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THE PROSPECTS OF PRODUCTION OF PERENNIAL GRASSES IN UKRAINE

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INTRODUCTION

Global climate change has led to a number of problems related to the stability of agricultural resources, which raises concerns about the future of global food security [1–3]. Climate change is accompanied by population growth, which is projected to reach 20 billion by 2050. At this rate of population growth, one billion hectares of land that are not currently used in agriculture must be used to meet projected food needs [4]. In turn, the transformation of natural ecosystems into agricultural land involves changes in the microclimate [5–7]. A number of researchers suggest that to ensure global food security, agricultural production should include elements of perennial, although currently almost two-thirds of the world sown area is allocated for annual crops [3, 8–11].

An urgent problem of modern agricultural production, along with climate change, is the reduction of soil fertility. Modern methods of land use do not meet the requirements of balanced nature management, which leads to increased degradation processes (water, wind erosion); loss of soil fertility (reduction of humus content, soil compaction, imbalance of nutrients, etc.) [12]. There is evidence that the soil is destroyed 95 times faster than it is restored [13], and high plowing of agricultural land is not identical to high yields. Thus, with the same crop production technologies, the profit from 1 hectare of crop rotation area on high-yielding lands is 3–5 times higher than on low-yielding lands [14]. It should be noted that in Ukraine the share of plowed land is the highest in the world – more than 50% of the entire territory of the country and almost 80% of the area of agricultural land [12].

There is a lot of research on the importance of perennial crops in the process of soil fertility improving. Thus, the results of research by Ukrainian scientists show that in crop rotations with a high accumulation of row crops without perennial grasses in the soil root mass remains 10–15 times less than in grassland crop rotation. With increasing duration of the use of perennial grasses, the number of plant residues in the soil also grows [15]. The main difference between perennial grasses and annual field crops is that perennial grasses die in late autumn and field grasses – in summer. As a result, plant residues fall into different decomposition conditions. The predominance of anaerobic conditions in the decomposition of the residues of perennial grasses leads to the formation of humus, while the residues of annual crops decompose under anaerobic conditions, are intensively mineralized and do not serve as a source of organic matter [15]. The introduction of perennial grasses in strip crops of cereal grasses allows more efficient use of natural and artificial components of the agrosystem [16].

A number of researchers believe that to resolve the contradiction between the balanced use of nature and providing the population of the planet with sufficient food grain in the long run is possible due to the gradual increase in the grain area share of perennial grasses [13]. Long-term agricultural production provides a solution to a number of key ecosystem advantages compared to annual sowing systems [16–18]. Perennial crops do not need to be sown annually, they do not require annual tillage or herbicide application, and have significant potential for adaptation to climate change [9]. Due to the biological features of different types of perennial grasses, the mineralization process of soil organic matter are regulated [16]. Thickened cuticle, epidermis, sclerenchyma of stems improve the plant ability to adapt to different living conditions [19]. But, unambiguously, annual cereals are now more productive than perennials. Because they spend a third of their energy on seeds and spare substances in it, while perennial grasses invest more of their energy in the root system and vegetative mass necessary for long-term existence. [13]. Therefore, in order to correct '... a small mistake at the dawn of agriculture 10 000 years ago' (Picasso), it is important to conduct fundamental selection and research work to obtain perennial grasses that could compete with annual crops. New types of cereals need significant advantages to take a prominent place among long-known crops in modern production [11].

The first domestic perennial wheat for food purposes was obtained in 1937 by M.V. Tsytsyn [17]. Perennial wheat of M34085 variety was stable, did not split and at the same time belonged according to the cycle of its development to both spring and winter forms, and according to the nature of flowering – to both self- and cross-pollinated plants. Along with perennity, the variety was resistant to lodging, drought, soil salinity and fungal diseases. Under the conditions of South Kazakhstan, the yield of perennial wheat was higher: from the area sown with perennial wheat, two yields were obtained: the first – 1.44 t/ha, the second – 0.32 t/ha, that is, in the amount of vegetation 1.73 t ha, at a time when the yield of winter wheat was 0.8 t ha, and spring – 0.75 t/ha [20]. Milling and nutritional properties of M34085 variety were as follows: flour yield – 78%, crude fibre content – 57.8%, bread volume of 100 mg – 407 ml, bread porosity – 67 points [17]. But later research work with perennial wheat was stopped.

Since the second half of the twentieth century, researchers in the United States and later in other countries, the selection and cultivation of perennial grasses as crops that meet the requirements of biological, energy-saving, environmental systems of agriculture, have gained widespread recognition. Due to increased investment in public funding and private charities, large-scale studies of the possibility of using perennial cereals for food purposes [17, 18]. In 1983, breeders from Rodeil Institute of Organic Production (USA) used Thinopyrum intermedium wheatgrass to develop perennial cereals [19]. Wheatgrass, along with high viability, may contain a large amount of fibre in the grain and has a low gluten content (at the level of barley flour) [18]. In terms of whiteness and fibre content, perennial wheat flour can be described as a high-grade bakery one [22]. Since 1988, researchers from Rodeil Institute have been conducting selection cycles to increase yields and improve the quality characteristics of intermediate wheatgrass [23].

At Earth Institute (USA) in 2003, under the leadership of Dr. Lee De Haan, a program was launched to create a variety of intermediate wheatgrass (Kernza®) for food purposes. Intermediate wheatgrass is a distant relative of wheat (the name, which is a trademark, comes from a combination of ‘kern’ – from the ‘kern’ and ‘za’ – from ‘Konza’ – an Indian word which the name Kansas comes from) [24]. Several stages of selection and combination of the best plants were carried out on the basis of their yield, seed size, disease resistance and other characteristics, which improved the population of perennial wheat. At this stage, the results showed great potential both for plant breeding and for obtaining products with good taste and nutritional properties [25]. Although the grain harvest of perennial wheat cannot compete with corn or soybeans, its harvest has tripled over the past 10 years to 900 pounds of acre grain in Wisconsin fields [26].

Recently, Utah, Minnesota, and Kansas have established breeding programs that are coordinated with each other, but develop plant types that are uniquely adapted to each of the different regions. Large-scale multifunctional studies of perennial grasses use are being conducted under the direction of J. Culman at Colorado State University, Land Institute, the University of Minnesota, Cornell University, Ohio State University, the University of Iowa, the University of Wisconsin, the University of South Dakota, the University of California, (Davis, California) [27–29].

Experiments of co-cultivation of Kernza® with legumes are also carried out to ensure the intensification of crops and the use of Kernza® for dual use – for food grain and fodder [24]. According to Picasso (2018), Kernza® leaves and stems have a high nutritional value for cattle, especially in spring and autumn, which makes it an important dual-purpose crop [30]. A five-year project using mini-rhizotrons has been launched in the United States, which is why researchers are studying the following questions with Kernza®: at what soil depth does Kernza® receive nutrients and water ?; how does the composition and function of the microbial community change with the soil depth?; how much Kernza® root mass dies away and grows in a year? [31, 32].

