and indicators of energy balance (EB) in early lactation and fertility in Holstein cows was investigated. Milk production, dry matter intake (DMI), BCS, endocrine and metabolite data from 96 cows were analysed using multivariate logistic regression and survival analysis. Fertility variables studied included the interval to onset of luteal activity (C-LA), calving to conception interval (CCI) and conception to first insemination ratio (CON1). The average daily EB, milk protein content and DMI during the first 28 days of milk production were positively related to CON1. Cows with lower fatness (≤ 2.25) at first insemination had lower CON1. Positive associations were found between EV, milk protein content, DMI and the probability of a shorter interval to C-LA. Cows with higher DMI and more positive EB had an increased probability of a shorter CCI, while lower BCS supervision was associated with an increased probability of a longer CCI. Thus, milk yield was not associated with any of the fertility variables studied (Patton *et al.*, 2007).

R.L. Nebel & M.L. McGilliard (1993), on the contrary, indicate correlations between reproductive traits and milk yield, namely, higher milk yields are phenotypically and genetically associated with reduced reproductive capacity in lactating cows. D. Raboisson *et al.* (2014) found an average positive correlation between age and milk yield, and age and reproductive capacity. Thus, when analysing age-related changes in the reproductive capacity of cows, it was found that the duration of the calving to conception interval decreased with the age of the animals. The duration of the period between calvings was optimal on average for cows, while its reduction with age was observed. The authors noted that with increasing age of cows, the number of inseminations for fertilisation increased. Currently, in the field of cattle breeding, the developed promising methods of biotechnological regulation of sexual functions in animals through the use of synthetic analogues of prostaglandins $F_{2\alpha}$ are widely used. Data on the effect of various drugs to regulate and synchronise the sexual desire of replacement heifers are shown in Table 7.

Table 7. *Use of prophylactic drugs for regulation and synchronisation of sexual desire in replacement*

Purpose of the group	Quantity, heads	Raised sexual desire after processing				Not raised sexual desire		Fertilization from the 1st insemination	
		first		second					
		heads	%	heads	%	heads	%	heads	%
Control group	18	-	-	-	-	7	38.9	10	55.5
II research group	18	7	38.9	9	50.0	2	11.1	14	77.8
III research group	18	8	44.4	9	50.0	1	5.6	16	88.9

Source: *authors' own development*

The experiments proved that the highest percentage of heifers coming into heat from the first treatment was observed in the group where the drug Catozal was used – 44.4%, and the second group was the group that was injected with the hormonal drug Estrophan along with the vitamin Tetravit – 38.9%. After 11 days, the heifers that did not come into heat were re-injected with the drugs and the following results were obtained: in both experimental groups, the same number of heifers came into heat – nine heads each, which is 50%. Females of the control group, where heifers were not administered any drugs at all, did not become pregnant, and two (11.1%) animals of the second experimental group did not become pregnant after the

second treatment and one head did not become pregnant in the third experimental group, which is 5.6%, respectively. In the control group (no stimulants were used), 10 heifers conceived from the 1st insemination, which is 55.5%, in the II experimental group, where Estrofan and Tetravit were used, 14 heifers conceived from the 1st insemination, which is 77.8%, in the III experimental group, where Catozal was used, 16 heifers conceived from the 1st insemination, which is 88.9%.

Various hormonal preparations are widely used for the treatment, prevention and regulation and synchronisation of the reproductive function of cows in the world. The use of biological products after calving cows reduced the risk of uterine subinvolution, endometritis and mastitis and improved the reproductive performance of cows. It has been shown that after the use of Salus-PE, 100% of cows are inseminated, of which 60% are inseminated in the first heat and 40% in the second heat. The fertilisation index was 1.4 (Barkema *et al.*, 2015).

A.W. Jonczyk *et al.* (2022) confirm the effectiveness of the method of intracellular administration of drugs/hormones, which can be a common tool for cattle reproduction. Arab scientists recommend the use of cloprostenol, which is an analogue of prostaglandin F2 (PG F2), but obtained synthetically, which acts as an agonist of the FP receptor and can cause luteolysis. Luteolysis is a key event in Ovsink's programmes for lactating dairy cows. The authors note that 20% of cows treated in the Presink/Ovsink programme experienced delayed or incomplete luteolysis with dinoprost tromethamine. Cows need to have complete luteolysis to have a chance of getting pregnant (Shahzad *et al.*, 2023).

The next stage was to study the effect of treatment of repair heifers with biologically active preparations (Estrofan + Tetravit, Catozal) on their reproductive capacity after calving and milk production (Table 8). It was established that the use of Estrofan together with Tetravit and Catozal does not reduce the milk yield of first-born cows, since according to the results of control milk yields for the first month in this group, the average daily yield was 16.7 kg, for the second – 18.1 kg and for the third – at the level of 17.9 kg. Further, analysing the service period for the first-born group, it was found that the minimum was 30 days, the maximum was 86 days, and the average for the group was almost 58 days, which is typical for this farm.

Table 8. *Influence of prophylactic drugs on reproductive capacity and milk production of repair heifers*

Alias	Inv. No.	Date of calving	Sex of offspring	Date of last insemination	Service period, days	Control yield of milk, kg		
						1	2	3
Mayka	124	20.01	heifer	6.06	76	15	19	20
Kvitka	262	21.01	heifer	20.02	30	17	19	18
Galka	420	22.01	heifer	15.03	49	17	18	17
Ruchka	164	23.01	bull-calf	19.04	86	13	15	14
Rosa	664	23.01	bull-calf	16.03	50	20	22	23
Litnia	652	24.01	bull-calf	26.03	61	19	18	17
Chereshenka	518	25.01	bull-calf	17.03	51	17	18	20
Mala	428	26.01	heifer	17.03	51	18	17	16
Pava	162	28.01	bull-calf	16.03	50	12	15	16
Sova	540	29.01	bull-calf	14.04	75	19	20	18
Average by group					57.9	16.7	18.1	17.9

Source: *authors' own development*

Planned reproduction of cattle involves the regulation of the estrous cycle and the use of artificial insemination. Cycle control involves the administration of exogenous progesterone for 5-8 days in a controlled manner, which allows females to synchronise their ovulation (Helbling *et al.*, 2018). Synchronisation of estrus using prostaglandin $F_{2\alpha}$ (PG $F_{2\alpha}$) and a combination of PG $F_{2\alpha}$ and gonadotropin-releasing hormone was also used in Indonesian research. The estrus response can be enhanced by providing PG $F_{2\alpha}$ and a combination of PG $F_{2\alpha}$-GnRH to allow for precise timing of mating using artificial insemination. Therefore, scientists concluded that the use of PG $F_{2\alpha}$ was more effective for the duration and intensity of estrus, and the PG $F_{2\alpha}$-GnRH combination was more effective for stimulating estrus (Astuti *et al.*, 2020).

A. Ayad *et al.* (2015) in the research used norgestomethate Crestar on estrus synchronisation and reproductive function of dairy cows. Treatment with norgestomethate Crestar, which was carried out for 9-10 days, did not improve the reproductive performance of dairy cattle. Nevertheless, the authors point out that this hormonal protocol can be used to obtain high estrus rates in cows to correctly determine the time of insemination. In

addition to the above studies, the influence of live weight of repair heifers on the results of artificial insemination was studied. For this purpose, seven groups of heifers were formed depending on their live weight at the first insemination (Table 9), using thawed semen from the red steppe bull Pilot 1069 by the rectocervical method.

Table 9. *Influence of live weight of repair heifers on their fertilisation after artificial insemination*

Weight category, kg	Average weight, kg	Number of heads inseminate	Fertilized from the 1st insemination	
			Heads	%
Up to 280	271±6.3	17	8	47.1
281-300	292±4.7	21	14	66.7
301-320	314±6.5	19	14	73.7
321-340	328±9.2	12	9	75.0
341-360	352±7.7	9	7	77.8
361-380	375±3.8	7	5	71.4
381 and more	393±5.2	6	4	66.7
Total	-	91	61	67.0

Source: *authors' own development*

It was established that the first group of heifers had an average live weight of 271 ± 6.3 kg and 8 heads, or 47.1%, were fertilised from the first insemination in this group. The second group of heifers weighed 292 ± 4.7 kg, and 66.7% of this group were fertilised from the first insemination. The highest percentage of fertilisation – 77.8 was in the fifth group of heifers with a live weight of 352 ± 7.7 kg, and further, with an increase in live weight, there is a decrease in the percentage of fertilisation from the first insemination, which in the group of heifers weighing 393 ± 5.2 was 66.7%. Since live weight does not sufficiently reflect the optimal time of insemination of heifers, therefore, in further experiments, the effect of the age of first insemination on their fertilisation was studied. For this purpose, heifers were selected and 5 age groups were formed (Table 10).

Table 10. *Influence of age at first insemination on fertility of replacement heifers*

Age group, months	Average age, months	Number of heads inseminate	Fertilized from the 1st insemination	
			Heads	%
16 - 18	17.5 ± 1.5	18	14	77.8
19 - 20	19.6 ± 1.1	29	21	72.4
21 - 23	22.1 ± 1.8	24	15	62.5
23 - 24	23.4 ± 1.0	15	9	60.0
Elder than 24 months	26.8 ± 2.7	5	2	40.0
Total	-	91	61	67.0

Source: *authors' own development*

Analysis of the table data shows that in the first group of heifers the average age was 17.5 ± 1.5 months. It was established that during artificial insemination, 14 out of 18 heads were fertilised from the first insemination, which is 77.8%; this is the highest fertility rate from the first insemination. With increasing age of heifers, there is a decrease in fertility from the first insemination, which was the lowest – 40% in heifers with an average age of 26.8 ± 2.7 months.

Many global scientists have concluded that achieving pregnancy for lactating dairy cows in the range of every 365 days optimises profitability for most cows and depends on the length of the voluntary waiting period (VWP) and reducing the number and variation of days to conception after cows become eligible for pregnancy (Stevenson & Britt, 2017; Stangaferro *et al.*, 2018; Fyl, 2020). Through the introduction of reproductive management programmes and technologies that better control artificial insemination rates and significantly increase pregnancies per artificial insemination (P/AI) for the first and subsequent artificial insemination operations. Therefore, combining an effective management programme with a service period that optimises the time to pregnancy during lactation can be a feasible strategy to increase herd profitability.

The use of synchronisation programmes is a standard component of efficient cow management in dairy herds. Many of them are based on measures that allow for timed insemination (TAI) to avoid the practical difficulties associated with detecting cows in heat. Almost all of the measures involve injections of prostaglandin $F_{2\alpha}$ (PGF) and gonadotropin-releasing hormone (GnRH) at strategically timed intervals, which determines the economic efficiency of the industry as a whole.

CONCLUSIONS

The analysis of the reproduction status shows that there is an annual shortfall in calf production, and the main reasons are: cow retirement, as well as beef cows and cows with an extended calving to conception interval. It has been established that pregnant cows left the herd for various reasons, such as injuries, diseases of various types, forced slaughter, etc. Reducing the calving to conception interval will contribute to a higher calf yield in cows, which has a positive impact on milk production. At the same time, it should be borne in mind that the calving to conception interval can be reduced to a number that is not less than 30 days, i.e. the period required to prepare the cow's body for new insemination.

The calculations of the correlation coefficient between the main signs of reproductive capacity and milk production of Red Steppe cows allowed us to establish a mutual positive influence between them. The conclusion made earlier about the best functioning of all organs and systems of the cow's body during the third lactation was confirmed. It also confirms the statement about the plasticity of the cows' organism and their active response to the favourable conditions of a particular year by increasing productivity and fertility. It has been established that the use of prophylactic drugs contributes to the synchronisation of heifers' sexual desire and increases their fertility during insemination. The latter should be started when heifers reach a live weight of 314 ± 6.5 kg, which will allow to obtain fertilisation from the first insemination at the level of 73.7-77.8%, and an increase in heifer weight leads to obesity, and therefore reduces the percentage of fertilisation from the first insemination. The optimal age for artificial insemination of heifers is 17.5 ± 1.5 months, and an increase in the age of heifers leads to overgrazing and culling them from the farm.

To diagnose problem cows in terms of reproductive function, it is worthwhile to conduct an early check on the 25-30th day of pregnancy in inseminated cows using ultrasound diagnostics. It is necessary to establish obstetric and gynaecological examination and treatment of problematic replacement heifers and cows, and it is advisable to use prostaglandin $F_{2\alpha}$ analogues in combination with vitamins or biologically active drugs to stimulate the sexual function of cows and heifers. The maximum number of Red Steppe heifers should be inseminated at the age of 16-18 months with a live weight of 314-360 kg to achieve a fertility rate of 75-77% from the first insemination. The prospect of further research on this topic may be the search for new insemination programmes that can increase the level of these two hormones during oestrus, which can help solve the problem of low fertility in lactating dairy cows.

ACKNOWLEDGEMENTS

The authors express their gratitude to the management and specialists of Pivdennyi Kolos for the opportunity to conduct research in the company.

CONFLICT OF INTEREST

None.

REFERENCES

[1] Abbara, A., Clarke, S.A., & Dhillo, W.S. (2018a). Novel concepts for inducing final oocyte maturation in in vitro fertilization treatment. *Endocrine Reviews*, 39(5), 593-628. doi: 10.1210/er.2017-00236.

[2] Abbara, A., Islam, R., Clarke, S.A., Jeffers, L., Christopoulos, G., Comninos, A.N., ... Dhillo, W.S. (2018b). Clinical parameters of ovarian hyperstimulation syndrome following different hormonal triggers of oocyte maturation in IVF treatment. *Clinical Endocrinology*, 88(6), 920-927. doi: 10.1111/cen.13569.

[3] Astuti, P., Airin, C.M., Widiyanto, S., Sarmin, S., Hana, A., Maheshwari, H., & Sjahfirdi, L. (2020). Estrus synchronization using prostaglandin F2α (PGF2α) and combination of PGF2α and gonadotropin-releasing hormone in ongole crossbred. *E3S Web of Conferences*, 151, 01009. doi: 10.1051/e3sconf/202015101009.

[4] Ayad, A., Salaheddine, M., Touati, K., Iguer-Ouada, M., & Benbarek, H. (2015). Evaluation of norgestomet Crestar® on oestrus synchronization and reproductive performance of dairy cows in Algeria. *Asian Pacific Journal of Reproduction*, 4(1), 54-60. doi: 10.1016/S2305-0500(14)60059-2.

[5] Barkema, H.W., von Keyserlingk, M.A.G., Kastelic, J.P., Lam, T.J.G.M., Luby, C., Roy, J.-P., ... Kelton, D.F. (2015). Invited review: Changes in the dairy industry affecting dairy cattle health and welfare. *Journal of Dairy Science*, 98(11), 7426-7445. doi: 10.3168/jds.2015-9377.

[6] Besbaci, M., Abdelli, A., Minviel, J.J., Belabdi, I., Kaidi, R., & Raboisson, D. (2020). Association of pregnancy per artificial insemination with gonadotropin-releasing hormone and human chorionic gonadotropin administered during the luteal phase after artificial insemination in dairy cows: A meta-analysis. *Journal of Dairy Science*, 103(2), 2006-2018. doi: 10.3168/jds.2019-16439.

[7] Bezuhlyi, M.D. (2002). *Biotechnology methods of reproduction of agricultural animals*. Kharkiv: Institute of Animal Husbandry of the National Academy of Sciences of Ukraine.

[8] Bobryk, V.H. (2020). *Optimization of the reproductive function of cows of the Swiss breed in the "Ekaterinoslavskyi" MVK in Dnipro*. (Master's thesis, Dnipro State Agrarian and Economic University, Dnipro, Ukraine). Retrieved from https://dspace.dsau.dp.ua/handle/123456789/4174.

[9] Bonacker, R.C., Stoecklein, K.S., Locke, J.W.C., Ketchum, J.N., Knickmeyer, E.R., Spinka, C.M., & Thomas, J.M. (2020). Treatment with prostaglandin F2α and an intravaginal progesterone insert promotes follicular maturity in advance of gonadotropin-releasing hormone among postpartum beef cows. *Theriogenology*, 157, 350-359. doi: 10.1016/j.theriogenology.2020.08.018.

[10] Bushtruk, M. (1998). *Estimation and selection of bulls black and white breed accoding to thir reproductive featares*. (Doctoral dissertation, M.V. Zubets Institute of Animal Breeding and Genetics of the National Academy of Sciences of Ukraine, Chubynske, Kyiv region, Ukraine).

[11] Cabrera, E.M., Lauber, M.R., Peralta, E.M., Bilby, T.R., & Fricke, P.M. (2021). Human chorionic gonadotropin dose response for induction of ovulation 7 days after a synchronized ovulation in lactating Holstein cows. *JDS Communications*, 2(1), 35-40. doi: 10.3168/jdsc.2020-0024.

[12] Chukhriy, B.M., Klevets, L.O., & Chaikovska, O.I. (1998). Bull blood groups as genetic markers of sperm quality. *Cytology and Genetics*, 32(2), 74-79. Retrieved from https://scholar.google.com.ua/scholar_host?q=info:EISTe9DXw5EJ:scholar.google.com/&output=viewport&pg=74&hl=uk&as_sdt=0,5.

[13] Code of practice for the housing and care of animals bred, supplied or used for scientific purposes. (2014). Retrieved from https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/388535/CoPanimalsWeb.pdf.

[14] Denis-Robichaud, J., Cerri, R.L.A., Jones-Bitton, A., & LeBlanc, S.J. (2018). Performance of automated activity monitoring systems used in combination with timed artificial insemination compared to timed artificial insemination only in early lactation in dairy cows. *Journal of Dairy Science,* 101(1), 624-636. doi: 10.3168/jds.2016-12256.

[15] Fedorovych, V.V., Fedorovych, E.I., Mazur, N.P., & Dyachenko, O.B. (2019). Formation of milk productivity of cows of the Ukrainian red-spotted breed, depending on indicators of reproductive capacity. *Scientific and Technical Bulletin of the State Research Control Institute of Veterinary Medicines and Feed Additives and the Institute of Animal Biology*, 20(1), 169-177. Retrieved from http://www.irbis-nbuv.gov.ua/.

[16] Fricke, P.M., & Wiltbank, M.C. (1999). Effect of milk production on the incidence of double ovulation in dairy cows. *Theriogenology*, 52(7), 1133-1143. doi: 10.1016/S0093-691X(99)00205-8.

[17] Fyl, S.I. (2020). *The role of selective and genetic factors in the formation of highyielding herds of Black-and-White cattle*. (Doctoral dissertation, M.V. Zubets Institute of Animal Breeding and Genetics of the National Academy of Sciences of Ukraine, Chubynske, Kyiv region, Ukraine).

[18] Gonchar, O.F., & Sotnichenko, Yu.M. (2015). Breeding aspects of reproductive capacity formation in dairy cows. *Animal Breeding and Genetics*, 50, 200-207. Retrieved from http://digest.iabg.org.ua/images/digest/50/Animal_breeding_and_genetics_50.pdf#page=200.

[19] Gryshchuk, G.P. (2012). Effect of fetoplacentate and estrophan on the reproductive function of cows. *Veterinary Medicine of Ukraine*, 2(192), 21-23. Retrieved from http://ir.polissiauniver.edu.ua/handle/123456789/2312.

[20] Guntik, L.M. (2003). An improved method of cryopreservation of bull semen. *Animal Breeding and Genetics*, 35, 39-43. Retrieved from http://www.irbis-nbuv.gov.ua/.

[21] Helbling, I.M., Busatto, C.A., Fioramonti, S.A., Pesoa, J.I., Santiago, L., Estenoz, D.A., & Luna, J.A. (2018). Preparation of TPP-crosslinked chitosan microparticles by spray drying for the controlled delivery of progesterone intended for estrus synchronization in cattle. *Pharmaceutical Research*, 35, 66. doi: 10.1007/s11095-018-2363-z.

[22] Jonczyk, A.W., Piotrowska-Tomala, K.K., & Skarzynski, D.J. (2022). Comparison of intra-CL injection and peripheral application of prostaglandin F2α analog on luteal blood flow and secretory function of the bovine corpus luteum. *Frontiers in Veterinary Science*, 8, 811809. doi: 10.3389/fvets.2021.811809.
[23] Kamenska, I.S. (2013). Reproductive ability and linear growth of offspring of different lines of the Simmental breed. *Bulletin of the Sumy National Agrarian University. Series: Livestock*, 1, 144-148. Retrieved from https://scholar.google.com.ua/scholar?cluster=6008991346174057 97&hl=uk&as_sdt=0,5.
[24] Kravchenko, M.A. (1973). *Breeding farm animals*. Moscow: Kolos.
[25] Kruglyak, O.V. (2016). Organizational and economic mechanism of preservation of biodiversity of agricultural animals of Ukraine. *Balanced Nature Management*, 4, 66-75. https://scholar.google.com.ua/scholar?cluster=12668679209404317628&hl=uk&as_sdt=0,5.
[26] Law of Ukraine No. 3447-IV "On the Protection of Animals From Cruelty". (2006, February). Retrieved from https://zakon.rada.gov.ua/laws/show/3447-15/ed20060221#Text.
[27] López-Gatius, F. (2012). Factors of a noninfectious nature affecting fertility after artificial insemination in lactating dairy cows. A review. *Theriogenology*, 77(6), 1029-1041. doi: 10.1016/j.theriogenology.2011.10.014.
[28] Melnik, V., Karateeva, H., Kravchenko, H., & Kogut, E. (2022). Hematological and biochemical blood indicators of young gilts after estrus synchronization. *Scientific Papers. Series D. Animal Science*, 65(1), 289-294. Retrieved from http://dspace.mnau.edu.ua/jspui/bitstream/123456789/13016/1/Art38.pdf.
[29] Moore, K., & Thatcher, W.W. (2006). Major advances associated with reproduction in dairy cattle. *Journal of Dairy Science*, 89(4), 1254-1266. doi: 10.3168/jds.S0022-0302(06)72194-4.
[30] Motta, J.C., Madureira, G., Silva, L.O., Alves, R.L., Silvestri, M., Drum, J.N., ... Sartori, R. (2020). Interactions of circulating estradiol and progesterone on changes in endometrial area and pituitary responsiveness to GnRH. *Biology of Reproduction*, 103(3), 643-653. doi: 10.1093/biolre/ioaa065.
[31] Nadtochiy, V.M., Nadtochiy, V.P., & Osipenko, O.P. (2011). Relationship of sperm production indicators with indicators of the humoral factor of non-specific resistance in breeding bulls. *Technology of Production and Processing of Livestock Products: A Collection of Scientific Papers*, 5(82), 19-23. Retrieved from https://rep.btsau.edu.ua/handle/BNAU/528.
[32] Nebel, R.L., & McGilliard, M.L. (1993). Interactions of high milk yield and reproductive performance in dairy cows. *Journal of Dairy Science*, 76(10), 3257-3268. doi: 10.3168/jds.S0022-0302(93)77662-6.
[33] Order of the Ministry of Agrarian Policy of Ukraine No. 230 "On Approval of the Instructions on Artificial Inseminationof Cows and Heifers". (2001, August). Retrieved from https://zakon.rada.gov.ua/laws/show/z0852-01#Text.
[34] Ostashko, F.I. (1995). *Biotechnology of reproduction of cattle*. Kyiv: Agrarian Science.
[35] Pabat, V., & Vinnychuk, D. (2001). Reproductive function of cows. *Tvarynnytstvo Ukrainy*, 1, 10-11.
[36] Patton, J., Kenny, D.A., McNamara, S., Mee, J.F., O'mara, F.P., Diskin, M.G., & Murphy, J.J. (2007). Relationships among milk production, energy balance, plasma analytes, and reproduction in Holstein-Friesian cows. *Journal of Dairy Science*, 90(2), 649-658. doi: 10.3168/jds.S0022-0302(07)71547-3.
[37] Pidpala, T.V., Ostapenko, O.M., Yasevin, S.Ie., Drovniak, O.V., Marykina, O.S., & Hrebeniuk, N.V. (2018). *Intensive technologies in dairy farming*. Mykolaiv: Mykolaiv National Agrarian University. Retrieved from https://dspace.mnau.edu.ua/jspui/bitstream/123456789/5472/1/Pidpala%20mono.pdf.
[38] Ponomarenko, I.V. (2005). The relationship between the reproductive capacity of Ukrainian Black-and-Red and Red-Spotted dairy cows with milk productivity. *Scientific Bulletin of the Lviv State Academy of Veterinary Medicine Named After S.Z. Gzhitskyi*, 7(2), 232-235.
[39] Povod, M.H., Nezhlukchenko, T.I., Papakina, N.S., Baranovskyi, D.I., Cill, M.I., & Khalak, V.I. (2015). *Genetics with biometrics*. Kherson: OLDI-PLIuS.
[40] Pursley, J.R., Mee, M.O., & Wiltbank, M.C. (1995). Synchronization of ovulation in dairy cows using PGF2α and GnRH. *Theriogenology*, 44(7), 915-923. doi: 10.1016/0093-691X(95)00279-H.
[41] Raboisson, D., Mounié, M., & Maigné, E. (2014). Diseases, reproductive performance, and changes in milk production associated with subclinical ketosis in dairy cows: A meta-analysis and review. *Journal of Dairy Science*, 97(12), 7547-7563. doi: 10.3168/jds.2014-8237.

[42] Sá Filho, M.F., Penteado, L., Reis, E.L., Reis, T.A.N.P.S., Galvão, K.N., & Baruselli, P.S. (2013). Timed artificial insemination early in the breeding season improves the reproductive performance of suckled beef cows. *Theriogenology*, 79(4), 625-632. doi: 10.1016/j.theriogenology.2012.11.016.

[43] Shahzad, A., Majeed, A., Lahiq, A.A., Alqahtani, T., Alqahtani, A.M., Bashir, K., ... Fu, Q. (2023). Preparation and characterization of dummy template molecularly imprinted polymers coupled with HPLC for selective extraction of spiked cloprostenol from milk samples. *Arabian Journal of Chemistry*, 16(9), 105045. doi: 10.1016/j.arabjc.2023.105045.

[44] Stakhovsky, V.F. (2009). A new method of using cryopreserved bull semen after thawing. *Animal Breeding and Genetics*, 43, 310-314. Retrieved from https://scholar.google.com.ua/scholar?cluster=14711424533604455038&hl=uk&as_sdt=0,5#.

[45] Stangaferro, M.L., Wijma, R., Masello, M., Thomas, M.J., & Giordano, J.O. (2018). Economic performance of lactating dairy cows submitted for first service timed artificial insemination after a voluntary waiting period of 60 or 88 days. *Journal of Dairy Science*, 101(8), 7500-7516. doi: 10.3168/jds.2018-14484.

[46] Stevenson, J.S., & Britt, J.H. (2017). A 100-year review: Practical female reproductive management. *Journal of Dairy Science*, 100(12), 10292-10313. doi: 10.3168/jds.2017-12959.

[47] Tadesse, B., Reda, A.A., Kassaw, N.T., & Tadeg, W. (2022). Success rate of artificial insemination, reproductive performance and economic impact of failure of first service insemination: a retrospective study. *BMC Veterinary Research*, 18(1), 1-10. doi: 10.1186/s12917-022-03325-1.

[48] Tippenhauer, C.M., Plenio, J.L., Madureira, A.M.L., Cerri, R.L.A., Heuwieser, W., & Borchardt, S. (2021). Timing of artificial insemination using fresh or frozen semen after automated activity monitoring of estrus in lactating dairy cows. *Journal of Dairy Science*, 104(3), 3585-3595. doi: 10.3168/jds.2020-19278.

[49] Ugnivenko, A.M., & Demchuk, S.Yu. (2018). Involution of reproductive organs and reproductive functions in beef cows. In *Modern scientific idea '2018* (pp. 21-22). Retrieved from https://www.sworld.education/konferbe5/be5-sbor.pdf#page=21.

[50] Vechorka, V.V. (2010). *Evaluation of productive qualities of Holstein animals of Canadian selection depending on genotypic and paratypic factors*. (Master's thesis, Kherson State Agrarian University, Kherson, Ukraine). Retrieved from http://repo.snau.edu.ua/handle/123456789/126.

[51] Walsh, R.B., Kelton, D.F., Duffield, T.F., Leslie, K.E., Walton, J.S., & LeBlanc, S.J. (2007). Prevalence and risk factors for postpartum anovulatory condition in dairy cows. *Journal of Dairy Science*, 90(1), 315-324. doi: 10.3168/jds.S0022-0302(07)72632-2.

[52] Yablonskyi, V.A. (1995). *Practical obstetrics, gynecology and artificial insemination of farm animals*. Kyiv: Urozhai.

[53] Yablonskyi, V.A., Khomin, S.P., Kalynovskyi, H.M., Kharuta, H.H., Kharenko, M.I., Zaviriukha, V.I., & Liubetskyi, V.I. (2011). *Veterinary obstetrics, gynecology and biotechnology of animal reproduction with the basics of andrology*. Vinnytsia: Nova Knyha.