In addition to the United States, perennial wheat is being developed in France, where scientists are testing Kernza® performance on a wide range of different environmental parameters, including the potential range of plant adaptation to local conditions, and studying markets for the crop. Joint research by Belgian scientists with the University of Kansas has also begun. A group of researchers in Poland is working to assess the potential of a perennial grain system with additional feed collection. A number of researchers are studying the potential adaptation of Kernza® to the Mediterranean environment, namely the effect of perennial and annual cereals biomass on soil microorganisms. Research on perennial wheat is also conducted at the University of Copenhagen (Denmark) together with the International Center for Organic Food Systems Research in Canada [33, 34].

Scientific research has confirmed that perennial wheat is a promising crop with high productive potential. Kernza® is only in the fourth selection cycle, and natural selection of main crops lasts at least 5 000 years. In the next decade, yields are expected at the level of traditional crops, but with the advantage of long-term use [26]. Kernza® plants develop a deep, dense root system, which helps to restore the soil, accumulate carbon; prevents erosion processes; provides plants with water and nutrients more efficiently than the root system of annual plants. Due to the peculiarities of the root system of perennial wheat, nutrient losses in the soil are slowed down. Thus, in the soil under Kernza® sowing in the second year of cultivation, nitrate leaching was reduced by 86% compared to the annual wheat [26].

Thus, a review of the literature shows that the cultivation of perennial wheat has a number of significant advantages over annual cereals. The main one is to resolve the contradiction between balanced nature management and providing the world population with sufficient food grain in the long run. However, the problem of growing perennial wheat in Ukraine remains unsolved, and to implement this crucial problem, the following tasks should be solved:

– to develop optimal agronomic measures for growing perennial wheat on an organic background in order to obtain several crops: for food and feed purposes – to assess the adaptability of perennial wheat to soil and climatic conditions of different regions, including the possible effect of winter temperatures on vernalization;

– to study the biological features of perennial wheat (competitiveness to weeds, resistance to pathogens and pests), to find out the peculiarities of crop formation and to determine the quality of grain;

– to determine the effect of perennial wheat growing on the content of macro- and microelements in the soil, its structure, the direction of microbiological and erosion processes.

1. Pachauri R.K., Meyer L.A. Climate Change 2014: Synthesis Report.

Contribution of Working Groups I, II and III to the fifth assessment report of the Intergovernmental Panel on Climate Change. IPCC: Geneva, 2014. 151 p.

2. Pimentel D., Cerasale D., Stanley R.C., Perlman R. et a!. Annual vs. perennial grain production. Agric. Ecosyst. Environ. 2012. No 161. P. 1-9.

3. Lobell D.B., Bala G., Duffy P.B. Biogeophysical impacts of cropland management changes on climate. Geophys. Res. Lett. 2006. No 33. P 1-4.

4. Findell, K.L.; Berg, A.; Gentine, P.; Krasting, J.P. et ак The impact of anthropogenic land use and land cover change on regional climate extremes. Nat. Commun. 2017. No 8. P. 1-10.

5. Saunders D.A., Hobbs R.J., Margules C.R. Biological consequences of ecosystem fragmentation: A review. Conserv. Biol. 1991. No 5. P. 18-32.

6. Schipanski M.E., MacDonald G.K., Rosenzweig S., Chappell M.J. et al. Realizing resilient food systems. Bioscience. 2016. No 66. P. 600-610.

7. Crews T.E., Carton W., Olsson L. Is the future of agriculture perennial? Imperatives and opportunities to reinvent agriculture by shifting from annual monocultures to perennial polycultures. Glob. Sust. 2018. No 1. P 1-18.

8. Monfreda C., Ramankutty N., Foley J.A. Farmingtheplanet: 2. Geographic distribution of cropareas, yields, physiological types, and net primary production in the year 2000. Glob. Biogeochem. Cycles. 2008. 22, No 1-19.

9. Glover J.D., Reganold J.P., Bell L.W., Borevitz J. et al. Increased food and ecosystem security via perennial grains. Science. 2010. No 328. P. 1638-1639.

10. Zhang Y., Li Y., Jiang L., Tian C. et al. Potential of perennial crop on environmental sustainability of agriculture. Procedia Environ. Sci. 2011. No 10. P. 1141-1147.

11. Uteush U. A. 1996. Feed resources of flora Ukraine. Introduction, biology, using, the basis of cultivation, economic feasibility of introduction into culture / U. A. Uteush, M. G. Lobas. - K.: Scientific thought, 1996. - 220 p. (in Ukrainian).

12. Palyanychko N.I. Analysis and efficient utilization of land resources in Ukraine / N.I. Palyanychko // Sustainable nature management. - 2016.- №1.P.128-132. (in Ukrainian).

13. International Law and Agroecological Husbandry: URL: https://books.google.com.ua/books?id=XMiVDQAAQBAJ&dq = kernza+pdf&hl = uk.

14. Vinnyuk O.O., Timofeev M. M., Bondareva O. B., Kovez G.I. etc. Recommendations for the creation, restoration and rational use of hayfields and pastures, in particular, cultural, as part of the implementation of anti-erosion measures on agricultural lands in the agro-climatic conditions of the Donetsk region. Donetsk, 2017. 21 p. (in Ukrainian).

15. Skrypnichenko SV Possibilities of partial compensation of loss of organic matter of peat: materials Allukr. science-practice on-line conf. Zhytomyr, May 13. 2015, Zhitomir, 2015. pp. 11-12. (in Ukrainian).

16. Korzh Z.V. Ecological evaluation of the use of phytocoenoses from perennial herbaceous crops on drained peatlands of the forest-steppe Ukraine: Author. of dis. to obtain the degree of Ph.D. Zhytomyr, 2001. 22 p. (in Ukrainian).

17. Tsitsin N. V. 1978. The perennial wheat / N. V. Tsitsin. - M.: Science, 1978.

- 288 p. (in Russian).

18. Tsitsin N. V. 1944. Additional plant resources to the service to the homeland / N. V. Tsitsin. - Moscow. - Leningrad: Publishing of Academy of Sciences of the USSR, 1944. - 59 p. (in Russian).

19. Contrasting Physiological and Environmental Controls of Evapotranspiration over Kernza Perennial Crop, Annual Crops, and C4 and Mixed C3/C4 Grasslands. URL: https://www.mdpi.com/2071-1050/11/6/1640.

20. Likholat Y. Influence of industrial pollutants on anatomical structure of stems of turfgrass. Visnyk of Lviv University. The biological series. Lviv, 2003. Vp. 33. P. 192-197. (in Ukrainian).

21. Kernza® Grain: Toward a Perennial Agriculture. URL: https:// landinstitute.org/our-work/perennial-crops/kernza/.

22. Barylnik K. G. Comparative characteristic of bakery properties of wheat and wheat-couch grass hybrid / K.G. Barylnik, L. I. Kuznetsova, N. S. Lavrenteva, O. A. Savkina, N. N. Chikida //Materials of the VI International Scientific and Technical Conference "Kazakhstan-Refrigeration Equipment 2016". March 1, 2016. - P.19-23. (in Ukrainian).

23. Food Facts: What is Kernza? URL: https://www.bestfoodfacts.org/whatis-kernza/.

24. General Mills Buys Kernza's Long Roots. URL:http://www.vegetablegardener.com/item/127778/general-mills-buyskernzas-long-roots.

25. Zeri M., Hussain M.Z., Anderson-Teixeira K.J., DeLucia E. et al. Wateruse efficiency of perennial and annual bioenergy crops in central Illinois. Geophys. Res.-Biogeo, 2013. No 118. P. 581-589.

26. Chimento C., Amaducci S. Characterization of fine root system and potential contribution to soil organic carbon of six perennial bioenergy crops. Biomass Bioenerg. 2015. No 83. P. 116-122.

27. Interview with a Plant Scientist: Shuwen Wang, Perennial Wheat URL:https://landinstitute.org/interview-with-a-plant-scientist-shuwenwang-perennial-wheat/.

28. Ecological Intensification & Perennial Polyculture URL: https://landinstitute.org/our-work/ecological-intensification/ .

1. AGROECOLOGICAL PROSPECTS OF THE USE OF PERENNIAL GRASSES IN THE WORLD AND UKRAINE

Modern agricultural technologies and markets focus mainly on a limited number of annual cereals. The main attention in the technologies of their cultivation is focused on leveling the increase in yield to social, ecological and market consequences. However, today food security and agriculture are entering an epoch characterized by scarce and depleted resources, climate change, and price volatility. To adapt to these conditions, agricultural technology, science and markets should be modified to provide sufficient food for a growing population while meeting the economic, social and ecological challenges of the twenty-first century. Current technologies used for growing crops require excessive water consumption, a significant amount of synthetic pesticides and mineral fertilizers and are characterized by increased levels of CO_2 emissions due to disruption of biological processes. Instead, perennial grasses are able to improve soil structure, be more resilient and adaptable to pathogens, pests and climate change, mitigate anthropogenic effects and promote biodiversity and ecosystem functioning. Perennial grasses are an alternative to paradigm shift in agriculture, as they have significant potential for inclusion in production systems.

According to the final document of the UNO Summit 'Transforming our world: the 2030 Agenda for Sustainable Development' dated September 25, 2015, 17 Sustainable Development Goals and 169 tasks were approved. Highlighted global goals include: overcoming famine and agricultural development, climate change mitigation, affordable and clean energy [1]. Ukraine has also joined the global process of sustainable development [2]. At the modern stage of development, and taking into account the world trends of Ukraine, to solve these problems requires technological re-equipment, modernization of agricultural industries with increased energy efficiency, ensuring compliance with environmental standards, international standards for food stuff and food raw material quality, and ensuring food security. [3]. According to the Global Food Security Index (GFSI) of 2018, Ukraine ranked only 63rd out of 113 countries, behind not only all European countries, but also those countries to which Ukraine actively exports food, including Egypt, Tunisia, Morocco [4]. Although in 2018, among 42 European countries, the largest areas of agricultural land in Ukraine – 35.9 million hectares [5] more than 14 million hectares of which are occupied by traditional cereals [6]. Currently, the world is conducting research [7–12] on the creation and study of technologies for growing and using perennial crops: wheat, rye, sunflower, rice, sorghum which can become an economic and environmental alternative in agriculture.

The first studies on the creation of perennial and grain-feed wheat, wheat-grass, wheat-elimus and rye-wheat hybrids were started in the 30s of the twentieth century by M.V. Tsytsyn. In 1978, on the basis of these studies, the work 'Perennial Wheat' was published [13]. M.V. Tsytsyn was the first to implement the idea of creating perennial wheat by crossing ordinary soft wheat with wild cereal - wheatgrass. Cultivated varieties had the ability to grow after mowing for two or three years, then the yield decreased sharply and their use became economically unviable [14]. The most studied was perennial wheat of M34085 variety. It was stable and did not split. According to the cycle of development, it simultaneously belonged to the spring and winter forms. According to the flowering pattern – both self-pollinated and cross-pollinated plants. This variety, in addition to perennials, was resistant to lodging, drought, soil salinity, fungal diseases. When tested under the conditions of South Kazakhstan and compared with winter and spring wheat, the yield of which was 0.8 and 0.75 t/ha, respectively, the yield of perennial wheat was significantly higher. Two yields were obtained: the first was 1.44 t/ha, the second – 0.32 t/ha, that is, a total of 1.73 t/ha during the growing season. Flour and nutritional properties were also suitable for further use: flour yield – 78%, raw fibre content – 57.8%, bread volume from 100 mg – 407 ml, bread porosity – 67 points. But later research work with perennial wheat was finished and it did not become widespread [13].

In the United States, the first researches for perennial cereal plants to obtain grain were conducted by W. Jackson at Rodeil Institute of Organic Production in Pennsylvania (USA) [15]. In 1983, almost 100 perennial grasses were studied to determine their suitability for grain production. Since 2003, these studies have been transferred to Earth Institute in Kansas (USA) [16]. The result of this hard work has been a Kernza® hybrid which has good prospects for food purposes and green mass. In 2018, on the basis of American breeding material by scientists of Omsk State Agrarian University, a new perennial cereal was created – Sova, which is dominated by wheatgrass characteristics [17]. Modern representatives of triticum-agropyron hybrids are obtained as a result of complex inter-varietal and inter-hybrid crosses with the participation of a large number of modern varieties of soft winter and durum wheat with three types of wheatgrass. One of the important features of them is perennity (overwintering ability for 2–3 years). In the course of research it was found that all triticum-agropyron hybrids can be divided into three groups: 1. Plants that have a stable regrowth the next year after grain harvesting (for the second year of vegetation – 30–60 plants per m^2); 2. Plants that do not regrow the next year after harvesting, that is, they are almost annual, but with the regrowth of green mass after grain harvesting or regrowth of green mass, which can be mowed 3–4 times during the growing season; 3. Plants occupying an intermediate place between the first and second group: the number of plants that overwintered in the second year depends on winter conditions and the duration of vernalization stage of seedlings, this group is the most numerous by the number of samples [18].