[54] Zhuravel, M.P., & Davydenko, V.M. (2005). *Technology of reproduction of agricultural animals*. Kyiv: Vydavnychyi Dim "Slovo".

[55] Ziecik, A.J., Klos, J., Gromadzka-Hliwa, K., Dietrich, M.A., Slowinska, M., Likszo, P., ... Kaczmarek, M.M. (2021). Endocrine and molecular milieus of ovarian follicles are diversely affected by human chorionic gonadotropin and gonadotropin-releasing hormone in prepubertal and mature gilts. *Scientific Reports*, 11(1), 13465. doi: 10.1038/s41598-021-91434-6.

[56] Zvierieva, H.V., Yablonskyi, V.A., Kosenko, M.V., Khomyn, S.P., Kharuta, H.H., & Kalynovskyi, S.P. (2001). *Recommendations for the prevention of infertility in livestock*. Kyiv: Naukovyi Svit.

Біотехнологія регуляції відтворювальних функцій порід *Bos primigenius taurus*

Михайло Іванович Гиль
Доктор сільськогосподарських наук, професор
Миколаївський національний аграрний університет
54008, вул. Георгія Ґонґадзе, 9, м. Миколаїв, Україна
https://orcid.org/0000-0001-7353-9865

Олена Іванівна Каратєєва
Кандидат сільськогосподарських наук, доцент
Миколаївський національний аграрний університет
54008, вул. Георгія Ґонґадзе, 9, м. Миколаїв, Україна
https://orcid.org/0000-0002-0652-1240

Михайло Михайлович Тимофіїв
Старший викладач
Миколаївський національний аграрний університет
54008, вул. Георгія Ґонґадзе, 9, м. Миколаїв, Україна
https://orcid.org/0009-0001-5920-9971

Анотація. Оскільки велика рогата худоба біологічно здатна народжувати лише одне теля в рік, її прийнято вважати одноплідним видом тварин. Одним із кардинальних методів вирішення проблеми прискореного відтворення худоби є біотехнологічна регуляція відтворювальної функції у корів та синхронізація їх статевої охоти. Метою дослідження є вивчення особливостей репродуктивної функції корів червоної степової породи під впливом різних методів її регуляції із застосуванням сучасних гормональних засобів. Для оцінки відтворювальної функції корів використано загальноприйняті зоотехнічні методики, для обрахунку даних застосовано методи варіаційної статистики, а для регуляції статевої охоти у корів біотехнологічні методи. На основі аналізу стану відтворення стада великої рогатої худоби встановлено, що щорічно штучно осіменяють 164-187 корів, 85-96 телиць, що забезпечує вихід приплоду телят на 100 корів 89-91 голів і щорічне введення в стадо від 36 до 40 первісток на 100 корів. Забезпечення скорочення сервіс-періоду сприяє як більшому виходу телят у корів, так і збільшенню надоїв, що є бажаним виробничим ефектом. Однак період необхідний для підготовки організму корови до нового осіменіння можна скоротити як мінімум до 30 днів. Осіменіння телиць апаратами штучного осіменіння слід починати при досягненні ними живої маси 314 ± 6,5 кг, що дозволить отримати заплідненість від першого осіменіння на рівні 73,7-77,8 % і тим самим упередити ожиріння телиць, через що в основному знижується відсоток заплідненості від першого осіменіння. Необхідно налагодити акушерсько-гінекологічну диспансеризацію та лікування проблемних ремонтних телиць і корів, а також доцільно використовувати аналоги простагландину $F_{2\alpha}$ в комплексі з вітамінами або біологічно активними препаратами з метою стимуляції статевої функції корів і телиць. Застосування профілактичних препаратів буде сприяти синхронізації статевого потягу телиць та сприяти підвищенню їх плодючості під час осіменіння. А організація відтворення стада великої рогатої худоби та запропоновані біотехнологічні шляхи вдосконалення штучного осіменіння маточного поголів'я червоної степової породи значно покращить їх відтворювальний статус, що підвищить в цілому економічну ефективність галузі

Ключові слова: простагландини; статева охота; сервіс-період; індекс осіменіння; сухостійний період; штучне осіменіння

UDC: 633.11:631.526.32
DOI: 10.56407/bs.agrarian/4.2023.52

Ukrainian Black Sea Region Agrarian Science
Vol. 27, No. 4

Use of effective sources of winter wheat resistance in breeding for immunity

Oksana Afanasyeva
PhD in Agriculture, Senior Researcher
Plant Protection Institute of the National Academy of Agrarian Sciences of Ukraine
03022, 33 Vasylkivska Str., Kyiv, Ukraine
https://orcid.org/0000-0002-2724-2080

Lesia Golosna
PhD in Agriculture, Senior Researcher
Plant Protection Institute of the National Academy of Agrarian Sciences of Ukraine
03022, 33 Vasylkivska Str., Kyiv, Ukraine
https://orcid.org/0000-0002-6276-8256

Galina Lisova
PhD in Biological Sciences, Senior Researcher
Plant Protection Institute of the National Academy of Agrarian Sciences of Ukraine
03022, 33 Vasylkivska Str., Kyiv, Ukraine
https://orcid.org/0000-0002-2045-4857

Anna Kryvenko*
Doctor of Agriculture, Professor
Odesa State Agrarian University
65012, 13 Panteleimonivska Str., Odesa, Ukraine
https://orcid.org/0000-0002-2133-3010

Ruslan Solomonov
PhD in Agriculture, Senior Researcher
Odesa State Agrarian University
65012, 13 Panteleimonivska Str., Odesa, Ukraine
https://orcid.org/0000-0002-6186-4676

Abstract. Winter wheat is one of the most important crops in Ukraine, and modern varieties have the potential to produce high yields under favourable conditions. The realisation of the genetic yield potential of a variety is the result of a complex interaction of genotype and environmental variables. In order to find effective sources of resistance, a collection of winter wheat accessions of different ecological and geographical origin was studied. The research was conducted in 2017-2019 in the Right-Bank Forest-Steppe, and the analysis of plant resistance of the winter wheat collection of the National Centre of Plant Genetic Resources of Ukraine was tested against a synthetic infectious background of septoria, brown rust and smut as opposed to the natural background of powdery mildew, leaf yellowing (pyrenophorosis) and other root rot. The collection of 32 varieties was represented

Article's History:
Received: 13.09.2023
Revised: 14.11.2023
Accepted: 12.12.2023

Suggested Citation:
Afanasyeva, O., Golosna, L., Lisova, G., Kryvenko, A., & Solomonov, R. (2023). Use of effective sources of winter wheat resistance in breeding for immunity. *Ukrainian Black Sea Region Agrarian Science*, 27(4), 52-59. doi: 10.56407/bs.agrarian/4.2023.52.

*Corresponding author

by 9 countries, most of them of Ukrainian origin. In the field, on artificial and natural infectious backgrounds, we identified varieties characterised by group resistance to pathogens of major diseases. The studies of adult plant resistance under conditions of infectious natural background and the use of the method of artificial complex infectious background have established that it is possible to investigate and identify sources of resistance to both individual pathogens and a complex of pathogens. As a result, no accessions were found to possess group resistance against the six pathogens presented. The selected varieties, Zdoba Kyivska, Vykhovanka Odeska and Feonia, can be used as sources of group resistance, which allows for excellent breeding efforts leading to the development of resistant wheat varieties. The selected sources are suitable for inclusion in breeding programmes as starting material for the development of modern high-yielding winter durum wheat varieties resistant to diseases and other environmental factors

Keywords: wheat samples; artificial infection background; group resistance; plant damage; hydrothermal coefficient

INTRODUCTION

Plant diseases are a factor of great importance in reducing the amount of food available and increasing its cost. Due to the tremendous growth rate of the world's population, the problem of food will continue to grow. The development of resistant varieties would be the ideal solution to the problem of diseases. However, it is not always possible to control important diseases through resistant varieties alone (Motsnyi *et al.*, 2022). However, many diseases can be controlled by combining resistance building with the use of reliable fungicides. Even partial or temporary resistance often reduces spraying costs (Mykhaylenko & Jam, 2022).

The problem of agricultural plant immunity has been relevant to researchers for a long time. This is due to the large losses caused by various diseases and pests to agricultural production around the world, including Ukraine. One of the most effective and environmentally friendly ways to combat this is to develop resistant varieties that are genetically engineered to resist diseases and pests. This approach is economically viable and reduces losses in agriculture. The same opinion is shared by O. Shevchuk & S. Mykhaylenko (2022) in their research on the resistance of wheat samples to a complex of pathogens.

Plant resistance to disease arose as a result of a long evolutionary process. This mechanism has evolved in different centres of plant origin over thousands of years. When plants acquired resistance genes, pathogens could still attack them due to the emergence of new physiological traits resulting from hybridisation, mutations, heterokaryosis and other processes. This approach allowed plants to adapt to a changing environment and provide greater resistance to disease (Lisova, 2021).

Breeding for immunity is based on the same principles as breeding for other plant characteristics, but it is much more sophisticated and specific. The main elements of this methodology are regular monitoring of the pathogenic environment, studying the morphological and physiological properties of populations of particularly dangerous pathogen species, objective assessment of the immunological characteristics of varieties and hybrids, establishing plant-pathogen interactions, and identifying and selecting highly effective sources and donors that are adapted to specific zonal conditions (Langridge & Reynolds, 2021).

Successful breeding mainly depends on the availability of high quality source material, where donors with high efficiency, especially those with dominant resistance genes, are a key factor. Existing varieties of Ukrainian and Western European breeding can serve as resistance donors. At the same time, it is important to create sustainable source material that is not only resistant to pathogens, but also has other economically valuable characteristics and properties (Miedaner & Juroszek, 2021).

Developing varieties with high resistance requires specialised breeding programmes that select only the most resistant plants. The main objective of these programmes is to develop methods for creating controlled infection conditions to assess the resistance of the material under study at all stages of the breeding process (Mahdavi *et al.*, 2022).

Thus, through the breeding approach, it is possible to add resistance characteristics to various pathogens to wheat varieties. An important factor is the diversity of genetic composition in donors, which contributes to effective selection for immunity. A key role in solving this problem is played by the source material from the world's collections, which contains a wide range of immune plant forms. Both cultivated and wild relatives of wheat are the main sources of genes that provide resistance to pathogens, which is important for one of the key crops – wheat. Therefore, the aim of the work was to study the source material of the winter wheat

collection and search for effective sources with group resistance to major pathogens.

MATERIALS AND METHODS

Based on the results of previous research conducted at the Crop Immunity Laboratory of the Institute of Plant Protection (IPP), a technology for creating an artificial complex infection background (ACIB) was developed. This background includes the pathogens of brown rust, leaf septoria and cercospora root rot caused by powdery mildew in winter wheat plants (Golosna *et al.,* 2019). A method of artificial infection of winter wheat plants with hard smut was also developed. Protection against smut infestation is necessary because these diseases are very harmful: they cause the formation of spore mass instead of grain, reduce plant resistance to other negative environmental factors and degrade crop quality.

In the period from 2017 to 2019, in the conditions of the Right-Bank Forest-Steppe, at the research farm of the Institute of Plant Physiology and Genetics of the National Academy of Sciences of Ukraine (NAS) in the village of Glevakha, Kyiv Region, the resistance of the winter wheat collection presented by the National Centre of Plant Genetic Resources of Ukraine was assessed. This evaluation was conducted using an artificial infection background that included Septoria, brown rust and hard smut against a background of natural spread of powdery mildew, yellow leaf spot (Pyrenophora) and root rot. The collection included 33 accessions from 9 countries. The majority of them were of Ukrainian breeding (20 varieties), while the rest were represented by Russia, Hungary, the Czech Republic, Bulgaria, Lithuania, the Netherlands, the USA and Kazakhstan.

The artificial infection backgrounds for leaf blight and downy mildew were created at the optimum time for plant infection. The assessment of resistance-susceptibility to leaf diseases and downy mildew was carried out during the phase of maximum disease development using the 9-point immunological scale used in the member countries of the Council for Mutual Economic Assistance (CMEA) during the peak development of the disease, where 9 points corresponded to very high resistance and 1 point – to very high susceptibility. The assessment of root rot damage to plants was carried out according to the method of A.F. Korshunova at the stage of milk-wax ripeness (Golosna *et al.,* 2019). The use of infectious material of pathogens of different diseases on the same plant material makes it possible to identify samples with signs of group resistance (Hovmøller *et al.,* 2021).

The study complies with all ethical standards in accordance with The Convention on Biological Diversity (2022). However, it is worth noting that in the period 2017-2019, the experimental plots experienced unfavourable conditions for the development and spread of cercospora root rot. Therefore, the surveys were carried out for the whole complex of root rot, due to the fact that the laboratory staff of the Institute of Plant Protection of the National Academy of Agrarian Sciences (IPP NAAS) annually create an artificial population of brown rust, septoria and cercospora root rot pathogens to form an artificial complex infectious background.

RESULTS AND DISCUSSION

Analysis of the resistance of the collection of winter wheat varieties to the main leaf diseases indicated a high level of powdery mildew infection in 2017, which was 54.5% against the background of provocation (Table 1).

Table 1. *Damage to wheat plants by major diseases in 2017-2019, %*

The causative agent of the disease	Year of accounting		
	2017	2018	2019
Powdery mildew	54.5	18.0	39.2
Septoria	44.8	53.4	63.3
Pyrenophorosis	48.4	35.4	20.3
Hard smut	-	55.2	78.4
Root rot	11.3	19.6	10.4

Source: *authors' development*

On artificial infectious backgrounds, the development of septoria was at the level of 44.8%, and pyrenophorosis – 48.4%. When analysing the weather conditions in 2017, the first and second ten-day periods of May were weak in terms of moisture, and only in the third ten-day period was the moisture level optimal, with a hydrothermal coefficient of 1.2 (HTC) (Fig. 1). The whole of June was almost without precipitation, and the moisture level was weak. The first and third ten-day periods of July were characterised by optimal moisture levels. In 2018, the development of powdery mildew was three times lower – 18.0, the development of Septoria was 13.4% higher and the development of Pyrenophora was 13% lower compared to 2017. This year was characterised by excessive moisture in the second and third decades of June and in July. In 2019, powdery mildew

development was at 39.2%, with the highest development of Septoria at 63.3% and the highest development of Pyrenophora at 20.3%. In May-July, the growing season was characterised by optimal moisture levels.

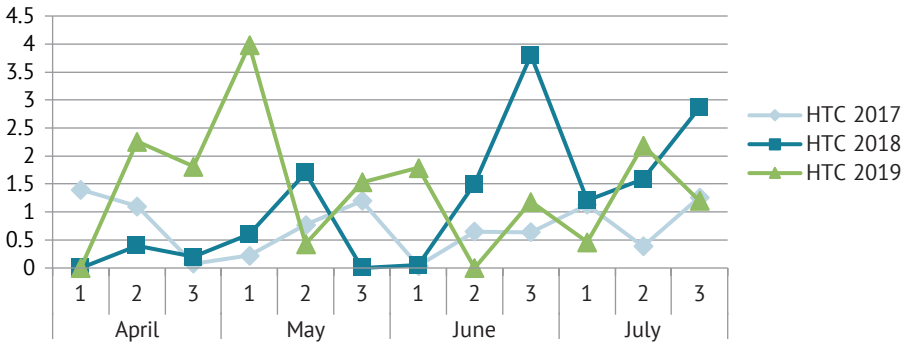


Figure 1. *Hydrothermal coefficient (HTC) values over the years of research, 2017-2019*
Source: *authors' development*

In a separate area of the collection, an artificial background of hard smut was created: in 2017, the development of the disease was 55.2%, in 2018 – 78.4%. There are only two varieties: Vykhovanka Odeska and Feonia were resistant to the pathogen, while all the others were affected by the pathogen *Tilletia caries*. During the years of research, no brown rust epiphytoties were observed on the winter wheat collection due to the avoidance of infection. In 2017, the development of the disease did not exceed 5%, in 2018 – up to 20%, in 2019 – 37.0%. One of the reasons is weather conditions. Only 7 varieties showed susceptibility to the brown rust pathogen: Erythrospermum 308-10, Borovytsia, Zoloto Ukrainy, Zelenyi Hai, Afina, MV Nador, OR 2070011. The evaluation for root rot was carried out against a natural background. Due to the low level of moisture in the periods optimal for root rot pathogens, a low level of infection was observed. In 2017, the development of rot was at 11.3%, in 2018 – 19.6%, and in 2019 – 10.4%. Over the 3 years of research, 14 varieties were found to be resistant. Among them: Buzhanka, Borovytsia, Talisman, Polianka, Koliada, Pochayna, Zdoba Kyivska, Niva Odeska, Vykhovanka Odeska, Zelenyi Hai, Feonia, Ershovska 11, Manella, OR 2070011. According to the results of evaluations over the years of research, 12 varieties characterised by resistance (points 6-7) to powdery mildew were identified: Ladyzhynka, Koliada, Pochayna, Zdoba Kyivska, Niva Odeska, Vykhovanka Odeska, Afina, Feonia, Magia, Dagmar, Lucio, Turkoaz. None of the accessions showed resistance to Septoria. The following were characterised by weak susceptibility (point 5): L 137-26-0-3, L 137-26-0-2, Erythrospermum 308-10, Kalancha, Krasnopilka, Serpanok Kyivskyi, Zdoba Kyivska, Feonia, Ershovska 11, MV Pengo, Manella. Resistance to the pathogen of pyrenophorosis was shown by 17 accessions: L 137-26-0-3, Erythrospermum 308-10, Buzhanka, Kalancha, Krasnopilka, Talisman, Polianka, Koliada, Pochayna, Zdoba Kyivska, Niva Odeska, Vykhovanka Odeska, Zelenyi Hai, Afina, Dagmar, Lucio, Turkoaz. The immunological evaluation of the varieties over the years of research is presented in Table 2. It is important for the selection of varieties to have resistance to several phytopathogens at the same time. Among the collection under consideration, there are varieties that show resistance to one, two, three, four and even five pathogens.

Table 2. *Resistance of varieties to various pathogens (average for 2017-2019), points*

№	Variety name	Powdery mildew	Septoria	Pyrenophthora	Root rot	Smut	Brown rust
1	L 137-26-0-3	6.67*	6.00*	7.00*	4.19	3.50	8.00*
2	L 137-26-0-2	6.67*	5.67*	6.67	5.48*	2.50	8.00*
3	Erytr. 308-10	6.00	5.67*	6.67	5.88*	4.50	6.00
4	Buzhanka	6.33	5.00	6.67	3.54	3.50	8.50*
5	Borovytsia	6.33	4.67	6.00	2.88	3.50	6.50
6	Ladyzhynka	7.33*	5.00	6.33	4.51	2.50	8.00*
7	Vinok Podillia	6.67*	5.33*	6.67	5.56*	5.00	7.00
8	Kalancha	6.00	5.00	7.33*	4.12	5.50	7.50*
9	Krasnopilka	6.00	5.00	8.00*	5.62*	3.00	7.00
10	Zoloto Ukrainy	6.00	5.67*	6.00	5.49*	3.50	7.00
11	Serpanok Kyivskyi	7.00*	5.33*	6.33	4.47	2.00	8.00*

Table 2, Continued

№	Variety name	Powdery mildew	Septoria	Pyrenophthora	Root rot	Smut	Brown rust
12	Talisman	7.00*	5.33*	6.67*	3.30	5.50	8.00*
13	Polianka	7.00*	5.00	6.67*	3.40	4.00	7.00
14	Koliada	7.33*	5.67*	8.33*	3.49	6.00	7.50*
15	Pochayna	7.33*	5.67*	8.00*	3.28	5.00	8.00*
16	Zdoba Kyivska	7.67*	5.33*	7.33*	6.63*	3.00	8.00*
17	Niva Odeska	7.00*	5.33*	6.33	2.69	5.00	8.00*
18	Nasnaha	6.00	4.67	5.67	4.43	2.00	8.00*
19	Vykhovanka Odeska	7.50*	5.00	6.00*	6.32*	8.00*	9.00*
20	Zelenyi Hai	4.67	4.33	7.33*	3.52	3.00	6.50
21	Afina	7.50*	4.00	7.00*	4.80	1.00	7.00
22	Nastia	6.67	5.33*	6.33	5.91*	5.50	8.00*
23	Feonia	7.33*	5.00	5.67*	6.70*	7.50*	8.50*
24	Magia	7.50*	5.50*	7.00*	4.65	5.50	7.00
25	Ershovska 11	7.00*	5.67*	7.33*	3.42	4.50	8.00*
26	MV Pengo	5.67	5.00	6.33	7.03*	2.50	7.00
27	MV Nador	7.33*	4.67	6.00	6.92*	3.00	6.00
28	Dagmar	7.67*	5.00	7.33*	6.92*	3.00	6.50
29	Lucio	8.00*	5.33*	7.67*	4.54	2.00	6.50
30	Turkoaz	7.33*	5.00	7.67*	4.79*	2.00	8.50*
31	Manella	6.33	5.00	7.00*	4.57	4.50	7.50*
32	OR 2070011	5.00	4.67	7.33*	2.89	4.00	7.00
33	Podolianka, St	6.00	6.33*	6.33	5.10*	2.00	7,50*
	X average.	6.72	5.19	6.82	4.76	3.86	7.47
	HIP_{05}	0.91	0.63	0.88	1.51	1.84	1.20

Notes: * – *high resistance point*
Source: *authors' development*

The following varieties were resistant to one pathogen: Buzhanka, Nasnaha, Zelenyi Hai, MV Pengo, OR2070011. Resistance to two pathogens was shown by 9 varieties: Erytr. 308-10, Ladyzhynka, Kalancha, Krasnopilka, Zoloto Ukrainy, Polianka, Afina, MV Nador, Manella. Among the studied varieties, the following showed resistance to three pathogens: Vinok Podillia, Serpanok Kyivskyi, Niva Odeska, Nastia, Magia, Dagmar, Lucio, Podolianka Standard. The following varieties were highly resistant to four pathogens: L 137-26-0-3, L 137-26-0-2, Talisman, Koliada, Pochayna, Ershovska 11, Turkoaz. Only 3 varieties were able to overcome the maximum number of five pathogens: two varieties of Ukrainian breeding Zdoba Kyivska, Vykhovanka Odeska and Feonia of Russian breeding. As a result of the research, no varieties with group resistance to the six pathogens presented were found.

The threat of disease damage to wheat plants remains high. The data provided by Y. Chai *et al.* (2022) show that 90% of wheat crops in the world are affected by at least one disease, and the yield shortfall is within 10%. At the same time, scientists also provide data on other important crops, with losses from diseases and pests as follows: wheat – 21.5%, rice – 30.0%, corn – 22.5%, potatoes – 17.2%, soybeans – 21.4%. At the same time, drought, cytological abnormalities or chemical mutations pose significant threats to all crops. The research by V. Horshchar & M. Nazarenko (2023), which also uses various pathogens, is devoted to the confrontation of such factors and their transformation into benefits.

Scientists S. Kaur *et al.* (2022) drew attention to the biochemical nature of plant resistance to pathogens. They noted that various natural compounds, ranging from cell wall components to metabolic enzymes, protect plants from pathogen infection and provide specific plant resistance against pathogens, which is called induced resistance.

Scientists M. Figueroa *et al.* (2018) focused their efforts on the problem of the interaction between plants and microbes. They believe that this is a phenomenal manifestation of symbiotic or parasitic relationships between living organisms. Plant growth-promoting rhizobacteria (PGPR) are one of the most widely studied plant beneficial microorganisms due to their ability to stimulate plant growth and development, as well as protect plants from biotic and abiotic stresses (Mashabela *et al.,* 2023). A. Morgounov *et al.* (2018) gave wheat resistance to diseases and pests using synthetic forms that also possessed a number of biologically and economically valuable traits, such as weight of 1,000 seeds, etc. The cloning of some rust resistance genes opens up new prospects for rust control in the future through the development of multiple resistance gene cassettes

(Soko *et al.*, 2018). However, as of 2023, chemical control based on disease surveillance, large-scale introduction of new varieties with multiple race-specific genes or sufficient adult plant resistance (APR), and reduced cultivation of susceptible varieties in rust hotspots are still the best strategies for controlling stem rust (Singh *et al.,* 2015).

Based on the results of the work carried out to assess the resistance of collection samples to various pathogens of the most common diseases of winter wheat over 3 years, a number of varieties were identified that were resistant to one or more pathogens. The need to search for sources of resistance among the studied set of wheat samples as a more effective method of preventing a decrease in the productivity of varieties and reducing the burden of chemical treatments against diseases is an urgent task, as many scientists from around the world are trying to solve the problem of wheat variety resistance using various sources and donors of resistance, including them in the breeding process (Blyzniuk *et al.,* 2019; Pavlov *et al.,* 2021). However, there are also cases when it is not possible to achieve the desired result, as in the study (Kokhmetova *et al.,* 2021). Therefore, the study, identification and use of sources and donors of resistance against major pathogens among the collection and breeding material of winter wheat, by involving them in artificial hybridisation, is an effective way to increase crop yields.

Thus, the threat of disease infection in wheat remains high, which is why scientists are studying the biochemical nature of plant resistance to diseases, pointing to induced resistance. This study, as well as similar ones, focuses on the use of modern breeding methods and genetic resources to ensure disease resistance in wheat varieties and increase crop yields.

CONCLUSIONS

The presented results provide an assessment of the resistance of wheat collection varieties against various pathogens. Resistance against two or more pathogens that differ in the biology of development, degree of damage and period of damage to wheat plants was revealed. The wide range of wheat collection samples of different origin (countries, scientific institutions – originators of varieties) studied allowed us to identify a number of sources of resistance to various diseases, which in turn opened up the possibility of their further use in the breeding process to create new original material that will have group resistance. The identification and use of new sources of resistance (including race-specific resistance) in wheat breeding as a promising method should take a worthy place among traditional methods (increasing yields, product quality, etc.). Therefore, the search for new sources of resistance (group, individual) in the study of various materials (collection, breeding, etc.) is always of great importance and will be relevant in scientific institutions when creating varieties more adapted to growing conditions.

The study of the resistance of adult plants under natural infection conditions and the use of the ACIB method made it possible to investigate and identify sources of resistance to both individual pathogens and a complex of pathogens. The varieties Zdoba Kyivska, Vykhovanka Odeska and Feonia were identified as sources of group resistance, which makes it possible to carry out high-quality breeding work to create resistant wheat varieties. The identified sources are recommended for inclusion in breeding programmes as starting material for the development of modern high-yielding soft winter wheat varieties with increased resistance to diseases and abiotic factors. There is also the problem of finding resistant samples against three or more pathogens among the wide range of collection material available at the National Plant Genebank in Kharkiv. Therefore, further study of wheat varieties using ACIB is especially important in identifying and studying resistance to various pathogens in the creation of new promising material in breeding to enhance immunity and yield of wheat.

ACKNOWLEDGEMENTS

The authors of this study express their sincere gratitude to the National Centre of Plant Genetic Resources of Ukraine of the V.Y. Yuriev Institute of Plant Industry for providing seed material of winter wheat of different ecological and geographical origin.

CONFLICT OF INTEREST

None.

REFERENCES

[1] Blyzniuk, R., Demydov, O., Chuhunkova, T., Fedorenko, M., & Berezovskyi, D. (2019). Resistance of soft spring wheat varieties against leaf fungal diseases. *Agroecological Journal*, 1, 74-79. doi: 10.36495/1606-9773.2019.65.35-50.

[2] Chai, Y., Senay, S., Horvath, D., & Pardey, P. (2022). Multi-peril pathogen risks to global wheat production: A probabilistic loss and investment assessment. *Frontiers in Plant Science*, 13, 1034600. doi: 10.3389/fpls.2022.1034600.

[3] Figueroa, M., Hammond-Kosack, K.E., & Solomon, P.S. (2018). A review of wheat diseases – a field perspective. *Molecular Plant Pathology*, 19(6), 1523-1536. doi: 10.1111/mpp.12618.
[4] Golosna, L., Lisova, G., Afanasieva, O., & Kucherova, L. (2019). Resistance of spring wheat cultivars to pathogens of leaf diseases and root rot in the Right-Bank Forest Steppe of Ukraine. *Interdepartmental Thematic Scientific Collection of Phytosanitary Safety*, 65, 35-50. doi: 10.36495/1606-9773.2019.65.35-50.
[5] Horshchar, V., & Nazarenko, M. (2023). Cytogenetic activity of a mutagenic factor with high damaging capacity in winter wheat. *Scientific Horizons*, 26(9), 131-142. doi: 10.48077/scihor9.2023.131.
[6] Hovmøller, M.S., Patpour, M., Rodriguez-Algaba, J., Thach, T., Justesen, A.F., & Hansen, J.G. (2021). *GRRC report of yellow and stem rust genotyping and race analyses 2020*. Slagelse: Aarhus University. Retrieved from https://agro.au.dk/fileadmin/www.grcc.au.dk/International_Services/Pathotype_YR_results/GRRC_annual_report_2020.pdf.
[7] Kaur, S., Samota, M.K., Choudhary, M., Choudhary, M., Pandey, A.K., Sharma, A., & Thakur, J. (2022). How do plants defend themselves against pathogens-biochemical mechanisms and genetic interventions. *Physiology and Molecular Biology of Plants*, 28(2), 485-504. doi: 10.1007/s12298-022-01146-y.
[8] Kokhmetova, A., Rsaliyev, S., Atishova, M., Kumarbayeva, M., Malysheva, A., Keishilov, Z., ... Bolatbekova, A. (2021). Evaluation of wheat germplasm for resistance to leaf rust (*Puccinia triticina*) and identification of the sources of *Lr* resistance genes using molecular markers. *Plants*, 10(7), 1484. doi: 10.3390/plants10071484.
[9] Langridge, P., & Reynolds, M. (2021). Breeding for drought and heat tolerance in wheat. *Theoretical and Applied Genetics*, 134, 1753-1769. doi: 10.1007/s00122-021-03795-1.
[10] Lisova, H. (2021). Characteristics of the resistance of spring wheat varieties to pathogens of leaf diseases typical for the zone of the Right-Bank Forest-Steppe of Ukraine. *Interdepartmental Thematic Scientific Collection of Phytosanitary Safety*, 67, 166-180. doi: 10.36495/1606-9773.2021.67.166-180.
[11] Mahdavi, S., Arzani, A., Maibody, S.A.M.M., & Kadivar, S. (2022). Grain and flour quality of wheat genotypes grown under heat stress. *Saudi Journal of Biological Sciences*, 29(10), 103417. doi: 10.1016/j.sjbs.2022.103417.
[12] Mashabela, M.D., Tugizimana, F., Steenkamp, P.A., Piater, L.A., Dubery, I.A., Terefe, T., & Mhlongo, M.I. (2023). Metabolomic evaluation of PGPR defence priming in wheat (*Triticum aestivum* L.) cultivars infected with *Puccinia striiformis* f. sp. *tritici* (stripe rust). *Frontiers in Plant Science*, 14, 1103413. doi: 10.3389/fpls.2023.1103413.
[13] Miedaner, T., & Juroszek, P. (2021). Climate change will influence disease resistance breeding in wheat in Northwestern Europe. *Theoretical and Applied Genetics*, 134, 1771-1785. doi: 10.1007/s00122-021-03807-0.
[14] Morgounov, A., Abugalieva, A., Akan, K., Akin, B., Baenziger, S., Bhatta, M., ... Bouhssini, M.E. (2018). High-yielding winter synthetic hexaploid wheats resistant to multiple diseases and pests. *Plant Genetic Resources: Characterization and Utilization*, 16(3), 273-278. doi: 10.1017/S147926211700017X.
[15] Motsnyi, I., Nargan, T., Nakonechnyi, M., Lyfenko, S., Molodchenкova, O., & Shcherbyna, Z. (2022). The influence of alien genes of resistance to common diseases on agronomic characteristics of bread winter wheat in the dry conditions of Southern Ukraine. *Odesa National University Herald. Biology*, 27(2(51), 9-29. doi: 10.18524/2077-1746.2022.2(51).268652.
[16] Mykhaylenko, S., & Jam, M. (2022). Effect of fungicides on leaf spotting of spring barley in the conditions of the Forest-Steppe of Ukraine. In *International scientific and practical conference "Modern aspects of increasing the productive potential of agricultural crops in the context of the European green course"* (pp. 93-94). Retrieved from http://elar.tsatu.edu.ua/bitstream/123456789/16521/1/stattya_13_2022_Малюк%20Т.В.pdf.
[17] Pavlov, O., Babenko, A., & Andrushchenko, A. (2021). Biological effectiveness of herbicides in winter wheat crops of autumn sowing. *Plant and Soil Science*, 12(4), 50-59. doi: 10.31548/agr2021.04.0050.
[18] Shevchuk, O., & Mykhaylenko, S. (2022). The influence of weather conditions on the development of leaf spotting of spring barley in Polissia of Ukraine. In *Materials of all-Ukrainian science and practice Internet conference "Productivity and quality of crop production under modern growing technologies"* (pp. 186-187). Retrieved from https://dspace.pdau.edu.ua/server/api/core/bitstreams/45d97191-0cb2-4cb2-ac4d-01c42ccb26c1/content.
[19] Singh, R.P., Hodson, D.P., Jin, Y., Lagudah, E.S., Ayliffe, M.A., Bhavani, S., ... Hovmøller, M.S. (2015). Emergence and spread of new races of wheat stem rust fungus: Continued threat to food security and prospects of genetic control. *Phytopathology*, 105(7), 872-884. doi: 10.1094/PHYTO-01-15-0030-FI.
[20] Soko, T., Bender, C.M., Prins, R., & Pretorius, Z.A. (2018). Yield loss associated with different levels of stem rust resistance in bread wheat. *Plant Disease*, 102(12), 2531-2538. doi: 10.1094/PDIS-02-18-0307-RE.
[21] The Convention on Biological Diversity. (2022). Retrieved from https://www.cbd.int/convention/.

Використання в селекції на імунітет ефективних джерел стійкості пшениці озимої

Оксана Геннадіївна Афанасьєва
Кандидат сільськогосподарських наук, старший науковий співробітник
Інститут захисту рослин національної академії аграрних наук України
03022, вул. Васильківська, 33, м. Київ, Україна
https://orcid.org/0000-0002-2724-2080

Леся Миколаївна Голосна
Кандидат сільськогосподарських наук, старший науковий співробітник
Інститут захисту рослин національної академії аграрних наук України
03022, вул. Васильківська, 33, м. Київ, Україна
https://orcid.org/0000-0002-6276-8256

Галина Михайлівна Лісова
Кандидат біологічних наук, старший науковий співробітник
Інститут захисту рослин національної академії аграрних наук України
03022, вул. Васильківська, 33, м. Київ, Україна
https://orcid.org/0000-0002-2045-4857

Анна Іванівна Кривенко
Доктор сільськогосподарських наук, професор
Одеський державний аграрний університет
65012, вул. Пантелеймонівська, 13, м. Одеса, Україна
https://orcid.org/0000-0002-2133-3010

Руслан Вячеславович Соломонов
Кандидат сільськогосподарських наук, старший дослідник
Одеський державний аграрний університет
65012, вул. Пантелеймонівська, 13, м. Одеса, Україна
https://orcid.org/0000-0002-6186-4676

Анотація. Пшениця озима є однією з найважливіших культур в Україні, сучасні сорти мають потенціал для отримання високих урожаїв у сприятливих умовах. Реалізація генетичного потенціалу врожайності сорту є результатом складної взаємодії генотипу та змінних чинників навколишнього середовища. З метою пошуку ефективних джерел стійкості, досліджено колекцію пшениці озимої різного еколого-географічного походження. Дослідження було проведено впродовж 2017-2019 рр. в умовах Правобережного Лісостепу, аналіз стійкості рослин колекції пшениці озимої Національного центру генетичних ресурсів рослин України протестований у синтетичному інфекційному фоні септоріозу, бурої іржі та суцільної сажки на противагу природному фону борошнистої роси, пожовтіння листків (піренофорозу) та інших кореневих гнилях. Колекція з 32 сортозразків була представлена 9 країнами світу, більшість з них української селекції. В польових умовах на штучних та природних інфекційних фонах були виділені сортозразки, які характеризувалися груповою стійкістю проти збудників основних хвороб. Проведеними дослідженнями стійкості дорослих рослин в умовах інфекційного природного фону та використання методу штучного комплексного інфекційного фону встановлено, що можливо досліджувати та виявляти джерела стійкості як до окремих патогенів, так і до комплексу патогенів. В результаті не було виявлено жодного сортозразка, який володів груповою стійкістю проти шести представлених збудників хвороб. Відібрані сорти Здоба Київська, Вихованка одеська та Феонія, можуть бути використані як джерела групової стійкості, що дозволяє створювати чудові селекційні зусилля, які призводять до створення стійких сортів пшениці. Вибрані джерела доцільні для включення в селекційні програми як вихідний матеріал при створенні сучасних високоврожайних сортів м'якої пшениці озимої, стійких проти хвороб та інших факторів навколишнього середовища

Ключові слова: зразки пшениці; штучний інфекційний фон; групова стійкість; ураження рослин; гідротермічний коефіцієнт

UDC: 621.822.5
DOI: 10.56407/bs.agrarian/4.2023.60

Ukrainian Black Sea Region Agrarian Science
Vol. 27, No. 4

Increasing the efficiency of machines and mechanisms of the agro-industrial complex using sliding bearings with curvilinear generators of the internal cylindrical surface

Oleksiy Sadovoy
PhD in Technical Sciences, Associate Professor
Mykolaiv National Agrarian University
54008, 9 Georgiy Gongadze Str., Mykolaiv, Ukraine
https://orcid.org/0000-0002-7369-0714

Oleg Savenkov
Assistant
Admiral Makarov National University of Shipbuilding
54007, 9 Heroyiv Ukrayiny Ave., Mykolaiv, Ukraine
https://orcid.org/0000-0002-7165-3995

Ihor Sydoryka*
PhD in Technical Sciences
Mykolaiv National Agrarian University
54008, 9 Georgiy Gongadze Str., Mykolaiv, Ukraine
https://orcid.org/0000-0001-9647-1744

Yuriy Shcherbak
PhD in Technical Sciences, Associate Professor
Petro Mohyla Black Sea National University
54000, 10 68 Desantnykiv Str., Mykolaiv, Ukraine
https://orcid.org/0000-0002-0875-6254

Anna Kondratieva
Student
Admiral Makarov National University of Shipbuilding
54007, 9 Heroyiv Ukrayiny Ave., Mykolaiv, Ukraine
https://orcid.org/0000-0002-8470-2813

Abstract. Sliding bearings with curved internal cylindrical surfaces have great potential and can play an important role in the repair and restoration of mechanisms of the agro-industrial complex. Since their use is becoming more and more common, there is a need to improve the design of such bearings to ensure their quality use and avoid errors in research on this issue, in addition, achieving better results in this area require significant financial investments to improve the efficiency of such mechanisms. The main goal of this work is to provide recommendations aimed at eliminating errors in the processes of improving and improving the quality of sliding

Article's History:
Received: 05.08.2023
Revised: 25.10.2023
Accepted: 12.12.2023

Suggested Citation:
Sadovoy, O., Savenkov, O., Sydoryka, I., Shcherbak, Yu., & Kondratieva, A. (2023). Increasing the efficiency of machines and mechanisms of the agro-industrial complex using sliding bearings with curvilinear generators of the internal cylindrical surface. *Ukrainian Black Sea Region Agrarian Science*, 27(4), 60-70. doi: 10.56407/bs.agrarian/4.2023.60.

*Corresponding author

bearings, as well as analyzing the functioning of machines used in the agro-industrial complex. An analytical method, a classification method, a functional method, a statistical method, and a synthesis method were used. In the course of the research, the peculiarities and differences of sliding bearings with curvilinear generators of the internal cylindrical surface were noted, errors and their causes, which are allowed during the improvement of agro-industrial mechanisms that ensure the development of the agricultural industry, were analyzed. It is important to analyze the functioning of these mechanisms in order to assess their effectiveness, development and complexity of work during the production of agricultural products. The issue of evaluating the performance of sliding bearings of this type, the expediency of using this element, their limitations during the process, the impact of limitations on the result was considered, and recommendations were proposed that would contribute to an effective mechanism for regulating the issue. It was determined that the use of sliding bearings of this type, in the process of restoring agro-industrial mechanisms, will ensure a significant increase in the productivity of these machines. The practical value of this work lies in the possibility of applying the obtained results to eliminate errors in the development and improvement of the mechanisms of the agro-industrial complex, studying the reliability of the use of sliding bearings in general, taking into account various factors, will provide a basis for recommendations on the appropriate use of these bearings

Keywords: wedging; agricultural production; shaft; deformations; repair

INTRODUCTION

The agro-industrial complex is an integral part of the economy of many countries, it unites various industries, such as the production of agricultural products, their processing, material and technical support of rural settlements, as well as the production and maintenance of mechanisms and infrastructure of the agro-industrial sector, in addition, it covers the fields of preservation, processing and sale of agricultural products. Thus, the development of the economy primarily depends on the sphere of the agro-industrial complex, which includes agricultural machine building, machine building for the food industry, agrochemistry, compound feed industry, the system of material and technical service of agriculture and land reclamation, and rural construction. In turn, the specified sphere of the agricultural industry directly depends on the efficiency of the machines and mechanisms entering it.

R. Marchuk & R. Mnatsakanov (2023) claim that the introduction of new technologies and equipment allows to increase the efficiency of the mechanisms of the agro-industrial complex and agricultural processes, reduce the consumption of energy, resources and labor, as well as improve the quality and quantity of products. Improving the mechanisms of the agro-industrial complex arises from the need to solve problems related to errors that occur at the stages of development and operation of these machines. These problems, in turn, arise in connection with the need to determine and optimize indicators at the stages of design, operation and development of equipment. In addition, the growing demand for affordable agricultural services leads to the need to reduce costs, which places certain demands on the improvement of these mechanisms.

In the study of V.A. Matviychuk *et al*. (2022) stated that the use of high-quality materials in the manufacture of sliding bearings provides higher reliability and durability in conditions of misalignment and elastic deformation of the shaft section. In this direction, it is necessary to expand the range of designs of sliding bearings, which will be specially calculated for the conditions of distortions and elastic deformations of the shaft section, which will allow to increase the number of working mechanisms of the agro-industrial complex and contribute to the modernization of production processes, and the result will be an increase in the quality of the provision of agricultural services to a high level.

V. Syrovatka (2023) states that sliding bearings do not require lubrication or lubrication equipment and can work directly on the sliding surfaces. After analysing the working mechanism of plain bearings, it was found that they show less sensitivity to external particles such as dust, which provides them with higher resistance to contamination, as a result of which plain bearings remain important components of industrial systems in many industries.

According to the results of D.V. Borysiuk *et al*. (2023), babbitt coatings on the working surfaces of plain bearings can peel or chip due to high loads or insufficient lubrication. It also indicates that stress and wear are causing cracking and ulceration of the bearing sliding surfaces. In view of this, timely maintenance, lubrication and replacement of bearings will ensure the preservation of their efficiency and reliable operation of machines and mechanisms of the agro-industrial complex.

Scientists M. Kindrachuk *et al*. (2023) note that when a liner becomes stuck between the shaft and the

bearing housing wall, the lubrication regime can be disrupted, leading to complete or partial cessation of lubrication. As a result, there is an increase in friction and an increase in temperature, which causes premature wear and damage to the bearing. Seizure of the liner can cause an unacceptable increase in pressure between the shaft and the liner. It was also not taken into account that as a result, if the shaft remains stationary in the plain bearing, the bearing may fail completely. O.V. Yeromenko *et al.* (2023) note that the most common method of restoring bearing performance is to completely replace the bearing with a new one. In this case, the old failed bearing is removed or pushed out of the bearing housing and a new bearing is installed.

The purpose of this study was to perform an objective analysis to identify problems and errors in the process of improving the efficiency of the mechanisms of the agro-industrial complex using sliding bearings, which are the basis of sustainable development of the agricultural sphere, at the current stage of development of this sector in order to formulate recommendations for their elimination. Completion of the task, which is formed on the basis of this goal, will provide an opportunity for the progressive development of innovative methods of reducing and avoiding errors in the process of increasing the efficiency of machines of the agro-industrial complex by means of the development of sliding bearings with curvilinear generators of the internal cylindrical surface.

It is worth noting that the issue of inhibiting the process of designing and improving sliding bearings is of particular importance, in connection with which it is necessary to study ways to overcome this problem and develop a certain range of recommendations, there is also a need to improve the mechanisms of the agro-industrial complex and their systems for the most efficient functioning of this process in countries.

MATERIALS AND METHODS

Theoretical studies were based on the theory of contact hydrodynamic lubrication taking into account the equation of hydrodynamic pressure at an arbitrary point of the bearing lubrication layer and the fundamental principles of mechanical engineering tribology using the approaches of theoretical mechanics and machine parts, as well as on the theory of contact strength of elastically compressed bodies. In addition, the method of assessing contact characteristics and predicting the durability of cylindrical sliding tribosystems was applied.

The application of the analytical research method made it possible to identify and isolate problems related to the operation of machines of the agro-industrial complex, which are used in the processes of production and processing of agricultural products. With the help of a statistical method, the indicators that help to understand the number and causes of errors in the improvement of sliding bearings, which are the basis of the sustainable development of agricultural mechanisms, the implementation of improving the operation of these mechanisms, the prospects for using these bearings, and the development of the stability and productivity of machines of the agro-industrial complex in the process of processing products were considered.

Applying the functional method, a detailed analysis of the role and essence of sliding bearings with curvilinear generators of the internal cylindrical surface was carried out at different levels of development of machines of the agro-industrial complex. The advantages and disadvantages of their operation were also identified, and the influence of the functioning of agricultural mechanisms on the material and technical support of rural areas was analysed. With the help of the structural-functional method, trends, factors and models aimed at improving sliding bearings were considered, and effective options for solving problems related to design errors, improving the maintenance of machines of the agro-industrial complex and its components were identified and analysed. In addition, the methods of improvement and innovation of mechanisms were studied in order to reduce inaccuracies in their functioning and to optimize indicators at the stages of development. Applying the deduction method, the concept of "increasing the efficiency of machines and mechanisms of the agro-industrial complex by using sliding bearings with curved internal cylindrical surface" was revealed by identifying its characteristics, which are necessary for a complete analysis of the work and solving the problems of this process, in particular, regarding the introduction of sliding bearings with curved internal surfaces cylindrical surface.

By applying the synthesis method, the obtained indicators of theoretical analysis and practical experience were summarized and considered in order to identify recommendations aimed at solving problems and achieving progressive growth of the process. Special attention was paid to improving the quality of development of mechanisms of the agro-industrial complex and reducing errors. Predictive models and design solutions were also presented for the component elements, in particular for plain bearings, which perform an important function in this process. Thanks to the methods of logical and functional analysis, the theoretical component of the work was revealed. They provided an opportunity to consider in more detail the concept of "sliding bearings with curved internal cylindrical surfaces".

These methods made it possible to characterize the peculiarities and principles of the functioning of the agro-industrial complex and the process of processing agricultural products. In addition, the complexity of the operation of mechanisms in agricultural processes and their impact on meeting the needs of the population and user requirements was analysed. As a result, the purpose of applying the methods was to study and consider recommendations regarding the feasibility of improving sliding bearings and using this mechanism.

RESULTS AND DISCUSSION

To ensure reliable processing of agricultural products and efficient operation of the mechanisms of the agro-industrial complex in various areas of the agricultural industry, progressive development of the production of sliding bearings is necessary. Special attention should be paid to the improvement of their components, in particular to accurate design and modelling, since these bearings are widely used in the mechanisms of the agro-industrial complex, which will contribute to increasing the production potential of agricultural machines. It is important to choose the right type of bearing for specific operating conditions. Plain bearings have unique characteristics and may be suitable for certain types of loading and operating conditions. Proper lubrication is essential for bearing reliability. It is necessary to take into account the type of lubricant or oil and the intervals between oil changes. Before refilling a bearing with babbitt, certain preparatory procedures must be performed, for example, the previous layer of babbitt must be removed to provide a clean surface for the new fill. A. Guo *et al*. (2015) emphasize that bearing surfaces must be thoroughly cleaned of dirt, rust, grease, and other contaminants. This can be done using special solvents, cleaning solutions or other cleaning methods.

As of 2023, it is important to solve the problem of errors that occur during the development, improvement and modelling of the mechanisms of the agro-industrial complex. These errors have a direct impact on increasing the production potential of the agricultural industry, the reliability of service provision and the safety of processing, and special attention should be paid to the efficiency of the mechanisms in remote areas and the further development of the use of these machines in the agricultural sector. The replacement of cylindrical surfaces with elliptical ones ensures better operation of the sliding bearing against distortions and elastic deformations of the shaft, and also reduces the risk of shaft jamming. However, reducing the effects of shaft seizing in plain bearings is limited and may not result in significant performance improvements. Many factors affect the reliability and performance of a bearing, and shaft seizing is just one of them. Antifriction alloys (babbitt), consisting mainly of tin and lead, are widely used in the production of sliding bearing liners. These alloys are known for their excellent anti-friction and lubricating properties, making them an ideal choice for use in bearings where it is important to ensure reliable operation at the metal-to-metal contact surface. S. Woo *et al*. (2023) note that babbitt has high lubricity and can effectively lubricate sliding surfaces.

In the field of machines of the agro-industrial complex, it is necessary to conduct an analysis and identify the root causes of errors during agricultural processing. Further resolution of these reasons is aimed at improving the quality of material and technical support. The anti-friction alloy must have high wear resistance to prevent serious mechanical damage and guarantee a long service life of the sliding bearing. In addition, this material must have sufficient resistance and strength to withstand the loads that occur during the operation of the bearing and prevent its deformation and damage. To solve the problem of jamming of the shaft in a sliding bearing, which consists of a housing, a liner, a lubrication groove and an opening for the supply of lubricant in the housing, on the internal cylindrical surface of which flat elements (ordinary bearings) are replaced by curved elements with a radius of curvature:

$$R = \frac{l^2}{8\Delta s}, \quad (1)$$

where l – the length of the bearing; ΔS = 0.010-0.030 mm – the value of the curvature parameter of the product in the end sections of the bearing.

Figure 1 shows a model of a conventional plain bearing.

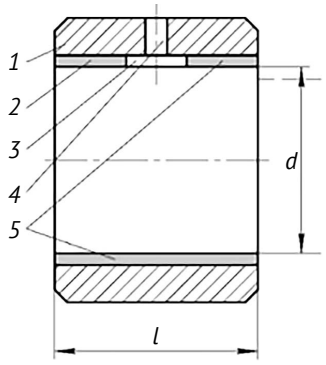


Figure 1. *Design of a conventional sliding bearing and a rotating section of a shaft loaded with a radial force*
Notes: *d – the diameter of the sliding bearing; l – the length of the sliding bearing; 1 – body; 2 – insert; 3 – grooves for lubrication; 4 – hole for supply of lubricant; 5 – rectilinear side internal cylindrical surfaces*
Source: *compiled by the authors*

Figure 2 shows a section of a rotating shaft under the action of a radial force.

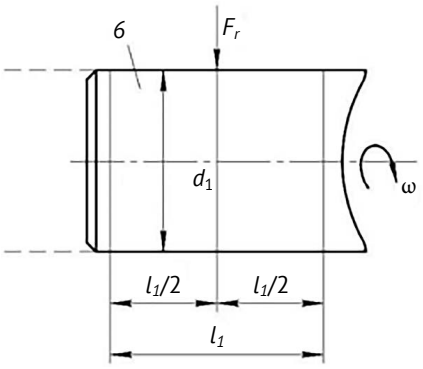


Figure 2. *Section of the rotating shaft (6) loaded with radial force*
Notes: *d1 – the diameter of the shaft, with $d_1 < d$; l – the length of the sliding bearing; F^r – radial force; ω – the angular speed of the shaft*
Source: *compiled by the authors*

Figure 3 shows a model of a sliding bearing with a curved product of the internal cylindrical surface, which is characterized by a constant radius of curvature.

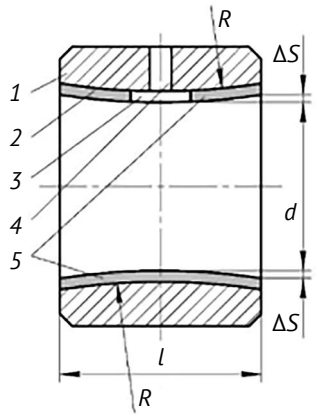


Figure 3. *The design of a sliding bearing with a curved product of the internal cylindrical surface, which is characterized by a constant radius of curvature*
Notes: *d – the diameter of the sliding bearing; l – the length of the sliding bearing; R – the radius of the curved product of the internal cylindrical surface of the sliding bearings; ΔS – the value of the measurement of the curvilinear product in the transverse sections of the sliding bearing; 1 – body; 2 – insert; 3 – grooves for lubrication; 4 – hole for supply of lubricant; 5 – curved side internal cylindrical surfaces*
Source: *compiled by the authors*

Y. Henry *et al.* (2015) noted that the development of new methods for solving the tasks of eliminating errors in the development, design and improvement of sliding bearings to increase the potential of the mechanisms of the agro-industrial complex in the agricultural sector currently has enormous progress and prospects. Alloys for the manufacture of liners must have the ability to retain lubricant on the surface to ensure lubrication of parts in contact during movement. This reduces friction and wear and improves bearing performance. A plain bearing works by causing a certain section of the shaft, which is within the length of the bearing, to rotate at a certain angular velocity. This area interacts with the bearing's internal bearing surface, causing a radial load on the plain bearing.

If in the improvement of machines of the agro-industrial complex, which are the basis of sustainable development of the agricultural sector, start using modern electronics and computerized data processing of transport footnotes, this will help to significantly increase the capabilities of these processes and mechanisms, as well as increase the demand for their use in many areas. S. Wadhwa & A. Chauhan (2023) noted that the adhesion between the babbitt layer and the base has a decisive effect on the performance of the bearing. Insufficient or unreliable adhesion can lead to problems such as babbitt delamination and delamination, resulting in reduced functionality and reduced bearing life. Optimal adhesion is achieved by using appropriate methods of surface preparation and interaction of materials. In most cases, the shaft is subjected to elastic deformations, which leads to its skewing relative to the sliding bearing. This skewing of the shaft has the effect of its clamping by the internal cylindrical surface of the bearing.

The task of effective management of the technological regimes of the mechanisms of the agro-industrial complex and their problems with the application and development of innovative parts and devices for use are gaining more and more relevance and practical value in many countries. Sliding bearings, which consist of a housing, a liner, a groove for lubrication and an opening for supplying lubricant, have the disadvantage of pinching the attached shaft under the action of radial loads. W. Zhang & B. Zhu (2023) determined that the shaft moves elastically during operation, which adversely affects the reliability and functionality of the bearing and, in most cases, leads to bearing failure. Pinching occurs when the shaft is subjected to radial loads, moves and presses on the internal surface of the bearing. This can be caused by incorrect or insufficient clearance between the shaft and the bearing, or insufficient rigidity of the bearing design. When the shaft is pinched in the sliding bearing, the shaft contacts the insert in the end sections. This leads to a violation of the lubrication conditions, an increase in the pressure between the shaft and the liner and, as a result, to the loss of bearing support.

In this complex process, reviewing the causes of errors in the improvement of sliding bearings with curvilinear generating internal cylindrical surfaces, which increase the potential of machines of the agro-industrial complex in the agricultural sphere, and their solution acquires special importance, since the development of this process and their mechanisms in the world is one of the urgent problems of modern times. C.I. Papadopoulos *et al.* (2014) noted that heavy plain bearings are subjected to high mechanical loads, high pressure and friction. This imposes special requirements on the materials used for the manufacture of bearings and their components. One of the important factors is the tribotechnical properties of materials. A low coefficient of friction leads to low wear and improved operational characteristics of the bearing. Materials must also have high wear resistance and withstand high loads. In the technical solution, it is shown that a sliding bearing with curved elements and a liner (Fig. 3) has special properties compared to rectilinear elements and an insert (Fig. 1). When the shaft is distorted within its elastic deformation during free rolling, jamming occurs in the sliding bearing, which is caused by the cross section of the shaft.

Very often, the processing and execution of proper processes in the system of mechanisms of the agro-industrial complex has certain errors, which impairs the efficiency of these vehicles for use in the agricultural sector. Changing the geometry of the liner can have a significant impact on the bearing capacity, service life and stability of shaft rotation in the lubricant layer. I. Terra *et al.* (2023) indicated that optimizing liner geometry improves pressure distribution and reduces jamming between the shaft and liner. This results in an improved lubricating film, reduced friction and wear, and increased bearing life. In addition, the liner geometry can be changed to affect load distribution and improve uniformity on the bearing surface. This reduces stresses caused by unbalanced loads and contributes to increased bearing reliability. The proposed sliding bearing (Fig. 3) meets the requirements and has stable performance, regardless of various types of distortions and elastic deformations of the shaft.

The elimination of errors in the improvement of sliding bearings is not fully resolved. In the agricultural sector, sliding bearings are used in tractors, combines, planters, sprayers and other agricultural machinery. In forestry, they are used in logging machinery such as logging machines, logging cutters and saws. The proposed sliding bearing differs from existing bearings in that the contact between the shaft and the liner is in the form of a point engagement instead of a linear engagement. This leads to significantly lower specific loads on the bearing, as the large force is distributed over a limited contact area.

Mechanisms of the agro-industrial complex and their components are often used due to their efficiency and low cost of operation. As of 2023, there is increasing interest in this process in many countries to increase agricultural potential. The use of sliding bearings with curved internal cylindrical surfaces allows to significantly increase the efficiency of machines and mechanisms in the agricultural sector. The main advantage of such bearings is that they avoid jamming of the shaft in the bearing, which can occur when using bearings with straight raceways. Jamming of shafts in bearings can cause serious problems such as seizing, wear, failure and reduced system performance. Thanks to the curved internal cylindrical surface of the bearing, the contact with the shaft occurs at a point or on a very small area, which allows the load to be distributed over a limited area. Thus, the bearings can withstand high loads with a minimum specific load, maintaining performance and extending the life of the shaft without constant maintenance and repair.