Perennial cereals have a number of advantages over traditional ones: they resist soil erosion, promote the large amount of organic matter into the soil, and reduce the use of fertilizers and pesticides. The phenology of perennial cereals differs significantly from annuals and depends on the age of plants, the beginning of vegetation restoration in spring and its end in autumn, which increases the possibility of their use for feed [19]. To understand the agronomic potential of perennial cereals, they need to be studied over several years, as grain and green mass production varies significantly with plant age. Perennial cereals, in terms of return on investment in their cultivation, can be equated to woody perennials. This is due to low reproductive properties in the first year of cultivation and the formation by plants primarily strong root mass. In subsequent years, perennial cereals have early regrowth, which makes it possible within one growing season to obtain two crops of green mass and one crop of grain. In addition, they have a lower yield, lower plant yield and grain weight. Studies in Michigan have shown that perennial wheat yielded 50% compared to its annual yield and perennial rye – 73% of its annual yield. It was found that the yield of perennial cereals remained stable, despite significant differences in air temperature and rainfall over the years of research [19]. In eastern Washington, [20] while investigating of 31 perennial wheat genotypes, the fifth-year grain yield was 93% of the one-year wheat with the highest yield. Australian researchers [21] based on 2 years of research, conducted on almost 90 perennial wheat derivatives, found that grain yield fluctuated greatly depending on weather conditions. The cultivation of perennial cereals is considered economically feasible for 40–60% of one-year yield of annual cereals and green mass yield up to 600–800 cwt/ha.

Perennial cereals are becoming a global trend in the production of bread for a healthy diet [14]. Modern forms have many positive qualities that distinguish them among many types of winter wheat varieties. Their grain has high baking qualities, which are much better than the general baking evaluation of modern varieties of soft winter wheat. This indicator averages 4.6 points, with a fibre content of the first quality group of 36% and protein in grain – 15.73% (the highest indicators: fibre – more than 40%, protein – 19%), while in traditional varieties of soft winter wheat, these figures are about 3.6 points, with a fibre content of the second quality group of 30.8% and protein in grain – 12.48%. At the same time, the grain yield on average for 5 years is in the range of 25 – 50 cwt/ha. These data suggest that modern triticum-agropyron hybrids can be used as improvers for weak wheat and triticale [18].

Flour from wheat-elimus hybrids and perennial wheat grain has physicochemical quality indicators which are characteristic of baking flour of the highest grade and general purpose, according to a technological evaluation on trial laboratory baking corresponds to GOST 27669-88 and therefore can be an alternative to flour from winter wheat grain. Fibre, antioxidants in the grain of many perennial wheats are placed in the shell of the grain, which makes them little available, so for bread manufacturing, wholemeal flour is recommended, that is together with the shell. This flour for bread baking is better to use in mixtures and to make dough to use sourdough. Bread from such flour is more similar in organoleptic parameters, taste and smell to bread from peeled rye flour or its mixture with wheat one [14, 22]. In the United States, Kernza® grain has been used for more than a decade to make a variety of products. To make bread from Kernza® grain, wholemeal flour is made and baked in a mixture with traditional wheat flour or other cereals. Such bread has a slightly nutty taste with honey hints. Kernza® flour is used to bake pancakes, salty waffles, crackers, cupcakes, and make pasta (with a Kernza® content of 51%) [23].

Kernza® grain is used to make healthy Kernza® Krunh breakfasts – flakes with a slightly sweet natural honey flavor. Grain grown in different regions of the United States has a different taste, which depends on the soil, so the flakes are dyed with natural food colours to indicate the region of cultivation: The Pacific Northwest is green, Kansas is red, and Minnesota is yellow. Kernza® grain is also suitable for beer brewing (Long Root Ale brand), which has a nutty-rye spicy taste [25, 26]. The grain of triticum-agropyron hybrids contains one of the most essential antioxidants for the human body – lutein. Therefore, grain can be used for the production of various medical dietary supplements [18].

In a human body, lutein is one of the main components of the macular pigment of the macula, which is located in the central part of the eye and is responsible for central vision and the highest visual acuity, acts as a blue light filter, protecting the eyes from ultraviolet light. Lutein is not synthesized in the human body, so it should come with food or medicine. With daily consumption of 6 mg of lutein, the risk of age-related manual degeneration, which is characterized by loss of central vision and blindness, is reduced by 43% [27–29]. Lutein is best accumulated in those parts of the body that are most exposed to free radicals, so lutein, like other carotenoids, is now important in preventing eye, heart, and breast diseases, strengthening the immune system, and reducing the risk of cancer development [30].

Perennial wheat belongs to the group of dual-use crops – as cereals and fodder, which is important for farmers who have a livestock component on their farms. The ability to make three mowings or pastures per season can increase the profitability of crop growing [31]. The study of the dual use of perennial grasses began with a field experiment by researchers at Michigan State University with a spring mowing [32]. After overwintering, perennials grew earlier and faster than annual wheat in spring. Therefore, during this period it became possible to graze cattle without compromising the future grain harvest [33]. Plants of perennial cereals are characterized by high tilling capacity – an average of 15 stems or more. Ripening in them begins with the ear and spreads to the bottom. When the grain reaches waxy maturity, leaves and stems are still green. Due to this feature, these hybrids after grain harvest can be used as fodder crop on the mowing of the green mass or for cattle grazing [18]. The growth rate and productivity of green mass after grain harvest is influenced by soil type, air temperature and the presence of precipitation, which also affects the next spring regrowth [32 – 34]. During the growing season, you can get up to 500 kg/ha of green mass, making three mowings during the growing season. The yield of green mass of modern triticum-agropyron hybrids can reach 600–800 cwt/ha on average for 5 years of cultivation. The yield of hay in weight units of green mass exceeds this figure for winter rye or oat mixture by one and a half times [18]. In addition, spring harvesting of perennial wheat for fodder contributes to an increase in grain yield in the year of mowing with the subsequent expansion of root biomass of plants [35]. Similar patterns of influence on grain yield and root biomass were observed during spring cattle grazing [36]. In the absence of a livestock component in the farm and, accordingly, the need for green mass as feed, there is a possibility of its alternative use. Green mass or straw of perennial grains contains cellulose and other polysaccharides, due to which it is suitable for use as a reproducible plant raw material for the biogas production [37 – 39]. Perennial wheat grain is also a valuable feed raw material in the manufacture of poultry feed due to the content of lutein pigment [18]. In poultry farming, xanthophylls (lutein for yellow and zeaxanthin for orange and yellow) are used to make the yolk of desired colour. Currently, the main natural sources of these substances are alfalfa flour with a high lutein content, and corn – zeaxanthin.

Given that the level of these pigments in natural feeds is not always constant and may change as a result of oxidation during long-term storage, the use of synthetic carotenoids is increasingly preferred [40]. To diversify and improve the quality of natural sources of lutein, alfalfa flour with triticum agropyron hybrids can be replaced. The current trend of agricultural development is aimed at organic farming, that is, the production of biologically pure products, without the use of chemical protection measures. With global warming, new diseases and pests are emerging. Energy-saving technologies with stubble left in the field also help to maintain an infectious background, so crops need to be treated regularly with pesticides to get high yields. In the absence of such protection, crop losses can reach 30 – 50%, and toxic substances are accumulated in the grain [14].

In all hybrid lines, which became the basis for the breeding of perennial cereals, disease resistance was found. This was another advantage of perennial cereals over annuals [41]. Newly formed perennial cereals are highly resistant to diseases such as fusarium blight, rust, powdery mildew, root rot [18, 42]. That allows to grow environmentally friendly products without the use of pesticides.

Perennial cereals, as an alternative to traditional cereals, have been widely studied around the world for a long time, and the results of these studies are Kernza® and Sova hybrids. Based on the literature, it is possible to clearly identify the prospects of these new cereals and outline the prospects for their further research and use in Ukraine, including:

– study of the phenology of perennial cereals in specific soil and climate conditions of the country in order to clarify the possible regions of cultivation, taking into account the peculiarities of their biology and the feasibility of their replacing of annual cereals;

- clarifying the prospects for the use of perennial cereals: in the food industry - for the manufacture of bread, confectionery, cereals, pasta, beer, alcohol; in the medical industry - for the manufacture of biologically active supplements with high lutein content, as a carotenoid which is important in the prevention of eye, heart and mammary glands diseases, strengthening of the immune system and reducing the risk of cancer;

- study of perennial cereals as a feed crop: study of the nutritional value of forage, mowing in different periods of the growing season and their effect on grain yield and regrowth of green mass; inclusion of grain as a high-protein component in the feed ration of livestock and poultry;

- study of the possibility of including perennial cereals in the form of green mass or hay in the list of renewable plant raw materials for biogas production;

– study of prospects for obtaining organic products, using soil potential, features of the root system of perennial cereals, resistance to pathogens and pests, drought and subzero temperatures, etc.

1. United Nations Educational, Scientific and Cultural Organization. (2017). Education for Sustainable Development Goals: learning objectives. Retrieved from https://unesdoc.unesco.org/ark:/48223/pf0000247444.

2. Ministry of Economic Development and Trade of Ukraine. (2017). Sustainable Development Goals: Ukraine. National report 2017. Retrieved from http://www.me.gov.ua/ (in Ukr).

3. Borodina, O.M. (Eds.), & Shubravska, O.V. (Eds.). (2018). Agrarian and Rural Development for Growth and Renewal of the Ukrainian Economy: Scientific Report. Kyiv: NAS of Ukraine, 152. (in Ukr).

4. The Economist Intelligence Unit. (2019). EIU Global Food Security Index – 2018. Retrieved from https://foodsecurityindex.eiu.com/

5. Agricultural Onesoil Map. (2019). Wheat data for the year 2018 Ukraine, all regions. Retrieved from https://map.onesoil.ai/2018/ua#2/44.35/-43.66 (in Bel).

6. State Statistics Service of Ukraine. (2019). Cultivation Lands of Agricultural Crops for Harvest in 2018 . Retrieved from www.ukrstat.gov.ua › operativ › operativ 2018. (in Ukr).

7. Bell, L.W., Wade, L.J., & Ewing, M.A. (2010). Perennial wheat: a review of environmental and agronomic prospects for development in Australia. Crop Pasture Science, 61(9), 679–690. doi: 10.1071/CP10064.

8. Sipos, T., & Halasz, E. (2007). The role of perennial rye (Secale cereale x S. montanum) in sustainable agriculture. Cereal Research Communications, 35 (2), 1073–1075. doi: 10.1556/CRC.35.2007.2.227.

9. Pearlstein, S.l., Felger, R.S., Glenn, E.P., Harrington, J., Al-Ghanem, K.A., & Nelson, S.G. (2012). Nipa (Distichlis palmeri): A perennial grain crop for saltwater irrigation. Journal of Arid Environments, 82, 60– 70. doi: 10.1016/j.jaridenv.2012.02.009.

10. Kantar, M.B., Betts, K., Michno, J.M., Luby, J.J., Morrell, P.l., Hulke, B.S., … Wyse. D.L. (2014). Evaluating an interspecific Helianthus annuus x Helianthus tuberosus population for use in a perennial sunflower breeding program. Field Crops

Research, 155, 254–264. doi: 10.1016/j.fcr.2013.04.018.

11. Shim, J. (2012). Perennial rice: improving rice productivity for a sustainable upland ecosystem. SABRAO Journal of Breeding and Genetics, 44 (2), 191–201.

12. Hu, F.Y., Tao, D.Y., Sacks, E., Fu, B.Y., Xu, P., Li, J., …Li, Z. K. (2003). Convergent evolution of perenniality in rice and sorghum. Proceedings of the National Academy of Sciences USA, 100 (7), 4050– 4054. doi: 10.1073/pnas.0630531100.

13. Tsitsin, N. V. (1978). The perennial wheat. Moscov.: Science. 288 (in Rus).

14. Medvedeva, A. (2019, May 14). The world needs healthy bread – Russian scientists have developed purple wheat and the unique SOVA variety. Agroxxi. Agro-industrial Portal. Retrieved from https://www.agroxxi.ru/ (in Rus).

15. Jackson, W. (1980). New roots for agriculture. University of Nebraska Press. 150.

16. Cox, T.S, Van Tassel, D.L., Cox, C.M., & DeHaan, L.R. (2010). Progress in breeding perennial grains. Crop and Pasture Science, 61(7), 513–521. doi:10.1071/CP09201.

17. Hayes, R.C., Wang, S., Newell, M.T., Turner, K., Larsen, J., Gazza, L., … Li, G.D. (2018). The Performance of Early-Generation Perennial Winter Cereals at 21 Sites across Four Continents. Sustainability, 10(4), 1124. doi.:10.3390/su10041124.

18. Upelniek, V.P., Belov, V.I., Ivanova, L.P., Dolgova, S.P., & Demidov, A.S. (2012). The legacy of academician N.V. Tsitsin – the current state and prospects of using the collection of intermediate wheatgrass hybrids. Vavylovskyi zhurnal henetyky y selektsyy (Vavilovskyi Journal of Genetics and Selection), 16(3), 667–674. (in Rus).

19. Jaikumar, N.S., Snapp, S.S., Murphy, K, & Jones, S.S. (2012). Agronomic assessment of perennial wheat and perennial rye as cereal crops. Agronomy Journal, 104(6), 1716–1726. doi: 10.2134/agronj2012.0291.

20. Murphy, K.M., Lyon, S.R., Balow, K.A., & Jones, S.S. (2010). Post-sexual cycle regrowth and grain yield in Thinopyrum elongatum x Triticum aestivum amphiploids. Plant Breed, 129(5), 480–483. doi: 10.1111/j.1439-0523.2009.01712.x.

21. Hayes, R.C., Newell, M.T., DeHaan, L.R., Murphy, K.M., Crane, S., Norton, M.R., … Larkin, P.J. (2012). Perennial cereal crops: An initial evaluation of wheat derivatives. Field Crops Research, 133, 68–89. doi: 10.1016/j.fcr.2012.03.014.

22. Barylnik, K. G., Kuznetsova, L. I., Lavrenteva, N. S., Savkina, O. A., & Chikida N. N. (2016, March). Comparative characteristic of bakery properties of wheat and wheat-couch grass hybrid. Poster session presented at the VI International Scientific and Technical Conference "Kazakhstan-Refrigeration Equipment 2016". Almaty, 19–23. (in Rus).