The economic effect of the introduction into the composition of machines and mechanisms is expected due to a significant increase in the service life of the sliding bearing, which does not clamp the shaft section due to elastic deformations. To simplify calculations, it should be taken into account that the calculation of sliding bearings is based on the determined load factor $K_p = (p \cdot \psi^2)/(\mu \cdot \omega)$, according to which the curve $l/d = 0.2\text{-}0.9$ (Fig. 4) characterizes the relative length of the bearing, the relative eccentricity $\chi = 2e/\delta$ and the minimum thickness of the lubricating layer are determined by:

$$h = (1 - \chi)\delta/2, \quad (2)$$

where $p = F_r/ld$ – conditional pressure, MPa; F_r – the radial force acting on the bearing, N; l, d – length and diameter of the bearing, respectively, mm; $\psi = 0.8 \cdot 10^{-3}\sqrt{V}$ – relative clearance in the bearing; V – shaft speed, m/s; μ – the absolute viscosity of the oil, MPa s; ω – angular speed of the shaft, 1/s; $\delta = \psi \cdot d$ – radial clearance in the bearing, mm; e – eccentricity.

Thus, the existing method of calculating sliding bearings is graphic and characterized by a sufficiently high error. The points of rupture of the lubricating layer and the maximum pressure are located symmetrically relative to the central line. In this regard, the angle $\varphi_2 = 180° + \varphi_{min}$, where φ_{min} – the angle characterizing the position of the end of the pressure distribution curve relative to the minimum thickness of the lubricating layer. The angle ψ_0 (Fig. 5) is called the load angle and characterizes the degree of loading of the sliding bearing.

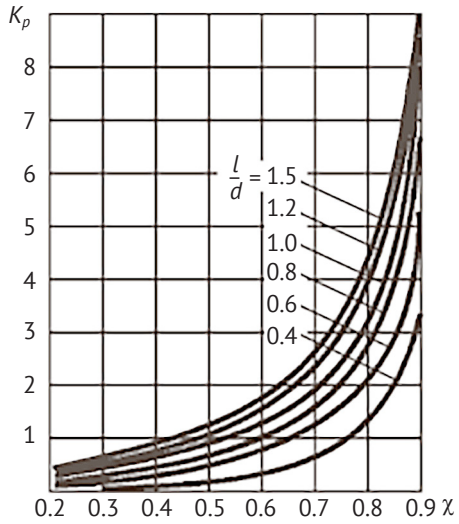


Figure 4. *Stress load diagram of a sliding bearing*
Source: *compiled by the authors*

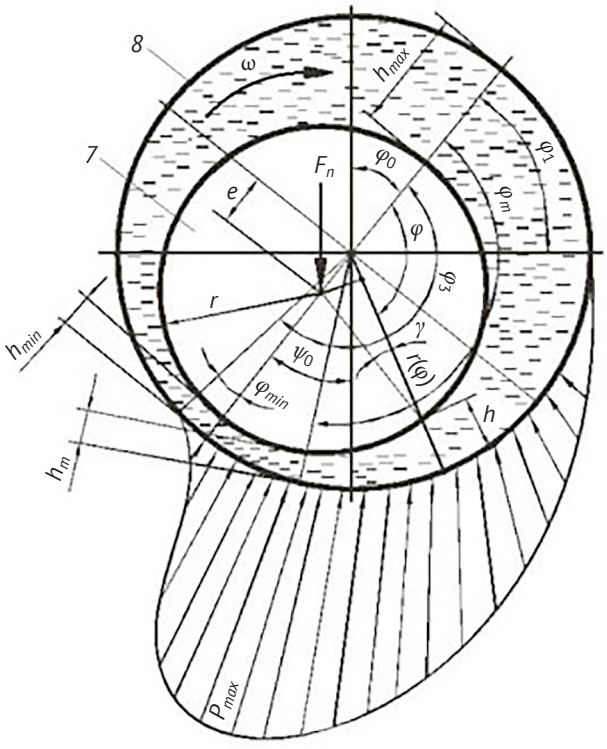


Figure 5. *Rotating shaft (7) in sliding bearing (8)*
Source: *compiled by the authors*

B. Vinod *et al.* (2023) note that in recent years, many countries have made significant progress in the development of design and modelling methods for improving machines and mechanisms of the agro-industrial complex, this direction has received considerable attention and undergone significant improvements. To reduce the specific load on the sliding bearing with curved elements, a design with a curved shape of the internal cylindrical surface of the liner is used. This geometry results in a point contact between the shaft and the liner, which distributes the load over a larger contact area. This distribution helps to reduce the specific pressure and improves the distribution of load forces on the bearing.

In achieving optimal productivity of the mechanisms of the agro-industrial complex and increasing the potential of the agricultural sector in countries, the qualification of personnel and timely diagnostics of equipment are of great importance. The main advantages of sliding bearings with curved contact surfaces are their reliability and service life. The curvilinear shape of the raceways provides an even distribution of the load over the contact area between the shaft and the liner, which reduces the specific load and increases the efficiency of the bearing. This design also reduces the impact of distortion and elastic deformation of the shaft, ensuring reliable operation of the bearing even under variable operating conditions. Based on the results of research by A. Xu *et al.* (2023) concluded that the use of plain bearings with curved raceways can improve the vibration and acoustic performance of the system. This is achieved due to several factors. First, in sliding bearings with curved contact surfaces, vibration is reduced because the shaft rolls more smoothly and without shocks. The curved geometry of the raceway provides a point contact between the shaft and the trunnion, which results in a smoother movement of the shaft. As a result, harmful vibrations in machines and equipment can be reduced, especially at high speeds and under heavy loads.

A. Soni *et al.* (2023) determined that the implementation of sliding bearings with curved raceways in machinery and equipment has significant economic benefits. One of the reasons for the longer service life is the absence of jamming of the shaft due to elastic deformation. In conventional plain bearings, the shaft and liner interact along the contact line, resulting in elastic deformation that can lead to shaft seizing, surface wear, and reduced bearing life. In radial thrust bearings, these problems are minimized because the point contact reduces the effect of elastic deformation, ensuring stable operation over a long period of time. In addition, maintenance and replacement costs are lower due to the longer life of plain bearings. This confirms the fact that the data of the authors' work coincide with modern trends in the field of designing and modelling methods for improving the mechanisms of the agro-industrial complex. In the modern world, great attention is paid to taking into account all factors that affect the quality of these works in

order to increase the potential of the agricultural sector. However, this work did not take into account that an important feature is the longer service life of sliding bearings, which in turn reduces the risk of accidents and unexpected stops in the event of bearing failure.

Researchers R. Phiri *et al*. (2023) determined that when designing sliding bearings, a load factor is used to determine the relative bearing length, relative eccentricity, and minimum thickness of the lubricant layer. This load factor is usually determined using a graphical method. Depending on the type of bearing and the specific situation, the appropriate load curve is selected. The curve shows the relationship between the relative length of the bearing, the relative eccentricity and the minimum thickness of the lubricant layer. But for a more correct operation of sliding bearings and mechanisms of the agro-industrial complex, it is necessary to carry out an inspection of buildings on a permanent basis, due to which the potential of the agricultural sector in the countries will soon reach high values. There are differences with this work in that the author did not notice exactly the importance of the features of using this type of sliding bearings.

D. Martins *et al*. (2023) note that such curves as load curves, stress loss curves, and load capacity curves are known in graphical methods of calculating sliding bearings. These curves are used to determine the required bearing parameters, such as relative length, relative eccentricity, and minimum grease layer thickness. However, this task is complex and may introduce some error. In addition, the graphical method requires the identification and interpretation of points on the curve. This can lead to errors in subjective assessments and determination of parameters. In this work, the results of the characteristics of sliding bearings were analysed and more precisely considered, so the results can be supplemented by the fact that the increase in the potential of the agricultural sector directly depends on the improvement and innovation of agricultural services and the provision of high-quality service to the machines of the agro-industrial complex and their mechanisms.

J. Pichler *et al*. (2023) showed that due to the limitations and inaccuracies of the existing graphical methods of calculating sliding bearings, it is necessary to develop new, simplified methods. More accurate results can be obtained without the use of graphs with the help of analytical models and mathematical formulas. This includes consideration of factors such as elastic deformation, bearing design parameters and operating conditions. However, the authors pointed out and considered that currently the use of computer programs and numerical methods allows modelling the behaviour of sliding bearings with different input parameters, which allows obtaining more accurate results and reduces subjectivity. It can also be noted that this is due to the fact that experimental tests on real bearings provide valuable data for improving calculation methods, because of this there is a difference between this work and the work of the specified author.

M. Mitra *et al*. (2023) state that relative eccentricity is defined as the distance between the centre of the bearing and the centre line of the shaft as a percentage of the bearing radius. It is used to estimate the degree of deviation from the ideal centre of the bearing. The relative eccentricity ranges from 0 to 100%, where 0% corresponds to the ideal centre and 100% to the maximum eccentricity. Changing the angle and relative eccentricity can affect load distribution, contact forces, friction and bearing wear. The determined values of the angle and relative eccentricity allow to analyse the parameters affecting the operation and reliability of the bearing, such as specific pressure, contact angle and distribution of lubricant. Research findings that this parameter is important in the design and calculation of plain bearings to account for eccentricity and to ensure proper loading and functional characteristics of the bearing should also be included. In order to achieve improvement in the design and modelling of methods for improving the mechanisms and machines of the agro-industrial complex, as well as to reduce errors in sliding bearings during complex technological processes, it is necessary to pay attention to two aspects: increasing funding and improving the qualifications of employees, as well as introducing new technologies. The main goal of these measures is to improve the quality and efficiency of the process of improving the mechanisms and machines of the agro-industrial complex, as well as to reduce the risk of errors.

CONCLUSIONS

Sliding bearings with curved internal cylindrical surfaces have a constant radius of curvature, which distinguishes them from rectilinear inserts with straight surfaces, which are used to regulate the shaft when it is skewed within the limits of elasticity. In bearings with curved bearing surfaces, when the shaft axis bends, the cylindrical surface is not pinched, which allows free rolling. The obtained results indicate that sliding bearings with curved elements of the internal cylindrical surface have a stable radius of curvature, which allows them to avoid pinching when the shaft is deflected within its elasticity. The proposed sliding bearings have a point contact

of the shaft with the insert and are characterized by lower specific load values compared to known sliding bearings. This paper reviewed and presented recommendations for eliminating errors in the processes of designing and implementing mechanisms of the agro-industrial complex. It was also carefully analysed technological processes in sliding bearings, errors and problems that are allowed during the functioning of agricultural product processing processes, and the introduction of effective tools that allow solving these issues and preventing errors was proposed. In order to improve the machines of the agro-industrial complex, sliding bearings were considered, which expand this resource base by introducing sliding bearings with curvilinear generators of the internal cylindrical surface, which have a constant radius of curvature, demonstrate stable performance, increased service life and improved vibroacoustic characteristics. It was considered that with the help of introduction of sliding bearings with curvilinear generators of the internal cylindrical surface with a constant radius of curvature, it is possible to increase the efficiency of the work of machines, mechanisms and aggregates in agriculture. The research successfully completed the assigned task, including the analysis of the problems of improving the mechanisms of the agro-industrial complex, the development of ways to improve the processes of the mechanisms, as well as the identification and proposal of methods for eliminating errors in the process of improving the efficiency of the machines of the agro-industrial complex. All this will help increase the potential, competitiveness and quality of agricultural services. Analysed modern approaches to the problems of improving sliding bearings will try to respond to modern needs for further prospective use of the mechanism. Future research will be aimed at creating and implementing innovative mechanisms in the agro-industrial complex in order to promote the agricultural sector.

ACKNOWLEDGEMENTS

None.

CONFLICT OF INTEREST

None

REFERENCES

[1] Borysiuk, D.V., Tverdokhlib, I.V., Kupchuk, I.M., & Polievoda, Yu.A. (2023). Mathematical model of diagnosing the bearing assembly of the hub of steered bridges of wheeled tractors of traction class 1,4. *Engineering, Energy, Transport AIC*, 1(120), 14-20. doi: 10.37128/2520-6168-2023-1-2.

[2] Guo, A., Wang, X., Jin, J., Hua, D.Y., & Hua, Z. (2015). Experimental test of static and dynamic characteristics of tilting-pad thrust bearings. *Advances in Mechanical Engineering*, 7(7). doi: 10.1177/1687814015593878.

[3] Henry, Y., Bouyer, J., & Fillon, M. (2015). An experimental analysis of the hydrodynamic contribution of textured thrust bearings during steady-state operation: A comparison with the untextured parallel surface configuration. *Proceedings of the Institution of Mechanical Engineers, Part J: Journal of Engineering Tribology*, 229(4), 362-375. doi: 10.1177/1350650114537484.

[4] Kindrachuk, M., Kharchenko, V., Humeniuk, I., & Leusenko, D. (2023). Influence of alloying the metal matrix on the anti-friction properties of eutectic coatings. *Problems of Friction and Wear*, 1(98), 63-69. doi: 10.18372/0370-2197.1(98).17360.

[5] Marchuk, R., & Mnatsakanov, R. (2023). Analysis of polymer composite materials for sliding bearings. *Problems of Friction and Wear*, 1(98), 55-62. doi: 10.18372/0370-2197.1(98).17359.

[6] Martins, D.H.C.S.S., de Lima, A.A., Pinto, M.F., Hemerly, D.D.O., Prego, T.D.M., e Silva, F. L., ... Haddad, D.B. (2023). Hybrid data augmentation method for combined failure recognition in rotating machines. *Journal of Intelligent Manufacturing*, 34(4), 1795-1813. doi: 10.1007/s10845-021-01873-1.

[7] Matviychuk, V.A., Gaidamak, O.L., & Karpiichuk, M.F. (2022). Prospects for creating surface layers of deta-leu with increased tribological characteristics using gas-dynamic filling. *Engineering, Energy, Transport AIC*, 1(116), 83-95. doi: 10.37128/2520-6168-2022-1-10.

[8] Mitra, M., Singha, N.R., & Chattopadhyay, P.K. (2023). Review on renewable energy potential and capacities of South Asian countries influencing sustainable environment: A comparative assessment. *Sustainable Energy Technologies and Assessments*, 57, 103295. doi: 10.1016/j.seta.2023.103295.

[9] Papadopoulos, C.I., Kaiktsis, L., & Fillon, M. (2014). Computational fluid dynamics thermohydrodynamic analysis of three-dimensional sector-pad thrust bearings with rectangular dimples. *Journal of Tribology*, 136(1), 011702. doi: 10.1115/1.4025245.

[10] Phiri, R., Rangappa, S.M., Siengchin, S., Oladijo, O.P., & Dhakal, H.N. (2023). Development of sustainable biopolymer-based composites for lightweight applications from agricultural waste biomass: A Review. *Advanced Industrial and Engineering Polymer Research,* 6(4), 436-450. doi: 10.1016/j.aiepr.2023.04.004.

[11] Pichler, J., Nothnangel, R.M., Besser, C., Pisarova, L., Dörr, N., Marchetti-Deschmann, M., & Frauscher, M. (2023). A comprehensive review of sustainable approaches for synthetic lubricant components. *Green Chemistry Letters and Reviews*, 16(1), 2185547. doi: 10.1080/17518253.2023.2185547.

[12] Soni, A., Das, P. K., Yusuf, M., Ridha, S., Kamyab, H., Chelliapan, S., ... Mussa, Z.H. (2023). Valorization of post-consumers plastics and agro-waste in sustainable polymeric composites for tribological applications. *Waste and Biomass Valorization*. doi: 10.1007/s12649-023-02103-w.

[13] Syrovatka, V. (2023). Obtaining composite powder materials and coatings based on titanium diboride. *International Science Journal of Engineering & Agriculture*, 2(3), 10-17. doi: 10.46299/j.isjea.20230203.02.

[14] Terra, I.C.D.C., Batista, F.G., Silva, D.W., Scatolino, M.V., Júnior, F.T.A., Martins, M.A., & Mendes, L.M. (2023). Mining waste and coconut fibers as an eco-friendly reinforcement for the production of concrete blocks. *Environmental Science and Pollution Research*, 30, 62641-62652. doi: 10.1007/s11356-023-26493-5.

[15] Vinod, B., Suresh, S., Reddy, S.S.K., & Sujith, K.S. (2023). Tribological and mechanical characteristics of Mg-Zn6.0-Y1.2-Zr0.2 alloy by SPS technique: Natural and agro-waste utilization. *Journal of Bio-and Tribo-Corrosion*, 9, 5. doi: 10.1007/s40735-022-00728-3.

[16] Wadhwa, A.S., & Chauhan, A. (2023). An overview of the mechanical and tribological characteristics of non-ferrous metal matrix composites for advanced engineering applications. *Tribology in Industry*, 45(1), 51-80. doi: 10.24874/ti.1359.08.22.12.

[17] Woo, S., O'Neal, D.L., Hassen, Y.M., & Mebrahtu, G. (2023). Enhancing the fatigue design of mechanical systems such as refrigerator to reserve food in agroindustry for the circular economy. *Sustainability*, 15(8), 7010. doi: 10.3390/su15087010.

[18] Xu, A., Darbandi, M., Javaheri, D., Navimipour, N.J., Yalcin, S., & Salameh, A.A. (2023). The management of IoT-based organizational and industrial digitalization using machine learning methods. *Sustainability*, 15(7), 5932. doi: 10.3390/su15075932.

[19] Yeromenko, O.V., Yeriomina, Ye.A., & Tomina, A.-M. (2023). Supply of operation modes on tribological power to basaltoplastics based on polytetafluororetylene. *Mathematical Modeling*, 1(48), 48-55. doi: 10.31319/2519-8106.1(48)2023.280072.

[20] Zhang, W., & Zhu, B. (2023). Optimization design for slip/no-slip configuration of hydrophobic sliding bearings using Monte Carlo search. *Tribology International*, 178(A), 108034. doi: 10.1016/j.triboint.2022.108034.

Підвищення ефективності машин і механізмів агропромислового комплексу застосуванням підшипників ковзання з криволінійними твірними внутрішньої циліндричної поверхні

Олексій Степанович Садовий
Кандидат технічних наук, доцент
Миколаївський національний аграрний університет
54008, вул. Георгія Ґонґадзе, 9, м. Миколаїв, Україна
https://orcid.org/0000-0002-7369-0714

Олег Ігорович Савенков
Асистент
Національний університет кораблебудування
імені адмірала Макарова
54007, просп. Героїв України, 9, м. Миколаїв, Україна
https://orcid.org/0000-0002-7165-3995

Ігор Миколайович Сидорика
Кандидат технічних наук
Миколаївський національний аграрний університет
54008, вул. Георгія Ґонґадзе, 9, м. Миколаїв, Україна
https://orcid.org/0000-0001-9647-1744

Юрій Георгієвич Щербак
Кандидат технічних наук, доцент
Чорноморський національний університет імені Петра Могили
54000, вул. 68 Десантників, 10, м. Миколаїв, Україна
https://orcid.org/0000-0002-0875-6254

Анна Андріївна Кондратьєва
Студент
Національний університет кораблебудування імені адмірала Макарова
54007, просп. Героїв України, 9, м. Миколаїв, Україна
https://orcid.org/0000-0002-8470-2813

Анотація. Підшипники ковзання з криволінійними твірними внутрішніми циліндричними поверхнями мають великий потенціал і можуть відігравати важливу роль у ремонті та відновленні механізмів агропромислового комплексу. Оскільки їх використання стає все більш поширеним, виникає необхідність у поліпшенні розробки таких підшипників, щоб забезпечити їх якісне використання та уникнути помилок при дослідженні цього питання, крім того, досягнення кращих результатів в цій області вимагають значних фінансових вкладень для підвищення ефективності таких механізмів. Основною метою цієї роботи є надання рекомендацій, спрямованих на усунення помилок у процесах покращення та підвищення якості підшипників ковзання, а також аналіз функціонування машин, що використовуються в агропромисловому комплексі. Було використано аналітичний метод, метод класифікації, функціональний метод, статистичний метод, метод синтезу. У ході проведення дослідження відзначено особливості та відмінності підшипників ковзання з криволінійними твірними внутрішньої циліндричної поверхні, проаналізовано помилки та їх причини, які допускаються під час покращення агропромислових механізмів, що забезпечують розвиток сільськогосподарської галузі. Важливе значення має аналіз функціонування даних механізмів з метою оцінки їх ефективності, розвитку та ускладнення роботи під час виробництва сільськогосподарської продукції. Розглянуто питання оцінки роботи підшипників ковзання даного типу, доцільність використання цього елементу, їх обмеження під час процесу, вплив обмежень на результат, було запропоновано рекомендації, які сприятимуть ефективному механізму регулювання питання. Було визначено, що використання підшипників ковзання даного типу, у процесі відновлення агропромислових механізмів, забезпечить суттєве підвищення продуктивності цих машин. Практична цінність цієї роботи полягає у можливості застосування отриманих результатів для усунення помилок у розробці та вдосконаленні механізмів агропромислового комплексу, вивчення надійності застосування підшипників ковзання в загальному, з урахуванням різних факторів, надасть основу для рекомендацій щодо доцільного використання цих підшипників

Ключові слова: заклинювання; сільськогосподарське виробництво; вал; деформації; ремонт

UDC: 631.582; 631.51; 631.872
DOI: 10.56407/bs.agrarian/4.2023.71

Ukrainian Black Sea Region Agrarian Science
Vol. 27, No. 4

Influence of by-products under different methods of soil cultivation on the yield of winter rape in the Western Forest-Steppe

Volodymyr Poliovyi
Doctor of Agriculture, Professor
Institute of Agriculture of Western Polissya of the National Academy of Agrarian Sciences
35325, 5 Rivnenska Str., Shubkiv, Rivne Region, Ukraine
https://orcid.org/0000-0002-3133-9803

Myroslava Furmanets
PhD in Agriculture
Institute of Agriculture of Western Polissya of the National Academy of Agrarian Sciences
35325, 5 Rivnenska Str., Shubkiv, Rivne Region, Ukraine
https://orcid.org/0000-0002-3091-4036

Olena Snizhok*
PhD in Agriculture
Institute of Agriculture of Western Polissya of the National Academy of Agrarian Sciences
35325, 5 Rivnenska Str., Shubkiv, Rivne Region, Ukraine
https://orcid.org/0000-0002-2239-1810

Liudmyla Yashchenko
PhD in Agriculture, Associate Professor
Institute of Agriculture of Western Polissya of the National Academy of Agrarian Sciences
35325, 5 Rivnenska Str., Shubkiv, Rivne Region, Ukraine
https://orcid.org/0000-0003-1407-0133

Abstract. The absence of a clear position on the application of a particular method of basic tillage and the use of post-harvest residues in crop rotation draws attention to the minimisation of tillage. Therefore, the need to substantiate and develop efficient energy-saving tillage technologies and the use of by-products in crop rotation is quite important and remains relevant. The aim of the research is to study the impact of by-products and soil cultivation, which will create optimal conditions for the development of winter rape in the Western Forest-Steppe of Ukraine. The research was carried out during 3 rotations of 4 crop rotation in a stationary field experiment of the Institute of Agriculture of Western Polissya of the National Academy of Agrarian Sciences in 2009-2020. Against the background of soil cultivation, including ploughing, disc cultivation to a depth of 10-12 and 6-8 cm, two methods of using crop residues of crop rotation were studied - diversion and use as fertiliser with the addition of compensatory nitrogen in the amount of N_{10} per 1 tonne. The results showed that when growing winter rape with the removal of the predecessor straw from the field during ploughing to a depth of 20-22 cm and disc cultivation to a depth of 10-12 and 6-8 cm, the soil density at a depth of 0-10 cm was 1.22-1.28, 1.23-1.28 and 1.23-1.35 g/cm³, respectively, and at a depth of 10-20 cm – 1.26-1.30, 1.30-1.35 and 1.32-1.36 g/cm³. The use of straw as an organic fertiliser led to a decrease in the bulk mass of all the studied soil layers under any method of treatment, but at

Article's History:
Received: 25.08.2023
Revised: 20.10.2023
Accepted: 12.12.2023

Suggested Citation:
Poliovyi, V., Furmanets, M., Snizhok, O., & Yashchenko, L. (2023). Influence of by-products under different methods of soil cultivation on the yield of winter rape in the Western Forest-Steppe. *Ukrainian Black Sea Region Agrarian Science*, 27(4), 71-80. doi: 10.56407/bs.agrarian/4.2023.71.

*Corresponding author

the same time contributed to an increase in the number of weeds, which increased with a decrease in the depth of treatment. On average, over the three years of crop rotation, the seed yields for ploughing by 20-22 cm, disking by 10-12 cm and disking by 6-8 cm against the background of straw alienation were 2.91, 2.83 and 2.59 t/ha, respectively, and for incorporating it into the soil – 3.04, 2.88 and 2.72 t/ha. As noted in the studies, tillage and fertilisation using non-commodity crop residues increase the soil protection effect, significantly reduce the negative impact of weeds in crops, improve soil fertility and increase the productivity of crops in the rotation

Keywords: crop rotation; soil density; ploughing; disking; weediness

INTRODUCTION

The transition of agricultural production to a market-based system is accompanied by significant changes in crop cultivation technologies due to the need to increase their competitiveness. One of the important reserves for reducing technological costs and improving the environmental condition of soils is the transition to no-till tillage methods (Kartashov *et al.*, 2019).

Mechanical tillage measures have a more intense impact on soil structure density than natural processes. Progressive soil compaction is a disadvantage of intensive tillage, which negatively affects its physical properties and reduces crop productivity (Orzech *et al.,* 2021). Therefore, in modern agricultural production, simplified tillage, reducing the number and intensity of operations to mitigate the negative impact on the soil while maximising crop yields in crop rotation, is becoming more common (Augustin *et al.*, 2020).

In addition, due to the impact of global warming since the 2010s, in particular in the Western Forest-Steppe zone, in the summer months and in September, there is an increasingly frequent lack of productive moisture reserves in the one-metre soil layer, which prompts the need to switch to moisture-saving and conservation tillage systems (Novokhatsky *et al.*, 2019). Conservation agriculture is a farming system that includes minimal mechanical disturbance of the soil, its permanent organic cover, and diversification of plant species in crop rotation (Kassam *et al.*, 2020). Currently, in Ukraine, most by-products remain on the field as organic fertiliser. Its positive effect is primarily due to the recycling of a significant part of the nutrients removed from the soil by crops to form the crop, as well as a positive impact on the humus state of the soil (Tkachuk, 2020). However, minimising tillage is not effective in all soil and climatic conditions and not for all crops, and can sometimes be inferior to ploughing in terms of its impact on yields. For example, J. Xu *et al.* (2019) point out that the introduction of rotational tillage is vital for grain production. The authors K. Orzech *et al.* (2021) also note that when growing winter rape, compaction and simplified tillage did not cause significant changes in bulk density, soil moisture, and yield.

Minimising tillage, including the use of no-till, can significantly increase weed infestation and, as a result, reduce crop yields. Therefore, the use of ploughing is primarily driven by the need to control weeds, for which sufficient moisture conditions are extremely favourable (Snizhok & Shevchenko, 2022). Therefore, it is important to track changes in soil physical properties, phytosanitary condition of agrocenosis under the influence of straw preservation under different tillage practices and their impact on crop productivity for a particular soil type and growing conditions. The aim of the article was to compare the effect of ploughing and different depths of disc cultivation and by-products on the volume mass of dark grey podzolic soil, weediness of crops and yield of winter rape in the Western Forest-Steppe.

LITERATURE REVIEW

Creating optimal agrophysical indicators of soil fertility for each crop in the crop rotation remains an important problem in agriculture as of 2023 (Yevtushenko *et al.*, 2018; Tsyuk *et al.*, 2021). Soil tillage is a key element of crop production technologies. It should provide favourable conditions for seed placement and germination and active growth of the root system, production of nutrient residues and phytomass, fertilisers and chemical ameliorants, accumulation and preservation of soil moisture, control of soil erosion, weeds, diseases, crop pests, etc. (Kolomiiets, 2000). In addition to many other functions, it should ensure optimal soil density, which directly or indirectly affects the conditions for seed placement and germination, root growth, aeration and soil moisture accumulation, microbiological activity, and other indicators (Biberdzic *et al.*, 2020). Thus, soil tillage is carried out mainly to optimise soil productivity by changing its chemical, physical and biological properties (Gawęda & Haliniarz, 2022). The most popular method of pre-sowing tillage is still the traditional system, which includes ploughing. However, the authors highlight its disadvantages, such as the destruction of the topsoil structure, a decrease in microbial biodiversity, and increased production costs (Li *et al.*, 2019; Yadav *et al.*, 2020; Afshar & Dekamin, 2022).