23. The Land Institute. (2017). A new grain – Kernza – finds its way into products. Retrieved from https://landinstitute.org/media-coverage/new-grain-kernza-finds-way-products/

24. The Future Market. (2019) Kernza Krunch — the future market. Retrieved from http://thefuturemarket.com/kernza-krunch.

25. Bland, A. (2016, October 26). After a long day of fighting climate change, this grain is ready for a beer. NPR. Food for Thought. Retrieved from https://www.lexiconoffood.com/link/after-long-day-fightingclimate-change-grain-ready-beer.

26. Patagonia Provisions. (2019). A short story about Long Root Wit. Retrieved from https://www.patagoniaprovisions.com/pages /long-root-wit.

27. Saksonova, E.O. (2005). Lutein and zeaxanthin – the main components of the antioxidant eye protection system. Russian Medical Journal, 13(2), 124–129. (in Rus).

28. Zavgorodnaya, N.G., & Muxalchuk, S.V. (2013, May). The use of short carotenoids for the prevention and treatment of diabetic retinopathy. "Filatovski chytannia", dedicated to the 80th anniversary of tissue therapy by the method of Academician V.P. Filatov, Odessa, 275–276. (in Ukr).

29. Garnuk, T.P., & Anokhina, S.V. (2016). The role of carotenoids in the health of the visual organ (Literature Review). Phytotherapy, 2, 39–42. (in Ukr).

30. Grigorenko, O. M. (2010). The role of vitamins in human nutrition. Food Science and Technology, 3, 3336. (in Ukr).

31. Ryan, M.R., Crews, T.E., Culman, S.W., DeHaan, L.R., Hayes, R.C., Jungers, J.M., & Bakker, M.G. (2018). Managing for Multifunctionality in Perennial Grain Crops. Bioscience, 68(4), 294–304. doi:10.1093/biosci/biy014.

32. Tinsley, S. G. (2012). An evaluation of perennial wheat and intermediate wheatgrass as dual-purpose, forage-grain crops under organic management (Master's thesis). Michigan State University, Michigan, USA.

33. Larkin, P.J., Newell, M.T., Hayes, R.C., Aktar, J., Norton, M.R., Moroni, S.J., & Wade, L.J. (2014). Progress in developing perennial wheats for grain and grazing. Crop and Pasture Science 65(11), 11471164. doi:10.1071/CP13330.

34. Newell, M.T., & Hayes R.C. (2017). An initial investigation of forage production and feed quality of perennial wheat derivatives. Crop and Pasture Science, 68(12), 1141–1148. doi:10.1071/CP16405.

35. Pugliese, J.Y., Culman, S.W., & Sprunger, C. D. (2019). Harvesting forage of the perennial grain crop kernza (Thinopyrum intermedium) increases root biomass and soil nitrogen cycling. Plant and Soil, 437(1–2), 241–254. doi: 10.1007/s11104-019-03974-6.

36. Lopez-Marisco, L., Altesor, A., Oyarzabal, M., Baldassini, P., & Paruelo, J.M. (2015). Grazing increases below-ground biomass and netprimary production in a temperate grassland. Plant and Soil, 392, 155–162. doi: 10.1371/journal.pone.0215223.

37. Geletuha, G.G., & Zheleznova, T.A. (2014). Prospects for the use of agricultural waste for energy production in Ukraine. Analytical note Nr. 7 of the Bioenergy Association of Ukraine. Retrieved from www.uabio.org/activity/uabio-analytics.

38. Abbasi, T., Tauseet, S., & Abbasi , S. (2012). Biogas Energy. New York: Springer, 169.

39. Biteco-energy.(2013). Biogas output from different types of substrates.

Retrieved from http://www.bitecoenergy.com/vyhod-biogaza-iz-razlichnogo-syrya-2/.

40. Vershnyak, T. (2011, March 22) Improving the quality of chicken eggs. Agribusiness Today. Retrieved from http://agro-business.com.ua.

41. Turner, M.K., DeHaan, L.R., Jin, Y., & Anderson, J. A. (2013). Wheatgrass–wheat partial amphiploids as a novel source of stem rust and fusarium head blight resistance. Crop Science, 53(5), 1994–2005. doi: 10.2135/cropsci2012.10.0584.

42. Culman, S.W., DuPont, S.T., Glover, J.D., Buckley, D.H., Fick, G.W., Ferris, H., & Crews, T.E. (2010). Long-term impacts of high-input annual cropping and unfertilized perennial grass production on soil properties and belowground food webs in Kansas, USA. Agric. Ecosyst. Environ, 137(1–2), 13–24. doi:10.1016/j.agee.2009.11.008.

2. BIOLOGICAL FEATURES AND PRODUCTIVITY OF PERENNIAL CEREALS UNDER THE CONDITIONS OF THE RIGHT BANK FOREST-STEPPE OF UKRAINE

Grain production for food and feed purposes at the international level has a number of environmental and socio-economic problems – soil erosion, water pollution, significant material costs, low efficiency of small-scale production and more. Climate change, observed in recent years, also makes a significant correction in the cultivation of annual cereals. In this regard, the cultivation of perennial cereals can be an important contribution to solving the urgent problem of agriculture – the restoration of eroded soils, preventing reduced fertility and plowing, reducing the pesticide load on the environment and stable food and feed supply. The world perspective of solving this problem is the creation of triticum-agropyron hybrids for grain production using as a donor valuable traits of blue wheatgrass (Agropyron glaucum (Desf. Ex DC) Roem. And Schult.). Studying the potential of this perennial cereal crop in Ukraine will contribute to the economic and environmental sustainability of grain production with the specified quality indicators.

Blue wheatgrass (Agropyron glaucum) was first described in 1805 as Triticum intermedium Host, then, in 1812 — Agropyron intermedia (Host) Nevski and in 1817 — as A. glaucum (Desf. Ex DC) Roem. et Schult [1]. The idea of using members of the Agropyron genus to improve the genotype of cereals, in particular wheat, belongs to M.V. Tsytsyn [2], who in the late 1920s began work on searching wild forms of cereals capable of crossing with such important crops as rye, wheat and barley. In 1930, his work was successful – the first hybrid seed was obtained by crossing Lutescens 30 wheat variety with plants of blue wheatgrass. And in 1934 he obtained the first triticum-agropyron hybrids. In addition to A. glaucum, three other wheatgrass varieties were found – A. elongatum, A. trichophorum and A. junceum, which were easily crossed with wheat. However, the most widespread donors of useful traits were A. glaucum and A. elongatum. Using these species, M.V. Tsytsyn created and introduced into production a number of spring and winter wheat varieties that are resistant to lodging and diseases [3–6].