Therefore, traditional ploughing is being replaced by other cultivation methods, such as disking and no-till. In the current climate change context, with the shortage of traditional organic fertilisers and the regime of saving material resources, so-called resource-saving technologies are gaining momentum (Pooniya *et al.*, 2021). Conservation tillage practices, such as no-till (NT) or reduced tillage, are widely used to mitigate the negative impacts caused by intensive tillage methods. One of the key principles of these technologies is the presence of permanent organic mulch on the field (crop residues, cover crops) aimed at optimising soil health (Jat *et al.*, 2023). The results of a study in conservation agriculture showed that plant residues stored on the soil surface have a greater impact on soil aggregation and organic matter retention (Mondal *et al.*, 2021).

The choice of tillage system is determined by the goal of creating optimal conditions for high crop yields with favourable quality indicators. However, the impact of tillage systems on yields remains uncertain. The results of tillage are largely influenced by environmental conditions and the specific types of crops grown (Gamayunova & Garo, 2017). In their works, most scientists and practitioners believe that the main reason for significant fluctuations in crop yields in 2023 is a decrease in potential soil fertility, deterioration of its structure due to excessive physical impact during annual ploughing (Poliovyi *et al.*, 2023). In crop rotations of different soil and climatic regions of Ukraine, it is necessary to carry out multi-depth cultivation, taking into account the agrophysical properties of the soil and biological characteristics of crops, using both shelf and non-shelf type tools (Kartashov *et al.*, 2019).

It is known that the decrease in crop yields occurs due to deviations in soil bulk mass, both in the direction of its decrease and increase, and it decreases sharply with compaction. The plough sole, which is formed as a result of constant ploughing to the same depth, negatively affects most soil processes (Havrylov, 2017). R. Zayats (2018) notes that soil density is significantly affected by the return of crop residues in the crop rotation and their distribution in the soil layers under different methods of tillage. In the Western Forest-Steppe, a limited number of studies have been conducted on the impact of minimising tillage and by-products of predecessors on the yield of winter rape.

MATERIALS AND METHODS

In the course of the research were used: field experiment to assess the impact of tillage and by-products on the yield of winter rape seeds and weediness of crops; laboratory methods to determine agrochemical (humus content, basic nutrients) and physical (bulk soil mass) indicators; accounting methods by counting the number and weighing the mass of weeds, seed yield from the experimental plot; comparative analysis to compare quantitative features of soil density, weediness of crops and yield of winter rape seeds obtained depending on the effect of the studied factors; statistical methods to assess the reliability of research results.

Field studies were conducted in a stationary experiment of the Institute of Agriculture of Western Polissya of the National Academy of Agrarian Sciences from 2009 to 2020 on dark grey podzolic soil. The arrangement of the variants in the experiment was sequential, replicated three times, and the area of the accounting plot was 50 m^2. The winter wheat was the predecessor of winter rape in the crop rotation, with a crop rotation of winter wheat – corn for grain – spring barley – winter rape.

The soil cultivation methods under study (factor A) included the following technological operations: ploughing at 20-22 cm, disking at 10-12 and 6-8 cm. The experimental design also included two options for the use of the predecessor's by-products (factor B): alienation and use for fertilisation with a compensatory dose of N_{10} per 1 tonne of straw. Mineral fertilisers, which served as a background for nutrition, were applied to winter rape at a dose of N_{150} P_{90} K_{150} in the form of ammonium nitrate, ammophos and potassium chloride.

For the agrochemical analysis of the soil, an average sample was prepared by mixing five diagonally collected samples and determined by the following methods: humus content by Tyurin, easily hydrolysable nitrogen compounds by Kornfield, and mobile phosphorus and potassium compounds by Kirsanov (Yeshchenko *et al.*, 2005). The soil was characterised by the following indicators: humus content of 1.93%, easily hydrolysable nitrogen content of 99 mg/kg of soil, mobile phosphorus content of 238 mg/kg and potassium content of 85 mg/kg of soil.

The winter rape protection system involved the use of pesticides with different mechanisms of action, namely a mixture of soil herbicides Clodex Pro (clomazone, 480 g/l) – 0.15 l/ha + Proxanil (propizochlor, 720 g/l) – 2.5 l/ha, against annual and perennial cereal weeds, herbicide Oreol Maxi KE (chisalofop-p-ethyl, 125 g/l) – 1.2 l/ha; insecticides Karate Zeon (lambda-cyhalothrin, 50 g/l) – 0.15 l/ha, Mospilan (acetamiprid 200 g/kg) – 0.12 kg/ha; fungicide Amistar Extra (ciproconazole, 80 g/ha + azoxystrobin, 200 g/ha) – 0.75 l/ha.

Before harvesting the winter rape, the soil compaction density was determined in triplicate diagonally by the method of 100 cm^3 cutting rings in the modification N. Kachynskyi (State Standard of Ukraine..., 2002) at a depth of 0-10, 10-20, 20-30 cm, the number of weeds

and their weight were determined from an area of 1 m^2 by the method of S. Trybel *et al.* (2001). The yield of winter rape was determined by weighing the seeds from the plots and then recalculating them per 1 ha of area. The results of the research were analysed using multivariate analysis of variance (MANOVA) in Microsoft Excel software, followed by the F-test to determine the significance of differences at $p \leqslant 0.05$.

RESULTS AND DISCUSSION

The density of soil compaction largely determines its water, air and nutrient regime and its biological activity, so it is considered one of the most important indicators of the physical condition of the soil. The experimental data obtained during three rotations of crop rotation indicate a significant effect of different methods of tillage for winter rape and vegetative mass of predecessors as fertiliser on the formation of its bulk (Table 1). Against the background of alienation of by-products from the site, ploughing 20-22 cm, disking 10-12 and 6-8 cm, the density of soil compaction in the 0-10 cm layer was 1.22-1.28, 1.23-1.28 and 1.26-1.35 g/cm^3, respectively, and in the 10-20 cm layer – 1.26-1.30, 1.30-1.35 and 1.32-1.36 g/cm^3.

Table 1. *Soil compaction density under winter rape depending on tillage methods and use of by-products, g/cm^3*

Soil cultivation (factor A)	The use of the predecessor's by-products (factor B)	Soil layer, cm	Crop rotation		
			I	II	III
Ploughing at 20-22 cm	alienation	0-10	1.22	1.28	1.23
		10-20	1.26	1.30	1.29
		20-30	**1.42**	**1.39**	**1.40**
	for fertiliser	0-10	1.20	1.24	1.20
		10-20	1.23	1.27	1.26
		20-30	**1.40**	**1.36**	**1.37**
Disking at 10-12 cm	alienation	0-10	1.23	1.28	1.28
		10-20	1.30	1.35	1.34
		20-30	**1.45**	**1.43**	**1.43**
	for fertiliser	0-10	1.19	1.25	1.24
		10-20	1.27	1.33	1.33
		20-30	**1.43**	**1.41**	**1.38**
Disking by 6-8 cm	alienation	0-10	1.26	1.32	1.35
		10-20	1.32	1.36	1.36
		20-30	**1.46**	**1.49**	**1.48**
	for fertiliser	0-10	1.22	1.30	1.25
		10-20	1.27	1.34	1.32
		20-30	**1.42**	**1.46**	**1.45**
HIP_{05} factor A		0-10	0.03	0.02	0.04
		10-20	0.02	0.03	0.03
		20-30	0.03	0.02	0.02
Factor B		0-10	0.01	0.01	0.02
		10-20	0.01	0.02	0.02
		20-30	0.02	0.02	0.02
Interactions AB		0-10	0.02	0.02	0.03
		10-20	0.02	0.03	0.03
		20-30	0.03	0.03	0.03

Source: *compiled by the authors*

That is, the lowest values of this indicator both in the 0-10 cm layer and in the 10-20 cm layer occurred during ploughing. Replacing it with disking was accompanied by an increase in the volume mass of not only the 10-20 cm layer of soil, which was not loosened, but also the 0-10 cm layer, which indicates worse loosening of the cultivated soil layer by disking compared to ploughing. The density of the 20-30 cm soil layer under all tillage options was significantly higher compared to the upper layers, which may indicate the tendency of the soil of the experimental plot to form a plough sole. During the three rotations of crop rotation, the lowest, in the range of 1.39-1.42 g/cm^3, was for ploughing. In the variants with disking at 10-12 and 6-8 cm, the value of the indicator increased to 1.43-1.45 and 1.46-1.49 g/cm^3, respectively.

The use of crop residues as organic fertiliser, regardless of tillage methods and soil depth, contributed to a decrease in the volume mass of all soil layers studied: 0-10, 10-20 and 20-30 cm. In particular, in the 20-30 cm layer, the soil density in the variants with by-products compared to its alienation from the field

decreased by 0.02-0.03, disking by 10-12 cm – by 0.02-0.05, and disking by 6-8 cm – by 0.03-0.04 g/cm^3.

The study in a stationary field experiment of the influence of different variants of soil tillage and the use of straw of the predecessor for fertilisation on the weediness of winter rape crops showed that, despite the use of herbicides, it significantly depended on the factors under study. During the three rotations of crop rotation, the number of weeds in the variants with straw alienation for ploughing varied within 5.0-9.0 pcs./m^2, disking by 10-20 cm – 17.0-27.0 pcs./m^2, disking by 6-8 cm – 35.0-47.0 pcs./m^2, and for the use of straw for fertilisation, respectively, 9.0-17.0, 28.0-39.0 and 46.0-57.0 pcs./m^2 (Table 2).

Table 2. *Influence of tillage and methods of using straw of the predecessor on weed infestation of winter rape crops*

Soil cultivation (factor A)	The use of the predecessor's by-products (factor B)	Crop rotation					
		I		II		III	
		pcs/m^2	gm/m^2	pcs/m^2	gm/m^2	pcs/m^2	gm/m^2
Ploughing at 20-22 cm	alienation	9.0	8.2	5.8	6.1	5.0	4.5
	for fertiliser	17.0	14.9	10.0	9.6	9.0	7.2
Disking at 10-12 cm	alienation	27.0	22.5	20.0	16.0	17.0	14.2
	for fertiliser	39.0	30.1	35.0	28.0	28.0	22.1
Disking at 6-8 cm	alienation	47.0	40.6	42.0	38.4	35.0	30.1
	for fertiliser	57.0	47.9	53.0	42.8	46.0	39.7
HIP_{05} factor A		2.17	0.81	1.72	0.89	1.89	0.70
Factor B		2.22	0.60	1.45	0.54	1.76	0.46
Interactions AB		3.50	0.83	2.86	0.86	3.29	0.81

Source: *compiled by the authors*

These data show that minimisation of tillage for winter rape was accompanied by an increase in weed infestation of its crops. After all, most of the weeds accumulate in the upper soil layer of 0-5 cm, while during ploughing they are in deeper layers: 5-10 and 10-20 cm. Also, a higher percentage of perennial weeds was observed with minimal tillage. The use of spring barley straw for fertilisation, which was the predecessor of winter rape, led to a significant increase in weed infestation of the latter compared to its removal from the field, especially in the variants with disking and reduced depth. Among the crops in the crop rotation, which included winter wheat, corn for grain, spring barley and winter rape, the latter had the least yield reduction from the transition to minimum tillage.

The obtained experimental data on the influence of the studied factors, namely the methods and depth of tillage, the use of by-products on the yield of winter rape seeds and its dynamics in crop rotation, indicate its rather high stability over time. Only when disking to a depth of 6-8 cm, without the use of by-products for fertilisation, a decrease in seed yield was observed from 2.81 t/ha in the first rotation to 2.46 t/ha in the third rotation of crop rotation. However, without alienation of by-products in this cultivation variant, the yield during crop rotation varied only within 2.68-2.77 t/ha. When ploughing by 20-22 cm and disking by 10-12 cm in the variants with alienation of by-products, the seed yield during the rotation of crop rotation varied within the range of 2.85-2.96 and 2.62-2.94 t/ha, respectively, and when incorporating by-product biomass into the soil – 2.98-3.11 and 2.85-3.1 t/ha. The yield of winter rape seeds averaged 2.91, 2.83 and 2.59 t/ha for three rotations of crop rotation for ploughing by 20-22 cm, disking by 10-12 cm and disking by 6-8 cm for alienation of the previous year's straw from the field and 3.04, 2.88 and 2.72 t/ha for its use as organic fertiliser, respectively (Table 3).

Table 3. *Yield of winter rape under different methods of tillage and use of by-products, t/ha*

Soil cultivation (factor A)	The use of the predecessor's by-products (factor B)	Crop rotation			Average for three rotations
		I	II	III	
Ploughing at 20-22 cm	alienation	2.96	2.91	2.85	2.91
	for fertiliser	3.04	3.11	2.98	3.04
Disking at 10-12 cm	alienation	2.94	2.62	2.94	2.83
	for fertiliser	2.85	2.79	3.01	2.88
Disking at 6-8 cm	alienation	2.81	2.49	2.46	2.59
	for fertiliser	2.77	2.68	2.70	2.72

Table 3, Continued

Soil cultivation (factor A)	The use of the predecessor's by-products (factor B)	Crop rotation I	Crop rotation II	Crop rotation III	Average for three rotations
HIP_{05} factor A		0.17	0.15	0.19	0.17
Factor B		0.12	0.16	0.13	0.14
Interactions AB		0.26	0.28	0.24	0.26

Source: *compiled by the authors*

That is, the by-product vegetative mass of the predecessor provided an increase in the yield of winter rape seeds, depending on the methods of tillage, of only 2.0-5.0%.

Modern agricultural production provides for the possibility of replacing energy-intensive ploughing with simplified tillage, reducing the number and intensity of tillage operations (Orzech *et al.,* 2021). Although this impact, according to Z. Wang *et al.* (2020), has a protective effect on the conservation of the ecosystem's natural value, it needs to be studied in terms of agrocenosis productivity. Different methods of soil cultivation are an important factor in regulating its physical parameters. In the study by M. Jat *et al.* (2023), minimising tillage led to a degradation of the exchange density index. The volumetric density of the soil in the system of minimised tillage is particularly high with little or no plant residues. The results of the analysis of this study show a statistically significant decrease in density from ploughing by 20-22 cm to disking by 6-8 cm. At the same time, the highest values of 1.36-1.49 g/cm^3 were obtained at a depth of 20-30 cm, depending on the method of cultivation, which is 12.7-14.8% higher than in the soil layer 0-10 cm deep. A similar trend was found in studies with winter wheat by M. Biberdzis *et al.* (2020). Soil compaction in all tillage systems increased with increasing depth, reaching its highest value at 30-40 cm.

One of the ways to prevent soil degradation during cultivation is to apply straw. The reduction in bulk density in conservation tillage compared to conventional tillage is due to less soil disturbance and preservation of crop residue mulch, which improves organic matter content, aggregation, porosity, and fauna activity. S. Jayaraman *et al.* (2021) and J. Dhaliwal *et al.* (2020) also reported that the residual retention of wheat residue reduced bulk density by 1.8% compared to no residue in the 0-15 cm layer. In the experiment with winter rape, straw incorporation contributed to a decrease in soil density in all cultivation options at all depths. At the same time, the greatest changes from straw harvesting for fertilisation were obtained for disking at 6-8 cm. On average, the use of straw allowed to reduce the bulk density of the soil under this tillage method in the soil layer 0-10 cm by 0.05 g/cm^3, 10-20 cm by 0.04 g/cm^3 and 20-30 cm by 0.03 g/cm^3 compared to the options for its removal from the field, which is significant at the $p = 0.05$ significance level. The positive effect of straw on reducing soil density is explained by J. Chen *et al.* (2020) by the greater storage of organic carbon (SOC) in the soil, improvement of the proportion of macroaggregate state and its stability in the arable layer. In their experiments, the bulk density decreased by 1.22-8.74% compared to the straw removal option, which is similar to the current figures.

Tillage is one of the main weed control measures. However, due to the growing use of herbicides, expansion of their range and improvement of quality indicators, this tillage function has significantly narrowed. In particular, some authors note that there is no statistical difference in the intensity of weed infestation depending on the treatment, but point to significant changes in the species composition of weeds (Winkler *et al.*, 2023). While others have pointed out that minimising tillage increases weed infestation, leading to a greater reliance on herbicides compared to conventional tillage (Steponavičienė *et al.*, 2021). The latter statement was true in the current research. In particular, during three rotations of crop rotation, the number of weeds in the alienation of the predecessor's by-products with minimal tillage increased significantly compared to ploughing. At the same time, reducing the depth of disking to 6-8 cm on average increased the weed infestation by almost 2 times, and their biological mass increased by 1.8-2.4 times, depending on the period of research.

According to the results of research on weed infestation, the leaving of crop residues in the field also had a significant impact, regardless of the method of tillage. However, an analysis of studies by different authors shows a contradictory result regarding the impact of crop residues on the spread of weeds. According to S. Fonteyne *et al.* (2020), only the combination of three components of conservation agriculture – minimal soil disturbance, constant presence of organic residues and species diversity in crop rotation when using herbicides – reduced weed biomass by 81-91% compared to conventional tillage. In studies of winter rape cultivation, leaving straw in the field and incorporating it into the soil at different depths led to an additional significant increase in the number of weeds.

The highest number of weeds was found at the lowest depth of disking. N. Verhulst *et al*. (2011) noted that without retention of residues on the field surface, the soil degrades, showing worse fertility and infiltration. Conversely, treatments with crop residue retention increased the ability of maize plants to compete with weeds, leading to higher yields.

Agricultural practices, such as tillage and crop rotation, are the main factors that have a significant impact on soil quality, crop productivity and, ultimately, the sustainability of cropping systems. A decline in soil physical quality, characterised by excessive topsoil compaction, is considered to be the main reason for the decline in yields of uncultivated soil. Studies conducted on sandy soils by the Lithuanian Research Centre of Agriculture and Forestry showed that the most favourable physical properties of the soil, including density, shear strength and air permeability, were achieved by conventional (deep) ploughing (Steponavičienė *et al.*, 2020).

In studies with winter oilseed rape, neither alienation nor straw harvesting of the predecessor had a significant effect on seed yield within a particular cultivation method on average over three rotations of crop rotation. Variations within the rotations were largely due to climatic conditions. However, the comparison of different tillage methods indicates the advantage of ploughing compared to shallow disking by 6-8 cm. D. Gawęda & M. Haliniarz (2022), in a four-year study, also found that both seed and straw yields of winter rape were significantly higher under conventional tillage compared to no-till. Ploughing to a depth of 20-22 cm and disking to 10-12 cm with the harvesting of the predecessor's by-products resulted in significant increases in rape seed yields at a significance level of $p = 0.05$ compared to disking to 6-8 cm.

The obtained results of the research are generally consistent with the data of other authors on the impact of minimising tillage on soil bulk, crop weediness and crop yields. Despite a certain increase in soil density and weediness of winter rape crops, the minimisation of tillage resulted in almost the same seed yield for ploughing and disking by 10-12 cm, which indicates the possibility of introducing more energy-saving and soil-protective tillage systems in the Western Forest-Steppe, which is in line with global trends.

CONCLUSIONS

Studies have shown that the replacement of shelf tillage for winter rape by disking by 10-12 and 6-8 cm led to an increase in soil density in the layers 0-10, 10-20 and 20-30 cm, respectively, amounting to 1.28-1.32, 1.35-1.36 and 1.43-1.49 g/cm^3. It should be noted that the soil density in the 20-30 cm layer for all treatment options was significantly higher compared to the upper layers, which may indicate the soil's tendency to form a tilthy sole. The introduction of straw of the predecessor into the soil contributed to its reduction, but as soil tillage was minimised, its bulk mass increased. Weed infestation of winter rape crops after replacing ploughing with disking by 10-12 and 6-8 cm, regardless of the use of herbicides, increased from 5.0-9.0 to 17.0-27.0 units/m^2, and to 35.0-47.0 units/m^2 when removing the straw of the predecessor from the field, and from 9.0-17.0 to 28.0-39.0 and 43.0-57.0 units/m^2, respectively, when using it for fertilizer. On average, over three rotations of crop rotation, the yield of winter rape against the background of removal of by-products of the predecessor by replacing ploughing with disking by 10-12 and 6-8 cm decreased from 2.91 to 2.83 and 2.59 t/ha, respectively. When using by-products for fertilisation, the yield of winter rape within a particular cultivation method increased by 2.0-5.0%, which is insignificant at $p = 0.05$. Reliable yield increases were obtained on average for ploughing to a depth of 20-22 cm, as well as for disking to a depth of 10-12 cm when incorporating the straw of the predecessor into the soil.

The Western Forest-Steppe is traditionally a zone of sufficient moisture, but as a result of global climate change, there is an increasing shortage of productive soil moisture reserves, especially in the second half of the growing season. From time to time, this causes early maturation of late crops such as corn, sunflower and soybeans and problems with germination of winter crops and green manure. The amount of unearned crop residues and crop by-products that mulch the soil surface, weakening surface runoff, promoting snow retention and reducing moisture evaporation, is crucial for the accumulation and preservation of soil moisture reserves. In view of this, it is promising to study the impact of soil cultivation methods on its water regime by expanding the above experimental design to include options that maximise the retention of plant residues on the soil surface: direct seeding, chiselling, strip-till, etc.

ACKNOWLEDGEMENTS

None.

CONFLICT OF INTEREST

None.

REFERENCES

[1] Afshar, R.K., & Dekamin, M. (2022). Sustainability assessment of corn production in conventional and conservation tillage systems. *Journal of Cleaner Production*, 351, 131508. doi: 10.1016/j.jclepro.2022.131508.

[2] Augustin, K., Kuhwald, M., Brunotte, J., & Duttmann, R. (2020). Wheel load and wheel pass frequency as indicators for soil compaction risk: A four-year analysis of traffic intensity at field scale. *Geosciences*, 10(8), 292. doi: 10.3390/geosciences10080292.

[3] Biberdzic, M., Barac, S., Lalevic, D., Djikic, A., Prodanovic, D., & Rajicic, V. (2020). Influence of soil tillage system on soil compaction and winter wheat yield. *Chilean Journal of Agricultural Research*, 80(1), 80-89. doi: 10.4067/S0718-58392020000100080.

[4] Chen, J., Pang, D.-W., Jin, M., Luo, Y.-L., Li, H.-Y., Li, Y., & Wang, Z.-L. (2020). Improved soil characteristics in the deeper plough layer can increase grain yield of winter wheat. *Journal of Integrative Agriculture*, 19(5), 1215-1226. doi: 10.1016/S2095-3119(19)62679-1.

[5] Dhaliwal, J.K., Singh, M.J., Sharma, S., Gupta, N., & Kukal, S.S. (2020). Medium-term impact of tillage and residue retention on soil physical and biological properties in dry-seeded rice-wheat system in North-West India. *Soil Research*, 58, 468-477. doi: 10.1071/SR19238.

[6] Fonteyne, S., Singh, R.G., Govaerts, B., & Verhulst, N. (2020). Rotation, mulch and zero tillage reduce weeds in a long-term conservation agriculture trial. *Agronomy*, 10(7), 962. doi: 10.3390/agronomy10070962.

[7] Gamayunova, V.V., & Garo, I.M. (2017). Yield and quality of winter rapeseed seeds, depending on the processing of soils, the time and method of sowing in the Forest-Steppe of Ukraine. *Scientific Horizons,* 1(58), 49-57. Retrieved from https://sciencehorizon.com.ua/en/journals/1-58-2017/urozhaynist-i-yakist-nasinnya-ripaku-ozimogo-zalyezhno-vid-obrobitku-gruntu-stroku-ta-sposobu-sivbi-v-umovakh-lisostyepu-ukrayini.

[8] Gawęda, D., & Haliniarz, M. (2022). The yield and weed infestation of winter oilseed rape (*Brassica napus* L. ssp. *oleifera* Metzg) in two tillage systems. *Agriculture*, 12(4), 563. doi: 10.3390/agriculture12040563.

[9] Havrylov, S. (2017). *Problems of the plow sole in the soil and ways to solve it*. Retrieved from https://propozitsiya.com/problema-pluzhnoy-podoshvy-u-pochvy-i-puti-ee-resheniya.

[10] Jat, M.L., Gathala, M.K., Choudhary, M., Sharma, S., Jat, H.S., Gupta, N., & Singh, Y. (2023). Chapter three – conservation agriculture for regenerating soil health and climate change mitigation in smallholder systems of South Asia. *Advances in Agronomy*, 181, 183-277. doi: 10.1016/bs.agron.2023.05.003.

[11] Jayaraman, S., Sinha, N.K., Mohanty, M., Hati, K.M., Chaudhary, R.S., Shukla, A.K., ... Dalal, R.C. (2021). Conservation tillage, residue management, and crop rotation effects on soil major and micro-nutrients in semi-arid vertisols of India. *Journal of Soil Science and Plant Nutrition*, 21, 523-535. doi: 10.1007/s42729-020-00380-1.

[12] Kartashov, S.H., Horodetskyi, E.Yu., Dudka, V.S., & Moskaliuk, A.A. (2019). The effect of optimal soil density for various agricultural crops on yield. *Tauride Scientific Bulletin*, 78, 21-27. Retrieved from https://www.tnv-agro.ksauniv.ks.ua/archives/78_2012/7.pdf.

[13] Kassam, A., Derpsch, R., & Friedrich, T. (2020). Development of conservation agriculture systems globally. In A. Kassam (Ed.), *Advances in conservation agriculture* (pp. 31-86). London: Burleigh Dodds Science Publishing. doi: 10.1201/9780429268724.

[14] Kolomiiets, M.V. (2000). The influence of tillage systems on crop productivity and soil fertility of crop rotation. *Agriculture*, 74, 23-30.

[15] Li, Y., Li, Z., Cui, S., Jagadamma, S., & Zhang, Q. (2019). Residue retention and minimum tillage improve physical environment of the soil in croplands: A global meta-analysis. *Soil and Tillage Research*, 194, 104292. doi: 10.1016/j.still.2019.06.009.

[16] Mondal, S., Mishra, J.S., Poonia, S.P., Kumar, R., Dubey, R., Kumar, S., ... McDonald, A. (2021). Can yield, soil C and aggregation be improved under long-term conservation agriculture in the eastern Indo-Gangetic plain of India? *European Journal of Soil Science*, 72(4), 1742-1761. doi: 10.1111/ejss.13092.

[17] Novokhatsky, M., Serdiuchenko, N., & Bondarenko, O. (2019). Concervation agriculture in climate change condition. *Technical and Technological Aspects of Development and Testing of New Machinery and Technologies for Agriculture in Ukraine*, 24(38), 278-287. doi: 10.31473/2305-5987-2019-1-24(38)-29.

[18] Orzech, K., Wanic, M., & Załuski, D. (2021). The effects of soil compaction and different tillage systems on the bulk density and moisture content of soil and the yields of winter oilseed rape and cereals. *Agriculture*, 11(7), 666. doi: 10.3390/agriculture11070666.

[19] Poliovyi, V., Furmanets, M., Snizhok, O., & Kolesnyk, T. (2023). Effectiveness of minimization of tillage and the use of by-products for spring barley in the conditions of Western Polissia. *Bulletin of National University of Water and Environmental Engineering. Agricultural Sciences*, 1(101), 223-234. Retrieved from https://ep3.nuwm.edu.ua/26216/.

[20] Pooniya, V., Biswakarma, N., Parihar, C.M., Swarnalakshmi, K., Lama, A., Zhiipao, R.R., ... Singh, K. (2021). Six years of conservation agriculture and nutrient management in maize-mustard rotation: Impact on soil properties, system productivity and profitability. *Field Crops Research*, 260, 108002. doi: 10.1016/j.fcr.2020.108002.

[21] Snizhok, O., & Shevchenko, T. (2022). Development of harmful organisms in corn crops depending on tillage and protection system. *Interdepartmental Thematic Scientific Collection of Phytosanitary Safety*, 68, 156-167. doi: 10.36495/1606-9773.2022.68.156-167.

[22] State Standard of Ukraine ISO 11272-2001 "Soil quality. Determination of bulk density on a dry weight basis (ISO 11272:1998, IDT)". (2002, February). Retrieved from http://online.budstandart.com/ua/catalog/doc-page?id_doc=58941.

[23] Steponavičienė, V., Bogužas, V., Sinkevičienė, A., Skinulienė, L., Sinkevičius, A., & Klimas, E. (2020). Soil physical state as influenced by long-term reduced tillage, no-tillage and straw management. *Zemdirbyste-Agriculture*, 107(3), 195-202. doi: 10.13080/z-a.2020.107.025.

[24] Steponavičienė, V., Marcinkevičienė, A., Butkevičienė, L.M., Skinulienė, L., & Bogužas, V. (2021). The effect of different soil tillage systems and crop residues on the composition of weed communities. *Agronomy*, 11(7), 1276. doi: 10.3390/agronomy11071276.

[25] Tkachuk, O. (2020). Biomass potential of plant by-products for soil fertilization. *IX International Scientific and Practical Conference "Scientific Achievements of Modern Society"*. Retrieved from http://repository.vsau.org/getfile.php/25065.pdf.

[26] Trybel, S., Sigaryova, D., Sekun, M., & Ivashchenko, O. (2001). *Methodology of testing and application of pesticides*. Kyiv: Svit.

[27] Tsyuk, A., Tsentilo, L., & Melnik, V. (2021). Changes in the agrophysical properties of typical chernozem under the influence of fertilizers and tillage. *Scientific Reports of the National University of Life and Environmental Sciences of Ukraine*, 5(93). doi: 10.31548/dopovidi2021.05.007.

[28] Verhulst, N., Nelissen, V., Jespers, N., Haven, H., Sayre, K.D., Raes, D., ... Govaerts, B. (2011). Soil water content, maize yield and its stability as affected by tillage and crop residue management in rainfed semi-arid highlands. *Plant and Soil*, 344, 73-85. doi: 10.1007/s11104-011-0728-8.

[29] Wang, Z., Li, Y., Li, T., Zhao, D., & Liao, Y. (2020). Tillage practices with different soil disturbance shape the rhizosphere bacterial community throughout crop growth. *Soil and Tillage Research*, 197, 104501. doi: 10.1016/j.still.2019.104501.

[30] Winkler, J., Dvořák, J., Hosa, J., Barroso, P.M., & Vaverková, M.D. (2023). Impact of conservation tillage technologies on the biological relevance of weeds. *Land*, 12(1), 121. doi: 10.3390/land12010121.

[31] Xu, J., Han, H., Ning, T., Li, Z., & Lal, R. (2019). Long-term effects of tillage and straw management on soil organic carbon, crop yield, and yield stability in a wheat-maize system. *Field Crops Research*, 233, 33-40. doi: 10.1016/j.fcr.2018.12.016.

[32] Yadav, D., Rani, K., & Wati, L. (2020). Impact of tillage practices on physico-chemical and microbiological properties of soil in wheat-pearl-millet cropping system. *Range Management and Agroforestry*, 41(2), 276-283. Retrieved from https://www.researchgate.net/publication/353166816.

[33] Yeshchenko, V., Kopytko, P., Opryshko, V., & Kostohryz, P. (2005). *Basics of scientific research in agronomy*. Kyiv: Diia.

[34] Yevtushenko, T., Tonkha, O., & Pikovska, O. (2018). Agrophysical indicators of typical chernozem depending on fertilization and tillage. *Plant and Soil Science*, 286, 188-196. Retrieved from https://agriculturalscience.com.ua/uk/journals/286-2018.

[35] Zayats, P. (2018). The effect of main tillage methods on the compaction density of gray forest soil in the chain of grain-row crop rotation. *Collection of Science Proceedings of the Educational and Scientific Center "Institute of Agriculture of the National Academy of Agrarian Sciences of Ukraine"*, 4, 11-20. Retrieved from http://www.irbis-nbuv.gov.ua/.

Вплив побічної продукції за різних способів обробітку ґрунту на врожайність ріпаку озимого в умовах Західного Лісостепу

Володимир Мефодійович Польовий
Доктор сільськогосподарських наук, професор,
Інститут сільського господарства Західного Полісся Національної академії аграрних наук
35325, вул. Рівненська, 5, с. Шубків, Рівненська обл., Україна
https://orcid.org/0000-0002-3133-9803

Мирослава Григорівна Фурманець
Кандидат сільськогосподарських наук
Інститут сільського господарства Західного Полісся Національної академії аграрних наук
35325, вул. Рівненська, 5, с. Шубків, Рівненська обл., Україна
https://orcid.org/0000-0002-3091-4036

Олена Василівна Сніжок
Кандидат сільськогосподарських наук
Інститут сільського господарства Західного Полісся Національної академії аграрних наук
35325, вул. Рівненська, 5, с. Шубків, Рівненська обл., Україна
https://orcid.org/0000-0002-2239-1810

Людмила Анатоліївна Ященко
Кандидат сільськогосподарських наук, доцент
Інститут сільського господарства Західного Полісся Національної академії аграрних наук
35325, вул. Рівненська, 5, с. Шубків, Рівненська обл., Україна
https://orcid.org/0000-0003-1407-0133

Анотація. Відсутність чіткої позиції щодо застосування того чи іншого способу основного обробітку ґрунту та використання післяжнивних решток в сівозміні, привертає увагу до мінімалізації обробітку ґрунту. Виходячи з цього, необхідність обґрунтування і розробки ефективних енергоощадливих технологій обробітку ґрунту та використання побічної продукції в сівозміні є досить важливими і не втрачають своєї актуальності. Мета досліджень – вивчення впливу використання побічної продукції і обробітку ґрунту, які створюватимуть оптимальні умови для розвитку ріпаку озимого у Західному Лісостепу України. Дослідження проводилися впродовж 3-х ротацій 4-х пільної сівозміни у стаціонарному польовому досліді Інституту сільського господарства Західного Полісся Національної академії аграрних наук в 2009-2020 рр. На тлі обробітку грунту, включаючи оранку, обробку дисками на глибину 10-12 см і 6-8 см, було проведено дослідження двох способів використання побічної продукції культур сівозміни - відведення та використання як добрива з додаванням компенсаційного азоту в кількості N10 на 1 т. Результати показали, що при вирощуванні озимого ріпаку із видаленням соломи попередника з поля під час оранки на глибину 20-22 см та обробки дисками на глибину 10-12 см та 6-8 см, щільність грунту на глибині 0-10 см становила відповідно 1,22-1,28; 1,23-1,28 і 1,23-1,35 г/см^3, а на глибині 10-20 см – 1,26-1,30; 1,30-1,35 і 1,32-1,36 г/см^3. Використання соломи як органічного добрива призвело до зменшення об'ємної маси всіх досліджуваних шарів грунту при будь-якому методі обробки, але при цьому сприяло збільшенню кількості бур'янів, яка зростала зі зменшенням глибини обробки. В середньому за три роки ротації сівозміни врожайність насіння за оранки на 20-22 см, дискування на 10-12 см і дискування на 6-8 см на фоні відчуження соломи склала відповідно 2,91; 2,83 і 2,59 т/га, а за заробки її в ґрунт – 3,04; 2,88 і 2,72 т/га. Як зазначено у дослідженнях, обробіток ґрунту і удобрення із використанням нетоварної продукції врожаю підвищують ґрунтозахисний ефект, суттєво послаблюють негативний вплив бур'янів у посівах, покращують родючість ґрунту та збільшують продуктивність культур сівозміни

Ключові слова: сівозміна; щільність ґрунту; оранка; дискування; забур'яненість

UDC: 629.113:621.431
DOI: 10.56407/bs.agrarian/4.2023.81

Ukrainian Black Sea Region Agrarian Science
Vol. 27, No. 4

Problems and prospects of creating modern agricultural gas diesel engines: A literature review

Vadym Ryaboshapka
PhD in Technical Sciences, Senior Lecturer
Vinnytsia National Agrarian University
21008, 3 Sonyachna Str., Vinnytsia, Ukraine
https://orcid.org/0000-0003-1812-1030

Roman Lysenko*
Master
Vinnytsia National Agrarian University
21008, 3 Sonyachna Str., Vinnytsia, Ukraine
https://orcid.org/0009-0007-9867-5581

Abstract. In conditions of constant growth in the cost of traditional oil products and their shortage, the issue of using alternative fuels becomes urgent. The purpose of the article is to identify ways of using alternative types of fuel for the operation of diesel engines. Research methods – analysis and verification of data obtained from scientific publications, which are part of the world-famous scient metric databases, for the relevance of the subject of research. The research results reveal the advantages and disadvantages of dual-fuel engines operating on gaseous fuel with diesel fuel additive, the impact of this type of engine on emissions and toxicity of exhaust gases, in particular nitrogen oxides NO_x. The application of the so-called gas nozzle and the cross-section of the holes of its nozzles are substantiated. It was analysed and established that the most economically expedient is the use of liquefied petroleum gas for the operation of diesel engines by implementing the gas-liquid cycle; it was found that the most promising for this is gas cylinder equipment of the so-called 4th generation. A retrospective analysis of studies of internal combustion engines with gas cylinder equipment showed an increase in motor resource when using gaseous fuels, as well as the negative side of using gaseous fuels, which consists in reduced power when converting carburettor engines, however, the use of these fuels for the operation of diesel engines completely eliminates this disadvantage. Based on the research analysis, the influence of the ignition dose, when the engine is operating on the gas-diesel cycle, on the performance at different loads was also established, and a recommendation was found to switch to the diesel cycle from the gas-diesel cycle at loads less than 30% of the nominal one. The optimal scheme for the implementation of the gas-diesel cycle, which is relevant and promising for more widespread energy and transport vehicles, has been substantiated and selected. Based on the analysed schemes, it was established that the scheme that can be taken as a basis for further research in this direction is the scheme of the DG-Flex BOSCH gas-diesel system. The practical value of the work lies in the justification of complex conversion with partial replacement of diesel fuel with liquefied petroleum gas as the most rational way of converting serial diesel engines into dual-fuel engines

Keywords: transport; liquefied petroleum gas; gas cylinder equipment; power supply system

Article's History:
Received: 27.07.2023
Revised: 07.11.2023
Accepted: 12.12.2023

Suggested Citation:
Ryaboshapka, V., & Lysenko, R. (2023). Problems and prospects of creating modern agricultural gas diesel engines: A literature review. *Ukrainian Black Sea Region Agrarian Science*, 27(4), 81-89. doi: 10.56407/bs.agrarian/4.2023.81.

*Corresponding author

INTRODUCTION

In the conditions of an increase in the share of fuel costs, many commercial transport operators are thinking about the possibility of compensating for the increase in prices by switching to gas. However, such radical methods as converting diesel engines to gas engines have their drawbacks. In the search for an optimal solution, an alternative option is often considered – the use of a gas-diesel engine, which combines the advantages of a traditional diesel and gas cylinder equipment (HBO) (Kabeyi & Olanrewaju, 2023; Liu *et al.*, 2023). Gas-diesel engines at the beginning of the 21st century (Shyamkishore *et al.*, 2023) are considered as a separate type of engines that are widely used in many sectors of the economy, in particular in agriculture, and which also have environmental advantages over traditional fuels (Emaish *et al.*, 2021). A dual-fuel gas-diesel engine is a power plant, which is additionally equipped with equipment for work involving gas (Sain *et al.*, 2018). The principle of operation of such an installation consists in the simultaneous supply of two types of fuel to the combustion chamber. The main fuel is gas of various origins, and the additional fuel is diesel oil. In this case, diesel fuel is supplied in a much smaller volume than usual. In the gas-diesel design (Zhu & Fan, 2022), diesel fuel acts as a kind of ignition for the air-gas mixture. The supply of diesel fuel is due to the fact that the ignition temperature of gas is higher than that of diesel fuel, and that is why at the moment of compression, in the combustion chamber, the gas itself cannot ignite. For its ignition during the compression stroke, a small amount of diesel fuel is fed into the combustion chamber. Based on the above, it can be concluded that the gas-diesel dual-fuel engine retains the ability to work only on diesel fuel, but is not capable of working on one gas. The use of gas-diesel engines in agriculture is a rather promising direction for the development of agricultural engineering, which preserves all the advantages of a diesel engine in terms of energy capabilities and improving environmental and economic parameters when using gas fuel (Mathur *et al.*, 2022; Saleem, 2022). The existing data of scientific research by scientists for the year 2022 (Bagagiolo *et al.*, 2022; Kutkovetska *et al.*, 2022) allow us to state the prospects for the development of the use of gas-diesel engines, but today there is no systematic approach to the use of this type of fuel equipment in agriculture.

The purpose of the work was to assess the prospects of using the gas-diesel engine system in agriculture. For this purpose, an analysis of modern scientific data on the use of auto-tractor diesel engines with the involvement of liquefied petroleum gas (LPG) was carried out. A search for scientific sources was conducted in the Google Scholar, Scopus, Web of Science databases of publications for the period 2000-2023 according to the set goal. Publications that lacked statistical justification, duplicated results, or contained data that could not be further verified were excluded from further analysis.

GAS-DIESEL ENGINES: PROBLEMS OF THEIR MODIFICATION AND OPERATION

Attention is drawn to the use of the term in the world scientific literature for an engine that uses both conventional diesel fuel and liquefied gas – "liquefied gas and diesel dual-fuel engine" (Ashok *et al.*, 2015). In publications from 2010-2020, dual-fuel LPG engines are modified diesel engines that use LPG as the primary fuel and diesel as the secondary fuel (Pielecha & Sidorowicz, 2021; Pham *et al.*, 2022). Dual-fuel LPG engines have good thermal efficiency at high power, but performance is lower at part-load conditions due to poor utilization of the energy potential of the combined fuel. This problem can be overcome by using a variety of factors such as fuel injection rate, injection timing, gaseous fuel composition and intake charge conditions to improve the performance, combustion and emissions of dual-fuel engines. However, the question of the most effective way to transfer a diesel engine to dual-fuel mode remains open (Bennour, 2021).

Several publications (Murthy *et al.*, 2021; Al-Dawody *et al.*, 2022) review the results of studies conducted to improve the performance, combustion parameters, and emissions of LPG and diesel engines. The data of the work showed that the use of liquefied gas in a diesel engine is one of the effective methods of reducing toxic emissions, but at the same time, under conditions of partial load, there is a drop in the efficiency and effective power of the diesel engine. Specifically, a diesel fuel blend with 10% LPG (Liquefied Petroleum Gas) is shown to produce a 5.35% reduction in NO_x, while diesel with 20 and 30% LPG emits 9.05 and 16.5% less NO_x, respectively. Increasing the percentage of LPG in diesel results in lower soot concentrations because LPG has a lower carbon to hydrogen ratio. The lowest ability to emit smoky combustion is found for fuel with 30% LPG, where a reduction of 7.4% is achieved. It was concluded that the optimal mixing ratio is 30% LPG.

One of the main problems of combining diesel fuel with LPG is the gas density, which is very low under ambient conditions (Anisimov *et al.*, 2016). This affects the fuel supply system, and to inject the required mass of fuel, a much larger cross-sectional area of the fuel injector is required than that of a diesel injector.

In modern units, the operation of gas cylinder equipment (HBO) on a diesel engine is performed according to the principle of the 4th generation of HBO gasoline engines with a slight difference in the fuel supply system (Semenov *et al.*, 2015). If in the gasoline analogue, the engine starts working on gasoline, and then uses only gas, then HBO on a diesel engine uses both types of fuel at the same time, feeding it to the cylinders in turn at different strokes (Kalinichenko *et al.*, 2019). The principle of operation of gas in a diesel engine is based on the fact that both types of fuel alternate in supply. The launch is carried out only on diesel fuel. In the first stroke, a portion of gas fuel mixed with air enters the cylinders, which is then compressed, and at the end of the compression stroke, an igniting dose of diesel fuel is supplied, which self-ignites from compression and ignites the gas-air mixture. The lower the octane number of gas fuel, the faster the gas burns with less heat release, and accordingly, the more it can replace diesel fuel (Poliakov *et al.*, 2015).

In 2010, the use of natural gas in a compressed form became the most widespread in cars with engines with external mixture formation and forced (spark) ignition (Melnyk *et al.*, 2018; Singh *et al.*, 2021). Usually, cylinders for storing natural gas under high pressure, gas reducers, electromagnetic valves and other gas equipment are additionally installed on a car with a carburetor engine, which ensures the possibility of engine operation on gas. The versatility of the power supply of such a vehicle (gasoline or natural gas) is also its disadvantage, since the full potential of the high detonation resistance of natural gas is not used (Lopatin, 2020). At the beginning of the 2020s, carburetor engines in agriculture recede into the background, due to their obsolescence and inefficiency, as well as unsatisfactory environmental parameters (Hua, 2021). However, there are publications about the experience of gas cars manufactured in the USSR (Union of Soviet Socialist Republics) running on compressed natural gas (CNG), which revealed a number of positive aspects (Poliakov & Mariyanko, 2014). The researchers established an increase in the motor resource of the converted engine by 35-40, an extension of the term of use of candles by 30-40%, as well as a reduction in engine oil consumption by postponing the replacement by 2-3 times. However, the same researchers noted a number of disadvantages of using the dual-fuel mode, in particular – a decrease in power by 18-20%, which leads to a decrease in maximum speed by 5-6%, respectively, and an extension of the acceleration time by 24-30%, a decrease in the maximum angles overcome by the climb and mileage limits at one gas station. At the same time, the carrying capacity decreases significantly (9-14%) due to the increase in the weight of the car due to the gas cylinder equipment.

The difficulty of using gas fuel in diesel engines is related to their poor flammability, low cetane number, and high ignition temperature (Zaharchuk & Zaharchuk, 2020). Therefore, to organize the operation of a diesel on natural gas, the gas-diesel process is used, which consists in feeding a dose of flammable diesel fuel into the cylinders, which ensures the ignition of the gas-air mixture (Kryshtopa *et al.*, 2018). Gas-diesel engine start-up and idling work only on diesel fuel. In other modes, an increase in engine power is achieved by increasing the gas fuel supply. The amount of incendiary dose delivery is 15-20% of the total fuel consumption.

LPG AS A PROMISING GAS-DIESEL ENGINE COMPONENT

In addition to liquid fuel – diesel, gaseous fuels such as hydrogen, compressed natural gas (CNG), diesel methyl ether (DME), biogas, and LPG are used in combination (Caban *et al.*, 2013; Kumar *et al.*, 2018). Liquefied petroleum gas (LPG) and CNG turned out to be the most popular among gas fuels in 2010-2020 due to the availability and simplicity of units for their use (Wei & Geng, 2016; Singh *et al.*, 2020). LPG fuel can be used as gas or liquid phase in diesel engines. In the gas phase, air from the intake is fumigated and an LPG-air mixture is formed in the intake manifold (Mueller & Guenthner, 2023). When LPG is a liquid, it is mixed with diesel fuel at a pressure above 0.5 MPa. LPG is mixed with diesel fuel under pressure by a high-pressure pump. A high-pressure pump supplies a mixture of diesel fuel and gas to the injector. The liquid phase of LPG is injected either as a mixture of LPG with diesel fuel at the same time by an injector or separately by a second injector (Vo *et al.*, 2022).

In gas-phase LPG diesel engines, vaporized LPG is fed into the cylinder with intake air and the LPG-air mixture is compressed as in a conventional diesel engine. The LPG-air mixture is not self-igniting due to the high auto-ignition temperature. A small amount of diesel fuel, called pilot, is injected to ignite the LPG-air mixture. Pilot diesel fuel injected by conventional diesel injection equipment only reduces a small fraction of engine power output (Canelada & Tischer, 2007). The use of LPG in the gas phase is quite well studied in many scientific works (Saleh, 2008; Ciniviz, 2010; Mohsen *et al.*, 2023). It was concluded that this combination leads to better engine efficiency, reduction of emissions of solid particles and smoke.

M. Ciniviz (2010) carried out a study of the effectiveness of the use of dual fuel (diesel / LPG) in a diesel engine on power and emissions. A gas control valve

system was designed to supply liquefied gas at a rate of 30% to the intake manifold. The experimental results showed that the engine power, engine torque and specific fuel consumption were improved due to the dual fuel supply. As a result of the use of dual-fuel engines, compared to single-fuel engines, torque and engine power increased by 5.8%, and NO_x emissions and excess air ratio decreased by 5.9 and 1/9%, respectively. Furthermore, CO_2 emissions were shown to be lower than in single-fuel mode, as *CO* emissions cannot be converted to CO_2 in dual-fuel mode.

Also P. Stålhammar *et al*. (2011) studied the performance and emissions of a 100% LPG direct injection diesel engine. They added di-tert-butyl peroxide (DTBP) and aliphatic hydrocarbon (AHC) to LPG fuel to increase the cetane number. The stable operation of the diesel in a wide range was demonstrated. The engine load range has been extended with the improvement of LPG cetane number. Several different LPG mixtures were obtained by varying the concentration of DTBP and AHC. LPG and only AHC fuel blends increased NO_x emissions compared to diesel operation. The results of the experiment showed that the thermal efficiency of a diesel engine running on liquefied gas was similar in basic parameters to running on pure diesel fuel. From the point of view of emissions of exhaust gases, their reduction was ascertained when using different mixtures of LPG, DTBP and AHC.

Attempts to convert YaMZ-240 GD and YaMZ-240 H1-GD diesels to gas diesel were carried out by a group of researchers from Ukraine (Kovbasenko *et al.*, 2016). The obtained data indicate the prospects of this type of conversion using the regulation of the starting ignition volume of a diesel engine with an electromagnet. Regulation of fuel supply to both diesel and gas in this case is carried out by separate screws. It is planned to switch to purely diesel mode when the load in the combined cycle is reduced below 20-30% of the maximum, which establishes the use of gas-diesel mode as the basic one. Also, the same scientists noted the improvement of environmental characteristics in the dual-fuel mode of engine operation in the form of a certain decrease in the content of carbohydrates and carbon monoxide, as well as the smokiness of exhaust gases. With the proposed mechanism of conversion to gas-diesel, slight differences in the emission of carbon oxides were noted in the two modes of engine operation. As for nitrogen oxide, the researchers even found an increase in the content of this compound when operating in gas-diesel mode. There are also significant disadvantages of this system in the form of an increase in the engine design due to the hydraulic amplifier of the gas dispenser drive and the impossibility of correcting the volume of flammable diesel fuel, which limits the amount of replacement of diesel with gas. When using a gas-diesel installation on a YAMZ-236 GD engine with mechanical multi-mode rotation control, the ignition dose of diesel fuel was 30%. The above results of scientists from Ukraine coincide with the conclusions of researchers from other countries and indicate the prospects for further development of gas-diesel engines, however, the very scheme of conversion to gas-diesel requires further improvement.

Also, work on the creation of engines with a gas-diesel type of power supply is carried out both in scientific institutions and by commercial companies in many countries of the world. In particular, as a good example of this is the development of the Bosch company Diesel-Gas System – Bosch (DG-Flex) (D'Agosto *et al.*, 2014). However, data on its installation on agricultural machinery has not been found. As standard, DG-Flex consists of sensors: detonation, air temperature, coolant temperature, phase, crankshaft, gas temperature and pressure, as well as a lambda probe and an electronic gas supply control unit. The use of the Diesel-Gas System – Bosch (Fontaras *et al.*, 2012; Gopalakrishnan & Tischer, 2014) leads to a significant improvement in environmental characteristics in the form of a six-fold reduction in solid emissions and nitrogen oxide volume compared to the diesel cycle. Also, a positive effect is saving money and reducing the volume of fuel consumption. However, some scientists (Owczuk *et al.*, 2019) point to the imperfection of this design in the form of the complexity of the system itself, a mixed method of power regulation with a throttle and a complicated control algorithm of this system.

PROBLEMS AND PROSPECTS OF USING A GAS-DIESEL ENGINE IN AGRICULTURE

The main problem in the practical application of a gas-diesel engine in agriculture is the choice of the principle of rebuilding the power system for the conversion of serial tractor engines (Mattarelli *et al.*, 2019; Giorgi *et al.*, 2020). Fundamental in this case is the difference in the two concepts of converting diesel engines to a gas-diesel power model. The most radical method is the complete replacement of fuel, which is accompanied by spark ignition of the gas-air mixture (Mattarelli *et al.*, 2021). This method involves complete disassembly of the diesel fuel equipment followed by reprogramming of the compression ratio, reducing it to 11-14 units, and at the end, the system is equipped with gas equipment (ignition system, cylinder, gas pipeline). The technical parameters of this conversion method correspond to the parameters of the engine

before the rebuild, and the environmental indicators are significantly improved, since in general this engine runs on gas fuel (Kabeyi & Olanrewaju, 2022). After the conversion, the engine can no longer run on diesel fuel, the reverse operation is economically impractical. Experiments were conducted by researchers M. Kabeyi & O. Olanrewaju (2022) to study the efficiency of a diesel engine with natural gas and diesel fuel in dual fuel mode with different proportions of diesel fuel 10-100% at 10% intervals. The results show that the overall efficiency of using CNG was lower than that of 100% diesel. At lower loads the efficiency was significantly lower and at higher outputs the performance was much better but still lower than when the diesel was running at 100%. The specific fuel consumption of the engine at 1.1 kW when operating on a mixture with 90% CNG was 68% higher than when the engine was operating in purely diesel mode. However, at 2.8 kW, the specific fuel consumption of the engine when running on 90% CNG was only 7% higher. Exhaust gas emissions show that in gas-liquid mode CO_2 and smoke emissions were lower due to the lower carbon to hydrogen ratio in CNG. *CO* emissions were higher due to the lower air-to-fuel ratio, as the injection of LNG into the intake air replaced some of the air in the intake tract.

The next option is the dual-fuel mode of rebuilding the diesel engine. In general, it is a variant of the standard gas-diesel engine with the predominant use of gas as the base fuel and diesel for the ignition of the gas mixture (Dasappa & Sridhar, 2011). However, the use of a specific ratio of diesel and gas in this scheme is a rather variable indicator that primarily depends on the type of gas fuel, individual design features of both the diesel engine and the gas plant. An important factor in this version of the gas-diesel engine is the possibility of using a full-fledged purely diesel mode, which is carried out by the operator himself.

In view of the energy crisis, many alternative fuels have been tested worldwide for use in internal combustion engines (Wang *et al.*, 2022; Das *et al.*, 2022). The conducted review indicates the perspective of conducting research on the use of natural gas as an alternative fuel, corresponds to the trend of finding new types of fuel with improved environmental performance and preservation of the technical characteristics of the diesel engine. Taking into account the above data, one of the promising types in terms of economy is the use of a diesel engine with an LPG system in agriculture. An increase in the number of publications on the study of optimal conversion schemes of diesel engines using biogas and LPG is attracting attention (Wei & Geng, 2016; Singh *et al.*, 2020). Analysis of the publications of scientists from Ukraine on this issue indicates that most of the research is devoted to the conversion of outdated engines or the use of biogas, which is quite debatable regarding the availability of this type of fuel in Ukraine (Zhuk, 2022).

Gas-diesel engines in agriculture can be rebuilt by completely replacing diesel fuel with gas, which leads to environmental improvement, but the loss of the ability to use diesel fuel. On the other hand, a dual-fuel mode can be applied, where gas is used as the base fuel, but diesel remains for ignition, giving greater flexibility of use.

CONCLUSIONS

The conducted review indicates the relevance of developing new schemes for conversion of serial diesel engines to dual-fuel mode using alternative fuel mixtures. Alternative types of gaseous fuels available on the market, such as hydrogen, CNG, diesel methyl ether, biogas and LPG have significant differences in the implementation of engine conversion and technical characteristics after modification. There are several options for converting a diesel engine to work in dual-fuel mode, but there are no generally accepted schemes for modifying diesel engines in agriculture. The diesel engine conversion schemes proposed for 2010-2020 are technically quite complex and require significant intervention in the engine layout, which increases the cost of this manipulation. It was established that the use of dual-fuel engines has a significant thermal efficiency at high power, but at the same time they are characterized by lower performance under partial load conditions due to insufficient use of the energy potential of the combined fuel. They are trying to overcome this problem by optimizing the power and combustion parameters. The optimal way to modify a diesel engine into a dual-fuel mode remains a debatable issue, which prevents serial conversion. Taking into account the available opportunities in Ukraine regarding the availability of various types of gaseous fuel, the most economically feasible type of gaseous fuel when converting a diesel engine is the use of liquefied petroleum gas. Taking into account the available schemes, the scheme of the DG-Flex BOSCH fuel supply system, which provides for the supply of liquefied petroleum gas to the intake manifold and its mixing with air on the intake stroke, and the supply of an ignition dose of diesel fuel, using modern diesel fuel equipment, is promising for the operation of a dual-fuel engine according to the gas-diesel cycle Common Rail. However, the existing schemes need to be improved, taking into account the existing shortcomings in the form of software and maintenance complexity, as well as a multi-level throttle control system. As a result of this

review, the existence of the problem of developing energy-efficient and environmentally safe gas-diesel systems, in particular, for use in the agriculture of Ukraine, was established, which requires further research with the aim of implementation in practical activities.

ACKNOWLEDGEMENTS

None.

CONFLICT OF INTEREST

None.

REFERENCES

[1] Al-Dawody, M.F., Al-Chlaihawi, K.K.I., & Al-Farhany, K.A. (2022). Numerical simulation of the effect of LPG blending on the characteristics of a diesel engine. *Heat Transfer*, 51(2), 1918-1938. doi: 10.1002/htj.22381.

[2] Anisimov, V., Ryaboshapka, V., & Ivanovs, S. (2016). Calculation of the performance indicators of machine and tractor aggregates using biofuel. *Journal of Research and Applications in Agricultural Engineering*, 61(3), 16-20. Retrieved from https://yadda.icm.edu.pl/baztech/element/bwmeta1.element.baztech-a64917a2-d68a-4e5f-8c73-97f953e35735.

[3] Ashok, B., Ashok, S.D., & Kumar, C.R. (2015). LPG diesel dual fuel engine - a critical review. *Alexandria Engineering Journal*, 54(2), 105-126. doi: 10.1016/j.aej.2015.03.002.