Scientists note the following valuable features of wheatgrass, which are desirable to transmit to cereals – tolerance for winter coditions [2], salt and drought resistance [7–9], high protein and fibre content in grain, resistance to diseases, compared with wheat less demanding on soil fertility, multiflowered and multispiculate [10, 11]. D. Devey [12] while studying the population of blue wheatgrass, grown from seeds collected in Iran, also noted the wide variability of its characteristics. Additionally, the author points out that in terms of vegetative mass, some plants of the Iranian population were 10 or more times more productive than others. Differentiated study of blue wheatgrass plants conducted by A. Ragulin [13] confirmed their biological heterogeneity in the ability to hybridize with wheat — pollen pollination of one wheatgrass plant yielded significantly more seeds than pollination of another. The dependence of the results of crossings on wheatgrass genotype is also demonstrated by studies of I. Kikot and E. Volkova [14], V. Chekurov and A. Orlova [15]. Differences in biological properties are confirmed by variability and other signs. Thus, the protein content in grain ranges from 7 to 25–2%, fibre – from 5 to 70% and above [6]. Fertility of flowers with cross-pollination varies from 0 to 100%, with artificial self-pollination of seeds in some plants are is not formed, and in others – up to 44 seeds are formed in the ear [16]. In the United States, intermediate wheatgrass has been used as animal feed for several decades. For the past decade, the University of Kansas [17] (Kansas) has been conducting research to increase its grain yield for food purposes. Researchers at the University of Minnesota [18] and the University of Wisconsin-Madison [19] are conducting experiments to study the agronomic efficiency of this perennial grain crop. The result of international cooperation [20] was the creation of a perennial triticum-agropyron hybrid of Sova variety, which has a grain and fodder purpose with long-term (up to seven years) use. The variety is characterized by complex immunity to fungal diseases, its grain has good baking qualities, including high protein content. Distinctive features of wheatgrass are high viability, resistance to adverse climatic conditions, frost and drought resistance, resistance to diseases and pests. In Ukraine, separate researches

[21] to study the species and varietal diversity of perennial grasses, which by their biological properties are resistant to adverse growing conditions are carried out. Evaluation and selection of source material to create high-yielding varieties of perennial grasses, including intermediate wheatgrass of different target use is done [20]. Selection work is carried out with Thinopyrum intermedium as a source of useful traits for wheat, including the resistance of triticum-agropyron hybrids to a complex of diseases [22].

Perennial cereals, forming a massive root system, shore the soil, preventing its erosion, which indirectly helps to reduce the need for mineral fertilizers by activating the soil microbiota. In the United States, Canada, China, in contrast to Ukraine, the area under intermediate wheatgrass is growing annually [23]. Therefore, for Ukraine the problem of using this culture in soil protection systems, organic farming, food industry remains unsolved.

Methodology. In order to scientifically substantiate the technology elements of growing perennial cereals for grain for food and animal fodder in 2017–2019, a study was conducted to assess their adaptability of perennial cereals in the context of the Right Bank forest-steppe of Ukraine, taking into account biological features, physiological and biochemical parameters and their formation of the crop structure.

The research was carried out on podzolic heavy loamed chernozem of research field and production department of Uman National University of Horticulture. The objects of research are Hors (triticum-agropyron hybrid), Kernza® (perennial wheat) and Zorya Ukrainy (spelt wheat). Seed samples of the studied crops were sown in triplicate with a feeding area of 5×15 cm with sequential placement of plots according to agrotechnologies generally accepted for winter crops under the conditions of the Right Bank forest-steppe of Ukraine. Evaluation of physiological and biochemical activity of plants (chlorophyll content (a+b)), accumulation of dry matter, enzyme activity of the class of oxidoreductases – catalase and peroxidase were performed according to the methods described by Z.M. Grytsaienko and others [24]. Statistical processing of experimental data was performed by the method of univariate analysis of variance [25]. Culinary evaluation of bread from high-grade flour according to the improved method described in the patent for the utility model 'Method of assessing the quality of spelt bread', culinary evaluation of bread from whole wheat flour – according to the improved method described in the patent for the utility model 'Method for evaluating bread from whole wheat triticale flour and wheat'.

Analysis of physiological and biochemical parameters of perennial cereals showed certain features depending on the stage of their development (Table 1). Thus, chlorophyll content (a+b) in the studied crops during the development stages varied in the range of 1.33–2.71 mg/g of raw material. In particular, for spelt wheat and Kernza® perennial wheat, the chlorophyll content was 2.19–2.71 mg/g of raw material, for Hors triticum-agropyron hybrid – 1.33–1.71 mg/g of raw material, that is, starting from the tillering stage to the flowering one its decrease was observed. During the grain formation stage, the chlorophyll content increased and averaged 1.71 mg/g of raw material. The highest dry matter content was observed in Kernza® perennial wheat — 29.9–32.3%. For Zorya Ukrainy spelt wheat and Hors triticum-agropyron hybrid, the level of this indicator was almost the same and amounted to 24.6–29.5% (spelt wheat) and 22.6–26.4% (triticum-agropyron hybrid). The highest catalase activity was found in triticum-agropyron hybrid — 55.4–80.0 μMol/g of raw material. In all other studied cultures, the activity of this enzyme decreased with increasing stage of development.

Peroxidase activity in the studied crops varied in the range of 14.9–24.0 μMol/g of raw material. The highest indicators of activity of this enzyme were observed in Hors triticum-agropyron hybrid — 16.3–24.0 μMol/g of raw material. As is the case with catalase, the peroxidase activity decreased with increasing phase of development from tillering to grain formation.

Table 1. **Physiological and biochemical parameters of leaves of different cereals**

Developing stage	Indicator			
	Chlorophyll (a+b), mg/g	Dry matter, %	Catalase, μMol decl.	Peroxidase, μMol of

	of raw weight		H_2O/g of raw weight	oxidized guaiacol/g of raw weight
Spelt wheat (Zorya Ukrainy variety (control))				
Tillering	2.03	24.6	56.0	21.2
Stem elongation	2.16	24.9	51.2	19.5
Earing	2.38	25.5	49.8	18.4
Milk	2.71	29.5	31.2	14.9
Wheatgrass average (Horse variety)				
Tillering	1.58	22.6	80.0	24.0
Stem elongation	1.47	23.1	75.4	22.2
Earing	1.42	23.4	72.3	20.3
Milk	1.71	26.4	55.4	16.3
Wheatgrass average (Kernza® variety)				
Tillering	2.19	29.9	68.0	22.9
Stem elongation	2.32	30.1	64.5	21.6
Earing	2.47	30.8	61.2	20.5
Milk	2.63	32.3	51.9	16.5

The highest indicators of enzymatic activity in Hors triticum-agropyron hybrid, compared to Kernza® and Zorya Ukrainy wheat, may indicate a high level of metabolic processes in plants and, probably, higher adaptability of this crop to growing conditions. Elements formation of the crop structure of the studied crops depending on their biological characteristics are given in Table 2.