[4] Bagagiolo, G., Vigoroso, L., De Paolis, G., Caffaro, F., Cavallo, E., & Pampuro, N. (2022). Barriers to adoption of alternative fuels for agricultural machinery: A study on a group of Italian farmers. *SAE Technical Paper*, 2022-24-0028. doi: 10.4271/2022-24-0028.

[5] Bennour, M. (2021). *LPG-diesel dual fuel engine: Literature review and CFD analysis*. Retrieved from http://repository.enp.edu.dz/jspui/handle/123456789/10357.

[6] Caban, J., Gniecka, A., & Holeša, L. (2013). Alternative fuels for diesel engines. *Advances in Science and Technology. Research Journal*, 7(20), 70-74. doi: 10.5604/20804075.1073063.

[7] Canelada, M.M., & Tischer, F. (2007). DualFuel system, diesel and natural gas - optimizing the concept. *SAE Technical Paper*, 2007-01-2616. doi: 10.4271/2007-01-2616.

[8] Ciniviz, M. (2010). Full load performance and emission characterictics of a LHR diesel engine for different insulation levels. *Technological Applied Sciences*, 5(2), 40-50. Retrieved from https://dergipark.org.tr/en/pub/nwsatecapsci/issue/20180/213935.

[9] D'Agosto, M. de A., Oliveira, C.M., & Assumpção, F. do C. (2014). Energy alternatives for urban public transportation in Rio de Janeiro: A Life Cycle Inventory (LCI) analysis. *TRANSPORTES*, 22(1), 76-97. doi: 10.14295/transportes.v22i1.736.

[10] Das, A.K., Sahu, S.K., & Panda, A.K. (2022). Current status and prospects of alternate liquid transportation fuels in compression ignition engines: A critical review. *Renewable and Sustainable Energy Reviews*, 161, 112358. doi: 10.1016/j.rser.2022.112358.

[11] Dasappa, S., & Sridhar, H.V. (2011). Performance of a diesel engine in a dual fuel mode using producer gas for electricity power generation. *International Journal of Sustainable Energy*, 32(3), 1-16. Retrieved from https://www.researchgate.net/publication/239792335.

[12] Emaish, H., Abualnaja, K.M., Kandil, E.E., & Abdelsalam, N.R. (2021). Evaluation of the performance and gas emissions of a tractor diesel engine using blended fuel diesel and biodiesel to determine the best loading stages. *Scientific Reports*, 11(1), 9811. doi: 10.1038/s41598-021-89287-0.

[13] Fontaras, G., Manfredi, U., Martini, G., Dilara, P., & Deregibus, G. (2012). Experimental assessment of a Diesel-LPG dual fuel supply system for retrofit application in city busses. *SAE Technical Paper*, 012-01-1944. doi: 10.4271/2012-01-1944.

[14] Giorgi, C., Teimuraz, K., & Romanoz, T. (2020). The possibility and analysis of using gas as an alternative fuel in the diesel engine. *Trans Motauto World*, 5(2), 68-70. Retrieved from https://stumejournals.com/journals/tm/2020/2/68.

[15] Gopalakrishnan, M., & Tischer, F.P. (2014). Torque model for a dual fuel engine. *SAE Technical Paper*, 2014-01-2417. doi: 10.4271/2014-01-2417.

[16] Hua, Y. (2021). Ethers and esters as alternative fuels for internal combustion engine: A review. *International Journal of Engine Research*, 24(1), 178-216. doi: 10.1177/14680874211046480.

[17] Kabeyi, M., & Olanrewaju, O. (2023). Diesel to gas engine power plant conversion: A review and preliminary design for an operting power plant. *Journal of Energy Management and Technology*, 7(2), 103-115. doi: 10.22109/JEMT.2022.292982.1312.

[18] Kabeyi, M.J.B., & Olanrewaju, O.A. (2022). Feasibility of conversion from diesel engine to natural gas power plants. In *IECON 2022 - 48th Annual Conference of the IEEE Industrial Electronics Society* (pp. 1-7). doi: 10.1109/IECON49645.2022.9968428.

[19] Kalinichenko, A., Havrysh, V., & Atamanyuk, I. (2019). The acceptable alternative vehicle fuel price. *Energies*, 12(20), 3889. doi: 10.3390/en12203889.

[20] Kovbasenko, S., Nazarenko, M., Petrenko, V., & Golyk, A. (2016). Prospects for the use of natural gas by vehicle engines in Ukraine. In *Systems and means of motor transport: Selected problems* (Vol. 7; pp. 159-164). Rzeszow: Oficyna Wydawnicza Politechniki Rzeszowskiej.

[21] Kryshtopa, S., Panchuk, M., Kozak, F., Dolishnii, B., Mykytii, I., & Skalatska, O. (2018). Fuel economy raising of alternative fuel converted diesel engines. *Eastern-European Journal of Enterprise Technologies,* 4(8), 6-13. Retrieved from http://www.irbis-nbuv.gov.ua/cgi-bin/irbis_nbuv/.

[22] Kumar, N., Sonthalia, A., & Pali, H.S. (2018). Alternative fuels for diesel engines: New frontiers. In *Diesel and gasoline engines*. London: IntechOpen. doi: 10.5772/intechopen.80614.

[23] Kutkovetska, T.O., Kravchenko, V.V., & Petrychenko, E.A. (2022). Prospects for the development of gas-diesel power tools in modern agricultural production. *Scientific Notes of the Tavrida V.I. Vernadsky National University. Series: Technical Sciences*, 33(6), 13-16. Retrieved from https://lib.udau.edu.ua/handle/123456789/9497.

[24] Liu, L., Zhang, M., & Liu, Zh. (2023). A review of development of natural gas engines. *International Journal of Automotive Manufacturing and Materials*, 2(1), 16. doi: 10.53941/ijamm0201004.

[25] Lopatin, O.P. (2020). Natural gas combustion in diesel engine. *IOP Conference Series: Earth and Environmental Science*, 421(7), 072019. doi: 10.1088/1755-1315/421/7/072019.

[26] Mathur, S., Waswani, H., Singh, D., & Ranjan, R. (2022). Alternative fuels for agriculture sustainability: Carbon footprint and economic feasibility. *AgriEngineering*, 4(4), 993-1015. doi: 10.3390/agriengineering4040063.

[27] Mattarelli, E., Rinaldini, C.A., & Savioli, T. (2019). Dual fuel (natural gas diesel) for light-duty industrial engines: A numerical and experimental investigation. In K. Srinivasan, A. Agarwal, S. Krishnan, & V. Mulone (Eds.), *Natural gas engines* (pp. 297-328). Singapore: Springer. doi: 10.1007/978-981-13-3307-1_11.

[28] Mattarelli, E., Rinaldini, C.A., Savioli, T., & Scrignoli, F. (2021). Optimization of a high-speed dual-fuel (natural gas-diesel) compression ignition engine for gen-sets. *SAE International Journal of Engines*, 14(3), 369-386. Retrieved from https://www.jstor.org/stable/27039294.

[29] Melnyk, V., Voytsehivska, T., & Sumer, A. (2018). Studying main technical-operating characteristics of the alternative fuels for diesel iternal combustion engines. *Scientific Works of Vinnytsia National Technical University*, 2. Retrieved from https://works.vntu.edu.ua/index.php/works/article/view/540.

[30] Mohsen, M.J., Al-Dawody, M.F., Jamshed, W., El Din, S.M., Abdalla, N.S.E., Abd-Elmonem, A., ... Shah, H.H. (2023). Experimental and numerical study of using of LPG on characteristics of dual fuel diesel engine under variable compression ratio. *Arabian Journal of Chemistry*, 16(8), 104899. doi: 10.1016/j.arabjc.2023.104899.

[31] Mueller, F., & Guenthner, M. (2023). Comparison of premixed fuel and premixed charge operation for propane-diesel dual-fuel combustion. *SAE Technical Paper*, 2023-24-0059. Retrieved from https://www.sae.org/publications/technical-papers/content/2023-24-0059/.

[32] Murthy, K., Srinivas, V.G., & Kumar, S. (2021). Modeling and prediction of NO_x emission in an LPG-diesel dual-fuel CI engine. *Heat Transfer*, 50(7), 6847-6867. doi: 10.1002/htj.22206.

[33] Owczuk, M., Matuszewska, A., Kruczyński, S., & Kamela, W. (2019). Evaluation of using biogas to supply the dual fuel diesel engine of an agricultural tractor. *Energies*, 12(6), 1071. doi: 10.3390/en12061071.

[34] Pham, Q., Park, S., Agarwal, A.K., & Park, S. (2022). Review of dual-fuel combustion in the compression-ignition engine: Spray, combustion, and emission. *Energy*, 250, 123778. doi: 10.1016/j.energy.2022.123778.

[35] Pielecha, I., & Sidorowicz, M. (2021). Effects of mixture formation strategies on combustion in dual-fuel engines - a review. *Combustion Engines*, 184(1), 30-40. doi: 10.19206/CE-134237.

[36] Poliakov, A.P., & Mariyanko, B.S. (2014). Study of the effect on gas-diesel performance of improving the power supply system using a gas release device. *Scientific Works of Vinnytsia National Technical University*, 2. Retrieved from http://ir.lib.vntu.edu.ua/bitstream/handle/123456789/4793/405.pdf?sequence=3.

[37] Poliakov, A.P., Galushchak, O.O., & Galushchak, D.O. (2015). Technique of motor vehicle indices calculation while transition of its engine for operation at the mixture of diesel and biodiesel fuels. *TEHNOMUS - New Technologies and Products in Machine Manufacturing Technologies*, 22, 76-81. Retrieved from http://inmad.vntu.edu.ua/portal/static/0AA9A0E8-0C4E-484D-BFAC-4C2CF5DF8066.pdf.

[38] Sain, M., Kaur, M., Singh, M., & Kumar, S. (2018). Development of a dual fuel system to operate tractor on biogas. *International Journal of Pure & Applied Bioscience*, 6(1), 1710-1720. doi: 10.18782/2320-7051.8065.
[39] Saleem, M. (2022). Possibility of utilizing agriculture biomass as a renewable and sustainable future energy source. *Heliyon*, 8(2), E08905. doi: 10.1016/j.heliyon.2022.e08905.
[40] Saleh, H.E. (2008). Effect of variation in LPG composition on emissions and performance in a dual fuel diesel engine. *Fuel*, 87(13-14), 3031-3039. doi: 10.1016/j.fuel.2008.04.007.
[41] Semenov, V.G., Komaha, V.P., & Ryaboshapka, V.B. (2015). The simulation of the combustion process in a tractor and combine diesel engines running on different fuels by using more refined models I.I. Vibe, based on the approximation experimental data. *Technology, Energy, Transport of Agricultural Industry*, 1(91), 52-58. Retrieved from http://socrates.vsau.org/repository/getfile.php/10269.pdf.
[42] Shyamkishore, I., Mundra, S., & Bhande, R. (2022). Alternative transportation fuels. *World Journal of Advanced Engineering Technology and Sciences*, 7(2), 044-053. doi: 10.30574/wjaets.2022.7.2.0123.
[43] Singh, A.P., Mustafi, N.N., Sharma, Y.C., & Agarwal, A.K. (2020). Introduction to alternative fuels and their utilization strategies in internal combustion engines. In *Fuels and their utilization strategies in internal combustion engines* (pp. 3-6). Singapore: Springer. doi: 10.1007/978-981-15-0418-1_1.
[44] Singh, G., Dogra, D., Ramana, R., Chawla, J., Sutar, P.S., Sagare, V.S., ... Thipse, S.S. (2021). Development of dual fuel (diesel + CNG) engine for off-road application. *SAE Technical Paper*, 2021-26-0119. doi: 10.4271/2021-26-0119.
[45] Stålhammar, P., Erlandsson, L., Willner, K., & Johannesson, S. (2011). *Demonstration and evaluation of dual-fuel technology*. Malmo: Svenskt Gastekniskt Center. Retrieved from https://www.osti.gov/etdeweb/servlets/purl/1035259.
[46] Vo, T.C., Tran, D.L., Sy, N.Q., Khai, C.Q., Nhan, N.T., & Hao, L.V.M. (2022). A study on LPG injection based speed regulator for dual fuel diesel engine. *Journal of Technical Education Science,* 72A, 1-9. doi: 10.54644/jte.72A.2022.1264.
[47] Wang, Y., Cao, Q., Liu, L., Wu, Y., Liu, H., Gu, Z., & Zhu, C. (2022). A review of low and zero carbon fuel technologies: Achieving ship carbon reduction targets. *Sustainable Energy Technologies and Assessments*, 54, 102762. doi: 10.1016/j.seta.2022.102762.
[48] Wei, L., & Geng, P. (2016). A review on natural gas/diesel dual fuel combustion, emissions and performance. *Fuel Processing Technology*, 142, 264-278. doi: 10.1016/j.fuproc.2015.09.018.
[49] Zaharchuk, V., & Zaharchuk, O. (2020). Indexes of gas engine converted from a tractor diesel. *Trans Motauto World*, 5(2), 71-73. Retrieved from https://stumejournals.com/journals/tm/2020/2/71.
[50] Zhu, Y., & Fan, L. (2022). Fuel delivery system for alternative fuel engines: A Review. In A.K. Agarwal, & H. Valera (Eds.), *Potential and challenges of low carbon fuels for sustainable transport* (pp. 67-95). Singapore: Springer. doi: 10.1007/978-981-16-8414-2_4.
[51] Zhuk, G.V. (2022). Prospects for the production of alternative automotive fuel in Ukraine: Transcript of the report at the meeting of the Presidium of the National Academy of Sciences of Ukraine on June 8, 2022. *Visnyk of the National Academy of Sciences of Ukraine*, 8, 19-24. doi: 10.15407/visn2022.08.019.

Проблеми та перспективи створення сучасних сільськогосподарських газодизелів: літературний огляд

Вадим Борисович Рябошапка
Кандидат технічних наук, старший викладач
Вінницький національний аграрний університет
21008, вул. Сонячна, 3, м. Вінниця, Україна
https://orcid.org/0000-0003-1812-1030
Роман Дмитрович Лисенко
Магістр
Вінницький національний аграрний університет
21008, вул. Сонячна, 3, м. Вінниця, Україна
https://orcid.org/0009-0007-9867-5581

Анотація. В умовах постійного зростання вартості традиційних нафтопродуктів та їх дефіциту, актуальним постає питання використання альтернативних палив. Метою статті є виявлення шляхів використання альтернативних видів палива для роботи дизельних двигунів. Методи досліджень – аналіз та верифікація даних отриманих з наукових публікацій, що входять до всесвітньо відомих наукометричних баз, на актуальність предмету досліджень. Результатами досліджень є виявленні переваги й недоліки двопаливних двигунів, що працюють на газоподібному паливі з присадкою дизельного палива, вплив цього типу двигунів на викиди та токсичність відпрацьованих газів, зокрема окисів азоту NO_x. Обґрунтовано застосування так званої газової форсунки та поперечного перерізу отворів її розпилювачів. Проаналізовано та встановлено, що найбільш економічно доцільним є використання для роботи дизельних двигунів зрідженого нафтового газу шляхом реалізації газорідинного циклу; виявлено, що найбільш перспективним для цього є газобалонне обладнання так званого 4-го покоління. Ретроспективний аналіз досліджень двигунів внутрішнього згорання з газобалонним обладнанням, показав збільшення моторесурсу при використанні газоподібних палив, а також негативну сторону використання газоподібних палив, яка полягає у знижені потужності при переобладнанні карбюраторних двигунів, однак використання цих палив для роботи дизелів повністю нівелює цей недолік. На основі аналізу досліджень, встановлено також вплив запальної дози, при роботі двигуна по газодизельному циклі, на показники роботи при різних навантаженнях та знайдено рекомендацію переходити на дизельний цикл з газодизельного при навантаженнях менших за 30 % від номінального. Обґрунтовано та вибрано оптимальну схему реалізації газодизельного циклу, що є актуальною і перспективною для більш розповсюджених енергетичних та транспортних засобів. Виходячи з проаналізованих схем, встановлено, що схемою, яку можна взяти за основу при подальших дослідженнях цього напрямку – це схема газодизельної системи DG-Flex BOSCH. Практична цінність роботи полягає в обґрунтуванні комплексного переобладнання з частковим заміщенням дизельного пального зрідженим нафтовим газом як найбільш раціонального способу переведення серійних дизельних двигунів в двопаливні

Ключові слова: транспорт; зріджений нафтовий газ; газобалонне обладнання; система живлення

UDC: 631.831.2
DOI: 10.56407/bs.agrarian/4.2023.90

Ukrainian Black Sea Region Agrarian Science
Vol. 27, No. 4

Evaluation of the effect of sugar mud and organic fertilizers on the productivity of sugar beets in the conditions of Podillia

Oksana Trembitska
PhD in Agriculture, Associate Professor
Polissia National University
10002, 7 Staryi Blvd., Zhytomyr, Ukraine
http://orcid.org/0000-0003-1152-0215

Sviatoslav Bohdan*
Master's Degree Candidate in Agronomy
Polissia National University
10002, 7 Staryi Blvd., Zhytomyr, Ukraine
http://orcid.org/0000-0002-3249-7096

Abstract. The application of lime fertilizer "defecation" on acidic and slightly acidic soils has a multifaceted positive effect, eliminating excessive acidity, and creating optimal environmental conditions for agricultural plants and soil microorganisms, increases the water resistance of structural soil aggregates, which determines favourable water and air modes, increases the accumulation of phosphorus, potassium. The goal is to investigate the influence of sugar mud and organic fertilizers on the productivity of sugar beets in the conditions of Podillia. In the presented study was carried out using such methods as field, measuring and weighing, laboratory, statistical. According to the results of the experiment, it was determined that the productivity of sugar beets increased depending on the doses of applied fertilizers. Thus, with the application of 2.0 Hr of sugar mud, the yield increase amounted to 15.27 t/ha. The combination of organic fertilizer and sugar mud 2.0 Hr had the strongest effect on productivity – 29.41 t/ha. The collection of sugar increased according to the experimental variants mainly due to the increase in yield. The increase in digestion was insignificant: from 0.08 to 0.56% according to the experiment variants. The segment of crop production will be profitable due to the drivers of the volume of the harvested crop. The side economic effect of the application of this measure will be to obtain a larger sugar harvest per hectare, which will allow to obtain a larger profit from the processing of sugar beets into sugar. The practical value of the research lies in the formation of recommendations for farms and agricultural enterprises growing sugar beet on acidic and slightly acidic soils in order to increase its productivity

Keywords: plant growing; agricultural techniques; liming; fertilization; soil acidity

Article's History:
Received: 25.08.2023
Revised: 23.10.2023
Accepted: 12.12.2023

Suggested Citation:
Trembitska, O., & Bohdan, S. (2023). Evaluation of the effect of sugar mud and organic fertilizers on the productivity of sugar beets in the conditions of Podillia. *Ukrainian Black Sea Region Agrarian Science*, 27(4), 90-98. doi: 10.56407/bs.agrarian/4.2023.90.

*Corresponding author

INTRODUCTION

As a result of the significant anthropogenic impact on the agricultural landscapes of Ukraine and the intensification of agricultural production, the state of soil acidification is characterized as catastrophic. The highest level of arable land acidification is characteristic of the Podillia zone, and this especially applies to the soils of the Vinnytsia region, where acidic soils make up more than 80% of the total arable land area (Voitova, 2020).

There are not many comprehensive studies on the impact of manure application and organic fertilizers on sugar beet productivity in the scientific environment. The general physiology of sugar beet and the factors affecting it are studied in the work of C. Hoffmann *et al.* (2021). Physico-chemical indicators and yield of sugar beets were considered in detail by I. Khan *et al.* (2018). M. Rašovský & V. Pačuta (2016) studied quite deeply and thoroughly the influence of certain agrotechnical measures and climatic conditions on the yield of root crops and the digestion of sugar beets. An interesting study is the assessment of the stability and adaptation models of the yield of white sugar from sugar beet varieties in a temperate climate, carried out by M. Studnicki *et al.* (2019). Agrotechnical measures in the management of soil fertility were studied by C. Kabala *et al.* (2016). Certain aspects of adaptive technology in the part of growing sugar beets on acidic soils are studied in the work of O. Balahura *et al.* (2018). The team of authors A. Zaryshniak *et al.* (2019), who examined the productivity of sugar beets under biologicization of their cultivation on weakly acidic soils, continues the development of this scientific direction. The general principles of sugar beet productivity, depending on the system of fertilization and tillage, were studied in the work of such scientists as O. Chernelivska *et al.* (2019).

Despite significant progress in the study of measures to increase the yield of sugar beets, there is a lack of comprehensive systematic work on the effect of applying manure and organic fertilizers on the productivity of sugar beets. One of the effective methods of increasing the fertility of acidic soils and ensuring the productivity of agricultural crops is liming and applying organic fertilizers. However, in the conditions of the existing price disparity for agricultural products and plant protection products, there is a need to find such methods of processing agricultural crops, which, at the lowest costs, ensured not only an increase in yield, but also the restoration of soil fertility. To solve this scientific and practical task, it was proposed to investigate the use of sugar production waste – sugar mud – which is especially relevant for enterprises that provide a full cycle of sugar production: from the provision of raw materials (growing sugar beets) and the actual production of sugar. Compared to traditional liming, sugar mud has advantages in cost, lower costs for transportation to the fields, in particular, its application allows for more efficient use of organic fertilizers.

MATERIALS AND METHODS

The study of the effect of sugar mud and organic fertilizers on the productivity of sugar beets was carried out in the Podillia area. The experiment was conducted at the limited liability agricultural company named after Bohdan Khmelnytskyi, as well as in the raw materials and factory laboratories of the sugar factory in the village of Horodkivka. The study was conducted on a pilot basis in 2022. The study adheres to the publication ethics established by Convention on Biological Diversity (1992), as any experiment involving plant research (both cultivated and wild). The experimental area is represented by grey podzolized soils mainly on loess rocks. The soil survey showed that the humus content is low, and the decline down the profile is gradual. The soil is slightly acidic, the content of mobile phosphorus is average, exchangeable potassium is high. The density of the arable horizon is 1.09 g/cm, an increase is observed down the soil profile.

The object of research within the scope of the conducted experiment was the process of formation, development, growth and ensuring the productivity of sugar beet depending on the application of sugar mud with organic fertilizers. Taking into account the pH of the soil at the level of 5.1-5.5, the degree of saturation with bases of 88.6%, the high hydrolytic acidity of 3.5-3.8 mg/eq., as well as the fact that a stable positive effect of liming is observed at the level of soil pH below the level of 5.5 and hydrolytic acidity of more than 2.0 mg/eq., there is a need for liming of this experimental plot. The total area of experimental plots was 45 hectares – 5 hectares for each of the formed schemes.

The predecessor of sugar beets was winter wheat. After harvesting, 2 weeks later, sugar mud was introduced, followed by planting in the soil. The weight rate of the introduced sugar mud was 25% of the full rate, depending on the indicator of hydrolytic acidity of the soil. Chemical composition of sugar mud: $CaCO_3$ – 44.3%, organic matter – 14%, N – 0.45%, P_2O_5 – 0.57%, K_2O – 0.75%, moisture – 14-23%. Compost with a dose of 12 t/ha was applied as an organic fertilizer. In particular, to prevent direct contact of sugar mud and amphos when applied to the soil, mineral fertilizers were applied during plowing. Plowing in the experiment was carried out at a depth of 28-30 cm (Humentyk *et al.*, 2018). In accordance with the purpose of the experiment to study the influence of sugar mud and organic fertilizers on the productivity of sugar beets, the following scheme was formed (Fig. 1).

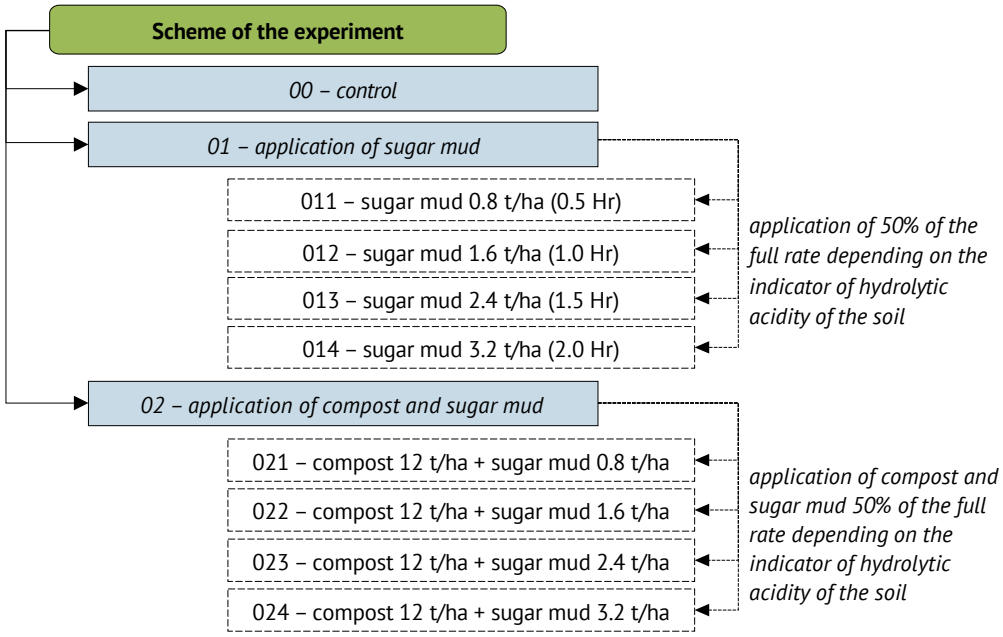


Figure 1. *Scheme of conducting an experiment to study the influence of sugar mud and organic fertilizers on the productivity of sugar beets*

Source: *authors' own development*

In the spring, when the physical maturity of the soil was reached, harrowing was carried out. 5 days after harrowing, when the soil was warmed at a depth of 10 cm to +5°C – +6°C, pre-sowing cultivation was carried out to a depth of 4-5 cm (Korovko, 2017). The Concertina KWS hybrid was used as seed material. Sowing rate – 1.2 s.u. on 1 ha. Sowing was carried out in a wide-row method with a Tempo Väderstad precision seed drill with 45 cm between rows, to a depth of 4-5 cm. At the beginning of the appearance of the second pair of true leaves, inter-row cultivation was carried out and the formation of optimal density by means of thinning. The yield of sugar beet was determined using the weighing complex of the beet point, and its technological qualities (digestion, content of dry substances, non-sugars, etc.) were determined in the raw material laboratory.

RESULTS

The main indicator of the effectiveness of the application of organic fertilizers is an increase in the yield of agricultural crops. Thus, the actual yield of sugar beets according to the schemes of the conducted experiment on the assessment of the impact of application of sugar mud and organic fertilizers deviated from the control value from 1.42 to 19.67 t/ha from 3 to 42% . The results of recording the yield indicators of sugar beet grown on the experimental plots according to different schemes are shown in the Figure 2.

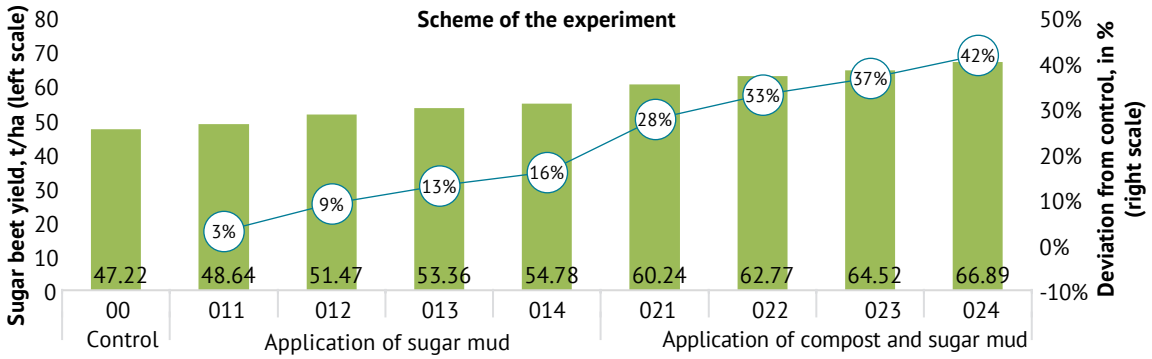


Figure 2. *The yield of sugar beets depending on the doses of application of sugar mud in combination with organic fertilizers in 2022*

Source: *authors' own development*

Application of only sugar mud provided an increase in the yield of sugar beets from 1.42 to 7.56 t/ha (from 3 to 16%). In turn, the application of sugar mud against the background of organic fertilizers (compost) ensured an increase in the yield of sugar beets from 13.02 to 19.67 t/ha (from 28 to 42%). Therefore, the application of organic fertilizer (compost) at a dose of 12 t/ha and sugar mud at a dose of 3.2 t/ha had the greatest positive effect on the productivity of sugar beets. This is due to the fact that applied organic fertilizers and sugar mud improve the water-air properties of soils, they become looser. Thanks to this, aeration, water permeability increases and the moisture reserve in the soil increases. What contributes to the powerful development of the root system of sugar beets, capable of more fully using soil moisture, developing sufficient vegetative mass.

The distribution of sugar in root crops is uneven. In the tail part and especially in the root head, the sugar content is lower than in the central part. The maximum amount of sugar accumulates slightly below the widest part of the root between the periphery and the central zone. Root crops belong to the group of crops that require a large amount of nutrients, so the application of fertilizers strongly affects the size of the harvest and its quality. The results of recording the digestion (sugar) indicators of sugar beet grown on the experimental plots according to different schemes are shown in the Figure 3.

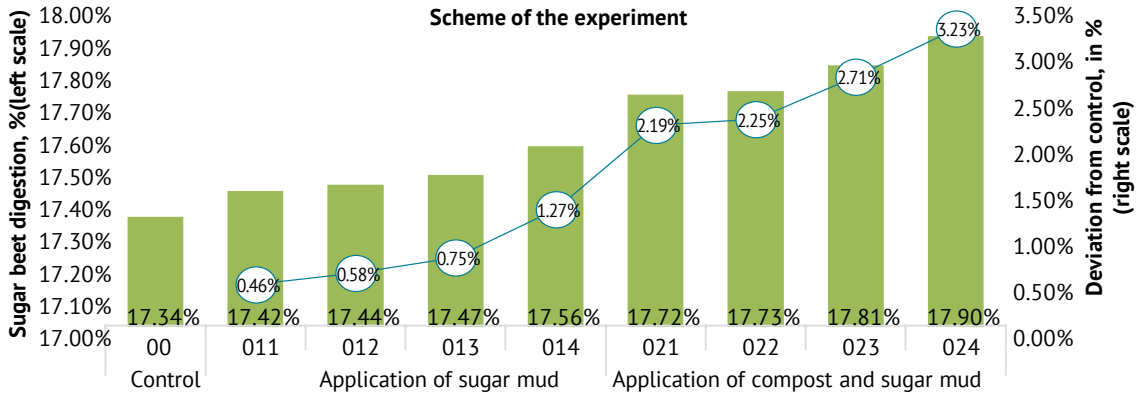


Figure 3. *Digestion of sugar beets depending on the doses of sugar mud application in combination with organic fertilizers in 2022*

Source: *authors' own development*

The application of only sugar mud provided an increase in the digestion of sugar beets from 0.08% to 0.22% (from 0.46 percentage points to 1.27 percentage points). In turn, the application of sugar mud against the background of organic fertilizers (compost) provided an increase in the digestion of sugar beets from 0.38% to 0.56% (from 2.19 percent to 3.23 percent). Therefore, the application of organic fertilizer (compost) at a dose of 12 t/ha and sugar mud at a dose of 3.2 t/ha had the greatest positive effect on the productivity of sugar beets. Based on the obtained results of yield and digestion of sugar beets, let's consider the resulting indicator – harvesting of sugar per hectare – and conduct a factor analysis of the contribution of individual indicators (yield and digestion) to its formation (Fig. 4-5).

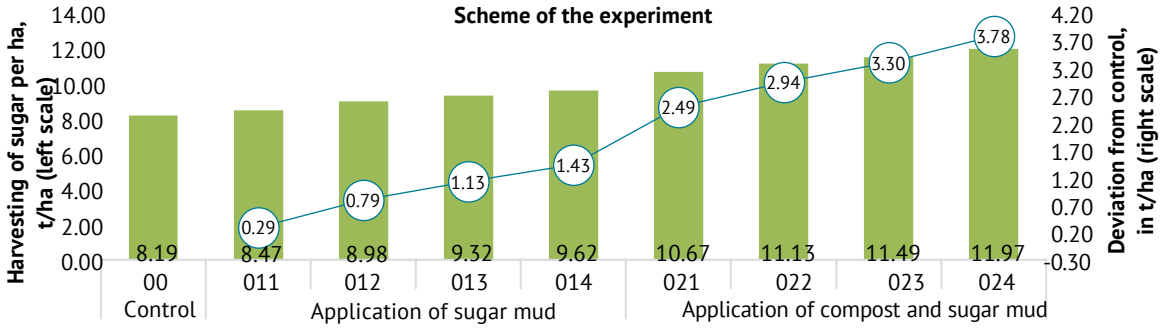


Figure 4. *Harvesting of sugar per hectare depending on the doses of application of sugar mud in combination with organic fertilizers in 2022*

Source: *authors' own development*

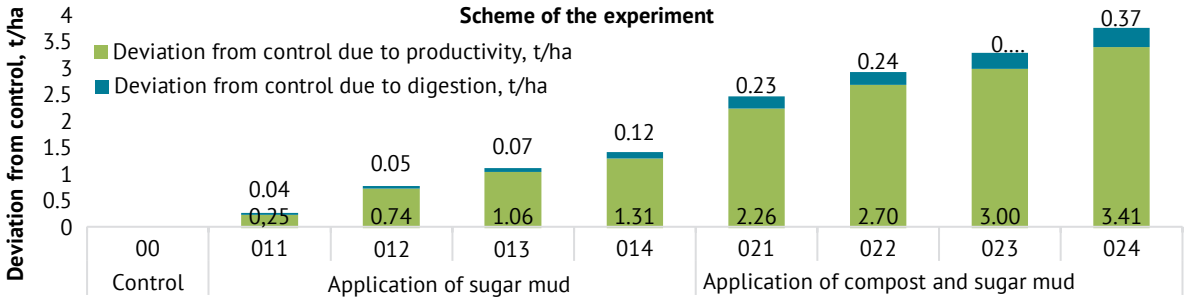


Figure 5. *Factor analysis of deviations of harvesting of sugar per hectare depending on the doses of application of sugar mud in combination with organic fertilizers in 2022*
Source: *authors' own development*

The application of only sugar mud provided an increase in the yield of sugar from 1 ha from 0.29 to 1.43 t/ha. In turn, the application of sugar mud against the background of organic fertilizers (compost) ensured an increase in the yield of sugar from 1 ha from 2.49 to 3.79 t/ha. Therefore, the greatest positive impact on sugar collection from 1 ha of sugar beet crops was made by the application of organic fertilizer (compost) at a dose of 12 t/ha and sugar mud at a dose of 3.2 t/ha. At the same time, it can be testified that the factor contribution of productivity in the formation of the indicator of sugar collection from 1 ha is at the level of an average of 94% against the factor contribution of sugar beet digestion at the level of 6%.

However, it should be noted that if organic fertilizers increase digestion, they simultaneously reduce the content of dry substances in the composition, which accounts for the share of sucrose, increasing the number of non-sugar soluble forms. These sugars, passing into beet juice, sharply deteriorate its quality. According to the results of the experiment, it was determined that with an increase in the doses of applied fertilizers, the content of dry substances and the total amount of non-sugars decreases (Fig. 6-8).

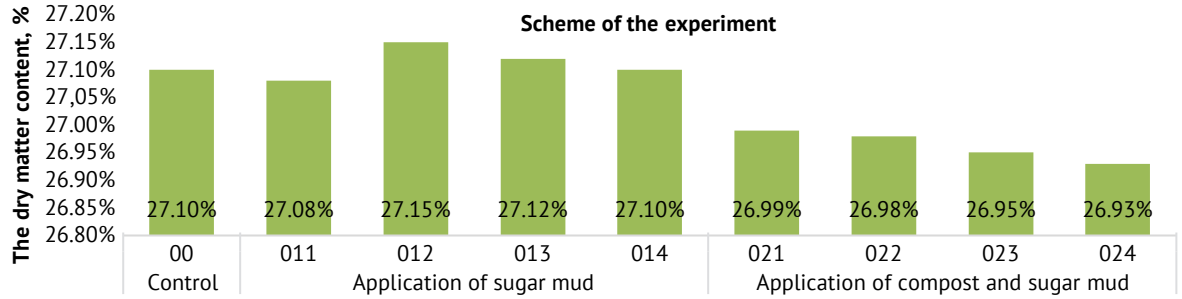


Figure 6. *Indicator of the quality of sugar beet "The dry matter content" depending on the doses of application of sugar mud in combination with organic fertilizers in 2022*
Source: *authors' own development*

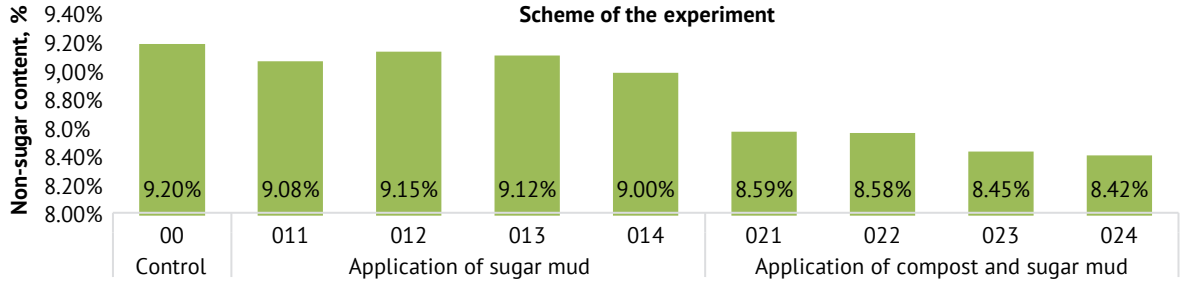


Figure 7. *Indicator of the quality of sugar beet "Non-sugar content" depending on the doses of application of sugar mud in combination with organic fertilizers in 2022*
Source: *authors' own development*

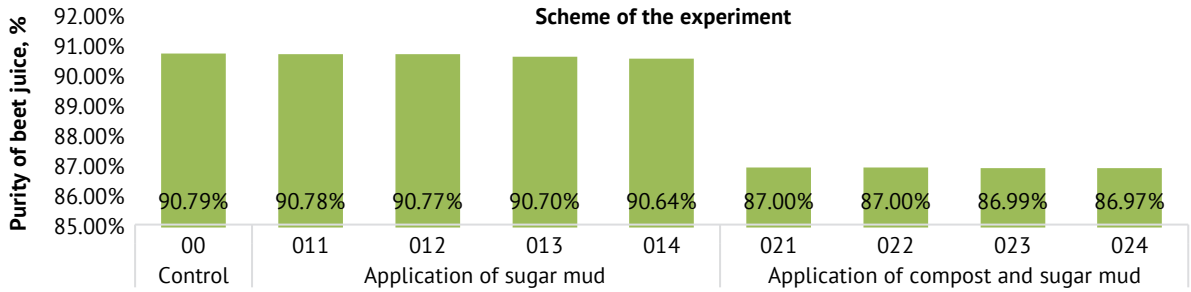


Figure 8. *Indicator of the quality of sugar beet "Purity of beet juice" depending on the doses of application of sugar mud in combination with organic fertilizers in 2022*
Source: *authors' own development*

According to the option of compost 12 t/ha + sugar mud 3.2 t/ha, the content of dry matter was 26.93% and non-sugar 8.42%, while in the control it was 27.10% and 9.20%, respectively. Despite the decrease in the content of dry matter in root crops due to the application of organic fertilizers, at the same time, the content of harmful soluble non-sugars increases, thereby worsening the quality of beet raw materials. The application of sugar mud reduces the content of soluble non-sugars. In the case of application of sugar mud with organic fertilizers, the purity of the juice deteriorates.

DISCUSSION

Studies show that the influence of the environment on plants depends on biological features and external factors. Laboratory studies have proven that increasing the concentration of calcium in the nutrient medium weakens the negative effect of hydrogen ions. This is explained by the antagonistic action of calcium in relation to hydrogen. In the presence of high calcium content, hydrogen ions are in the nutrient medium, but their entry into the plant is delayed (Shyrokostup, 2014). Acidic soils are characterized by unfavourable biological, physical and chemical properties. The colloidal part is poor in calcium and other bases. Hydrogen ions displace calcium from humus, increase its dispersion and mobility, and hydrogen saturation of mineral colloidal particles leads to their gradual destruction. This explains the low content of the colloidal fraction in acidic soils, which is why they have poor physical properties, low absorption capacity, and weak buffering capacity. In acidic soils, the activity of nitrifying, nitrogen-fixing and other beneficial bacteria and microorganisms is inhibited (Zaryshniak *et al.*, 2019). The negative effect of increased acidity is largely related to the mobility of aluminium and manganese in the soil. The main mass of aluminium is in the soil in a sedentary state and does not affect plants, but in acidic, for example, grey, dark-grey podzolic soils, the content of mobile aluminium often ranges from 3 to 20 mg/100 g of soil (Kliachenko & Kolomiiets, 2013), per sowing unit 1 ha is 60-400 kg of movable aluminium, which is 120-800 times higher than its content in plants. With increased soil acidity, there is poor growth and strong liquefaction of clover, alfalfa, sugar beets, winter wheat and other crops. Some weeds - horsetail, sedge, sedge, creeping buttercup, sedge, heather grow well on acidic soils and are indicator plants. For each type of plant, there is a certain, most favourable for growth and development reaction interval of the medium (pH 6.5-7.5). Alfalfa, sugar beet, hemp, cabbage do not tolerate acidic soils at all (pH 7.0-7.5).

The process of soil impoverishment with calcium is observed almost everywhere, but it has a different quantitative expression and therefore does not have the same effect on fertility, as evidenced by the data on agrochemical soil survey (Kurylo *et al.*, 2014). Various meliorants can be used to improve soil fertility: lime, gypsum, dolomite flour, etc., as well as sugar mud, the effectiveness of which was not inferior to chalk and dolomite flour. Thus, when applying equal doses of chalk, dolomite flour and sugar mud under sugar beets, the yield was: background (control): 445 t/ha; background + chalk: 477 c/ha; background + dolomite flour: 483 c/ha; background + defect: 490 c/ha. That's why V. Butov & V. Porudieiev (2014) also consider fragmentary application of organic fertilizers under sugar beet.

According to research data, defecate is not inferior to gypsum in terms of its remedial effect (Chernelivska, 2012). Fecal doses of 4, 8, 20, 40, 60 t/ha were studied, which were applied respectively in the spring for cultivation and in the fall for plowing. Observation of growth and development showed that the application of sugar mud (4 and 8 t/ha) did not have a significant effect on the initial growth and development of plants,

but their application under cultivation significantly reduced the volumetric weight of the soil, which was 1.13 g/cm against 1.26 g/cm when applying meliorant under plowing (Roik *et al.*, 2014). The volume weight is reduced to 1.12 g/cm, as well as the use of 20 t/ha of manure for cultivation. The use of sugar mud of 4-8 t/ha for cultivation reduces the number of soil particles of 1.0-0.25 mm and increases the number of particles of 5-10 mm (Sinchenko *et al.*, 2014) In this version, the indicators of soil fertility also improved. Thus, the content of mobile phosphorus and exchangeable potassium increased by 17 and 21%, respectively.

In the conditions of the Cherkasy region, the influence of defecation on soil fertility and crop yields was studied (Shevchenko, 2015). The efficiency is shown for single and double doses of sugar mud of 10 t/ha and 20 t/ha. The number of absorbed bases and the degree of saturation with bases increased significantly, the hydrolytic acidity significantly decreased from 6.82 in the control to 2.10 when 1.0 Hr was applied, and 2.27 mg/eq per 100 g of soil when 2.0 Hr was applied. The pH value reached 6.52-6.60 in the arable layer.

Other studies have shown that liming with sugar mud improves the agrochemical properties of the soil (Balahura *et al.*, 2018). On the calcareous areas, the pH changed from 6 to 6.3 mg/eq. (salt extract), hydrolytic acidity from 4.4 to 1.7 mg/eq., phosphorus and potassium reserves increased. The application of sugar mud in a complex with manure contributed to an increase in the humus content compared to the initial indicator by 0.53%; a significant increase in the potassium content in the soil was noted in cases where ameliorants were used in combination with manure up to 138 mg/kg.; on control 78 mg/kg. The use of calcium-containing ameliorants (sugar mud and calcium carbonate) both on the background of manure and in combination with mineral fertilizers contributed to the deacidification of leached soils (Kokovikhin *et al.*, 2012). The pH increased from 5.0-5.3 to 5.9-6.0, the hydrolytic acidity decreased from 6.0-7.0 to 2.6-4.1 mg/eq. per 100 g of soil, and the degree of saturation with bases increased from 79-82 to 88-92%.

Thus, as evidenced by the conducted research, the application of lime fertilizer "defecation" on acidic and slightly acidic soils has a multifaceted positive effect, eliminating excessive acidity, and creating optimal environmental conditions for agricultural plants and soil microorganisms, increases the water resistance of structural soil aggregates, which determines a favourable water and air modes, increases the accumulation of phosphorus, potassium. As a result of this influence, the yield and quality of agricultural crops increase significantly.

CONCLUSIONS

Thus, sugar mud is a valuable ameliorant that has a positive effect on the condition of the soil. The application of sugar mud reduces the exchangeable acidity of the soil from 5.50 to 6.75 pH. The application of sugar mud on acidic and slightly acidic soils has a multifaceted positive effect, eliminating excessive acidity, and creating optimal environmental conditions for agricultural plants and soil microorganisms, increases the water resistance of the structural aggregates of the soil, which determines favourable water and air regimes, increases the accumulation of phosphorus and potassium. As a result of this influence, the yield and quality of agricultural crops increase significantly. Sugar beet productivity increased depending on the applied fertilizer doses. Thus, with the application of 2.0 Hr of manure, the yield increase amounted to 7.56 t/ha. The combination of organic fertilizer and manure 2.0 Hr had the strongest effect on productivity – 19.67 t/ha. The collection of sugar increased according to the experimental variants mainly due to the increase in yield. The increase in digestion was insignificant: from 0.08% to 0.56% according to the experiment variants.

According to the results of the conducted research and experiments, the farm is recommended to apply compost at a dose of 12 t/ha and sugar slurry at a dose of 3.2 t/ha. The specified agronomic measure will allow to increase the productivity of sugar beet - to ensure a high yield of this crop, an increase in digestion and, accordingly, sugar collection per hectare. It should be noted that this measure is economically feasible for both the crop production segment and the sugar production segment. Further directions for deepening the research may be the exclusion of factors of meteorological influence, which are usually carried out in order to determine a reliable assessment of the effectiveness of certain agrotechnical techniques in agricultural practice.

ACKNOWLEDGEMENTS

The authors of the study express their gratitude to the Bohdan Khmelnytskyi limited liability agricultural company, on whose fields an experiment was conducted to evaluate the impact of sugar mud and organic fertilizers on sugar beet productivity. Also, great gratitude for providing the results of laboratory studies to the raw materials and factory laboratory of the sugar factory in Horodkivka. Also, boundless gratitude to the Armed Forces of Ukraine for the opportunity to conduct research under the clear sky, to get an education and help in this modern generation.

CONFLICT OF INTEREST

None.

REFERENCES

[1] Balahura, O.V., Balan, V.M., Tsvei, J.P., & Volokha, M.P. (2018). Scientific basis of adaptive technology of growing sugar beets. *Sugar Beets*, 3, 10-13. Retrieved from http://nbuv.gov.ua/UJRN/Cb_2018_3_4.

[2] Butov, V.M., & Porudieiev, V.O. (2014). Productivity of sugar beet depending on nutrition background under irrigation conditions. *Ecology: Scientific Works*, 107(94), 48-50. Retrieved from https://lib.chmnu.edu.ua/pdf/naukpraci/ecology/2009/107-94-11.pdf.

[3] Chernelivska, O.O. (2012). Productivity of sugar beet hybrids in the Right Bank Forest Steppe of Ukraine. *Collection of Scientific Papers of the Institute of Bioenergy Crops and Sugar Beet*, 15, 178-181. Retrieved from http://nbuv.gov.ua/UJRN/znpicb_2012_15_44.

[4] Chernelivska, O.O., Sychuk, L.V., Dziubenko, I.M., & Nakonechnyi, V.O. (2019). Productivity of sugar beets depending on the system of fertilization and tillage. *Bioenergetics*, 1(13), 24-27. doi: 10.47414/be.1.2019.229283.

[5] Convention on Biological Diversity. (1992). Retrieved from https://www.cbd.int/doc/legal/cbd-en.pdf.

[6] Hoffmann, C.M., Koch, H.-J., & Märländer, B. (2021). Sugar beet. In V.O. Sadras, & D.F. Calderini (Eds.), *Crop physiology – case histories for major crops* (pp. 634-672). San Diego: Elsevier Inc. doi: 10.1016/B978-0-12-819194-1.00020-7.

[7] Humentyk, M.Ya., Radeiko, B.M., Fuchylo, Ya.D., Sinchenko, V.M., Hanzhenko, O.M., Bondar, V.S., ... Katelevskyj, V.M. (2018). *Cultivation of bioenergy crops: Monograph*. Kyiv: LLC "CP "Komprint". Retrieved from https://bio.gov.ua/ sites/default/files/documentation/vyroshchuvannya_bioenergetychnyh_kultur.pdf.

[8] Kabala, C., Musztyfaga, E., Galka, B., Labuńska, D., & Mańczyńska, P. (2016). Conversion of soil pH 1:2.5 KCl and 1:2.5 H2O to 1:5 H2O: Conclusions for soil management, environmental monitoring, and international soil databases. *Polish Journal of Environmental Studies*, 25(2), 647-653. doi: 10.15244/pjoes/61549.

[9] Khan, I., Iqbal, M., & Hashim, M.M. (2018). Physicochemical characteristics and yield of sugar beet (*Beta vulgaris* L.) cv. "California-Kws" influenced with irrigation intervals. *Sarhad Journal of Agriculture*, 35(1), 57-69. doi: 10.17582/journal.sja/2019/35.1.57.69.

[10] Kliachenko, O.L., & Kolomiiets, Iu.V. (2013). *Sugar beets. Biology. Physiology. Biotechnology*. Kyiv: NUELS.

[11] Kokovikhin, S.V., Shepel, A.V., Pysarenko, P.V., & Piliarskyj, V.H. (2012). Economic and energy justification of elements of the technology of growing sugar beets on irrigated lands of the South of Ukraine. *Taurida Scientific Herald*, 79, 62-67. Retrieved from http://www.tnv-agro.ksauniv.ks.ua/archives/79_2012/12.pdf.

[12] Korovko, I.I. (2017). Evaluation of the effectiveness of the elements of sugar beet cultivation technology. *Agrobiology*, 1, 117-121. Retrieved from https://agrobiologiya.btsau.edu.ua/en/content/ elements-technology-sugar-beet-growing-efficiency-assessment.

[13] Kurylo, V.L., Hanzhenko, O.M., Khivrych, O.B., Mazurenko, A.M., Humentyk, M.Ya., Zykov, P.Yu., ..., & Ivanova, O.H. (2014). *Methodical recommendations on the technology of growing energy sugar beets*. Vinnytsia: Nilan Ltd.

[14] Rašovský, M., & Pačuta, V. (2016). Influence of selected agrotechnical measures and climate conditions on root yield and digestion of sugar beet. *Journal of Central European Agriculture*, 17, 1070-1081. doi: 10.5513/JCEA01/17.4.1812.

[15] Roik, M.V., Hizbullin, N.H., Sinchenko, V.M., & Prysazhniuk, O.I. (2014). *Research methods in beet growing*. Kyiv: IE Korzun.

[16] Shevchenko, T.V. (2015). Use of microfertilizers and fungicides in foliar fertilization and their effect on the productivity of sugar beet plants of different biological forms. *Scientific Reports of NUELS of Ukraine*, 5(34). Retrieved from https://nd.nubip.edu.ua/2015_5/24.pdf.

[17] Shyrokostup, O.V. (2014). An important element of sugar beet cultivation technology. *Quarantine and Plant Protection*, 9, 6-9. Retrieved from http://nbuv.gov.ua/UJRN/Kizr_2014_9_5.

[18] Sinchenko, V.M., Pyrkin, V.I., Haponenko, H.D., Horelenko, V.I., Hizbullina, L.N., Moskalenko, V.P., ... Askarov, V.R. (2014). Bioadaptive technology of growing sugar beets: Technological aspects. *Sugar Beets*, 3, 6-10. Retrieved from: http://nbuv.gov.ua/UJRN/ Cb_2014_3_3.

[19] Studnicki, M., Lenartowicz, T., Noras, K., Wójcik-Gront, E., & Wyszyński, Z. (2019). Assessment of stability and adaptation patterns of white sugar yield from sugar beet cultivars in temperate climate environments. *Agronomy*, 9(7), 405. doi: 10.3390/agronomy9070405.

[20] Voitova, H.P. (2020). Elements of biologization to ensure high energy and economic efficiency of sugar beet cultivation in the conditions of Podillia. *Bioenergetics*, 1, 24-26. doi: 10.47414/be.1.2020.224947.

[21] Zaryshniak, A.S., Sypko, A.O., Strilets, O.P., Zatserkovna, N.S., Sinchuk, H.A., Honcharuk, H.S., ... Mazur, H.M. (2019). Productivity of sugar beets under biologization of their cultivation on slightly acidic soils in the conditions of the Forest Steppe of Ukraine. *Bioenergetics*, 1(13), 8-10. doi: 10.47414/be.1.2019.229277.

Оцінка впливу дефекату та органічних добрив на продуктивність буряків цукрових в умовах Поділля

Оксана Іванівна Трембіцька
Кандидат сільськогосподарських наук, доцент
Поліський національний університет
10002, Старий бульвар, 7, м. Житомир, Україна
http://orcid.org/0000-0003-1152-0215

Святослав Володимирович Богдан
Здобувач ступеня магістра з агрономії
Поліський національний університет
10002, Старий бульвар, 7, м. Житомир, Україна
http://orcid.org/0000-0002-3249-7096

Анотація. Внесення вапняного добрива «дефекату» на кислих і слабокислих ґрунтах має багатогранний позитивний ефект, усуваючи надмірну кислотність і створюючи оптимальні екологічні умови для сільськогосподарських рослин і ґрунтових мікроорганізмів, підвищує водостійкість структурних агрегатів ґрунту, що визначає сприятливий водний і повітряний режими, збільшує накопичення фосфору, калію. Мета – дослідити вплив цукрового розчину та органічних добрив на продуктивність цукрових буряків в умовах Поділля. У представлених дослідженнях використовувались такі методи: польовий, вимірювально-ваговий, лабораторний, статистичний. За результатами досліду встановлено, що продуктивність буряків цукрових зростала залежно від доз внесених добрив. Так, при внесенні 2,0 д.р. цукрового розчину прибавка врожаю склала 15,27 т/га. Поєднання органічного добрива та цукрового розчину 2,0 грд. мало найсильніший вплив на врожайність – 29,41 т/га. Збір цукру збільшився по варіантах досліду в основному за рахунок збільшення врожайності. Зростання дигестії було незначним: від 0,08 до 0,56 % відповідно до варіантів експерименту. Сегмент рослинництва буде прибутковим за рахунок драйверів обсягу зібраного врожаю. Побічним економічним ефектом від застосування цього заходу буде отримання більшого збору цукру з гектара, що дозволить отримати більший прибуток від переробки цукрових буряків на цукор. Практична цінність досліджень полягає у формуванні рекомендацій для фермерських господарств та сільськогосподарських підприємств, які вирощують цукрові буряки на кислих і слабокислих ґрунтах, з метою підвищення їх продуктивності

Ключові слова: рослинництво; агротехніка; вапнування; удобрення; кислотність ґрунту

ВІСНИК АГРАРНОЇ НАУКИ ПРИЧОРНОМОР'Я

Науковий журнал

Том 27, № 4. 2023

Заснований у 1997 р.
Виходить чотири рази на рік

Оригінал-макет видання виготовлено у видавничому відділі
Миколаївського національного аграрного університету

Відповідальний редактор:
Т. Прокопчук

Редагування англомовних текстів:
С. Воровський, К. Касьянов

Комп'ютерна верстка:
О. Глінченко

Підписано до друку 12 грудня 2023 р.
Формат 60*84/8
Умов. друк. арк. 11,7
Наклад 300 прим.

Адреса видавництва:
Миколаївський національний аграрний університет
54008, вул. Георгія Ґонґадзе, 9, м. Миколаїв, Україна,
тел.: +38(0512) 70-93-54
E-mail: info@bsagriculture.com.ua
www: https://bsagriculture.com.ua/uk

UKRAINIAN BLACK SEA REGION AGRARIAN SCIENCE

Scientific Journal

Volume 27, No. 4. 2023

Year of establishment: 1997
Publication frequency: Four times a year

The original layout of the publication was made in the Publishing Department
of Mykolaiv National Agrarian University

Managing Editor:
T. Prokopchuk

Editing English-language texts:
S. Vorovsky, K. Kasianov

Desktop publishing:
O. Glinchenko

Signed for print of December 12, 2023
Format 60*84/8
Conventional printed pages 11.7
Circulation 300 copies

Publishing Address:
Mykolaiv National Agrarian University
54008, 9 Georgiy Gongadze Str., Mykolaiv, Ukraine
tel.: +38(0512) 70-93-54
E-mail: info@bsagriculture.com.ua
www: https://bsagriculture.com.ua/en