Table 2. **Elements of the grain harvest structure of different cereals**

Variety	Indicator				
	Ear length, cm	Number of spikes in ear, psc.	Number of grains in ear, psc.	Grain weight from one ear, g	Weight of 1000 grains, g
Zorya Ukrainy	14	24	41.2	2.13	38.6

Hors	18	15	29.3	0.35	6.2
Kernza®	23	16	30.9	0.97	10.2
HIP_{05}	*2–4*	*1–2*	*5.6–6.1*	*0.22–0.24*	*1.6–2.1*

Thus, in the studied crops, there was a significant difference in the elements of the crop structure, which is confirmed by the results of analysis of variance. Thus, in the studied crops, there was a significant difference in the elements of the crop structure, which is confirmed by the results of analysis of variance. By all indicators, except for the length of the ear, spelt wheat exceeded Kernza® perennial wheat. However, despite much longer ear in Kernza® (exceeding the ear of spelt by 8.6 cm), it had fewer ears and grains in the ear – 16 and 30.9 pieces respectively (with 24 and 41.2 pieces for spelt). The same applies to the weight of grains from one ear and the weight of 1000 grains – 0.97 and 10.2 g with spelt rates of 2.13 and 38.6 g. Indicators of the structure elements of the yield of Hors triticum-agropyron occupied an intermediate place between Zorya Ukrainy spelt wheat and Kernza® perennial wheat. The number of grains from the ear of this hybrid was 29.3 pieces, which is not much less than spelt wheat and Kernza®. However, the weight of grain from one ear and the weight of 1000 grains were much smaller and amounted to 0.35 and 6.2 g, respectively.

Thus, given the possibility of using perennial cereals during several growing seasons and using them for food or technical purposes (biofuel production), these crops have significant economic value. However, currently agrotechnology and features of their cultivation need further study and refinement.

The research revealed some differences in physiological and biochemical parameters and the formation of elements of the yield structure of perennial cereals: having higher physiological and biochemical parameters by weight of grain from one ear and weight of 1000 grains perennial wheat is significantly inferior to the annual one. At the same time, due to the reduction of unit costs, improvement of the ecological condition of agrophytocenoses and the environment, these crops can take a prominent place in agricultural production.

The study found that the culinary quality varied depending on the content of whole wheat flour from intermediate wheatgrass (Table 3). Thus, the overall evaluation of bread decreased from 8.6 to 8.0 points. A significant decrease in this indicator was with the addition of such flour of 15–25%.

Table 3. **Culinary evaluation of bread from high-grade soft wheat flour depending on the content of intermediate wheatgrass whole wheat flour (Kernza® grade), score**

Indicator	Content of intermediate wheatgrass whole wheat flour, %						*LSD_{05}*
	0	5	10	15	20	25	
Colour	9	9	9	7	7	7	*1*
Surface	9	9	9	9	9	9	*1*
Size of glossy surface	7	7	7	7	7	7	*1*
Crumb color	7	7	5	5	5	3	*1*
Softness	9	9	9	9	9	9	*1*
Smell	9	9	9	9	9	9	*1*
Taste	9	9	9	9	9	9	*1*
Size of pores	9	9	9	9	9	9	*1*
Uniformity of placement	9	9	9	9	9	9	*1*
Consistency	9	9	9	9	9	9	*1*
Overall evaluation	8.6	8.6	8.4	8.2	8.2	8.0	*0.4*

1. Tsvelev N.N. (1973) Overview of the species of the Triticeae Dum. family of cereals (Poaceae) in the flora of the USSR. News of the systematics of higher plants: L .: Nauka, V. 10. P. 19–59. (in Russian).

2. Tsitsin N.V. (1954) Remote hybridization of plants. Moscow : Selkhozgiz, 432 p. (in Russian).

3. Tsitsin N.V. (1963) On the shape and speciation. Hybrids of distant crosses and polyploids: Moscow : Publishing House of the USSR Academy of 15 Sciences, P. 5–24. (in Russian).

4. Ivanova N.E., Bolsunkovskaya O.V. (1972) Spring wheat Grekum 114. Breeding and seed production.. No. 3. P. 43–44. (in Russian).

5. Goryunov D.V. (1958) Winter wheat-wheatgrass hybrids in production Remote hybridization in the cereal family: Moscow : Publishing House of the USSR Academy of Sciences, P. 232–282.

6. Tsitsin N.V. (1971) The success of breeding for distant plant hybridization. Breeding and seed production. No. 4. S. 16-21. (in Russian).

7. Dewey D.R. Salt tolerance of 25 strains of Agropyron. Agron. J. 1960. Vol. 52, P. 631–635. (in English).

8. Mc Guire P.E., Dvorak J. High salt-tolerance potential in wheatgrasses. Crop Sci. 1981. Vol. 21. № 5. P. 497–500. (in English).

9. Nikolaenko V.P. Effect of salinization on the growth and development of elongated wheatgrass and reed fescue. Agrochemistry. 1982. No. 11. P. 96–102. (in Russian).

10. Tsitsin N. V. (1978). The perennial wheat. Moscov.: Science, 1978. – 288 p. (in Russian).

11. Tsitsin N.V. (1981) Winter wheatgrass hybrids. Theory and practice of distant hybridization. Moscow : Nauka,160 p. (in Russian).

12. Dewey D.R. Intermediate Wheatgrasses of Iran. Crop Sci. 1978. Vol. 18. № 1. P. 48. (in English).

13. Ragulin A.A. Issues of wheat and wheatgrass crossbreeding. Remote hybridization in the cereal family. M.: Publishing House of the Academy of Sciences of the USSR, 1958. S. 181–196.

14. Kikot I.I., Volkova E.F. (1937) Sterility and fertility of wheatgrass hybrids. The problem of wheatgrass hybrids. Moscow : Selkhozgiz, . P. 38-60. (in Russian).

15. Chekurov V.M., Orlova A.M. Isolation of homozygous lines of bluegrass wheatgrass for interbreeding with soft wheat. S.-h. biology. 1982. T. 17. No. 1. P. 55–61. (in Russian).

16. Diaconi P. Caryological aspects of the F1 hybrid Triticum aestivum × Agropyron intermedium. Analele Inatitutului de Cercetari pentru Cereale si Plante Technice-Fundulea. 1969. № 35. P. 189–200. (in English).

17. Li J.L., Sun S.C. Study of the genetics of the intermediate forms derived from wheat × Agropyron glaucum crosses. Acta Genet. Sin. 1980. Vol. 7. № 2. P. 157–164. (in English).

18. Li H., Wang X. Thinopyrum ponticum and Th. intermedium: the 16 promising source of resistance to fungal and viral diseases of wheat. J. Genet. Genom. 2009; Vol. 36. P. 557-565. (in English).

19. Monfreda C., Ramankutty N., Foley J.A. Farmingtheplanet: 2. Geographic distribution of cropareas, yields, physiological types, and net primary production in the year 2000. Glob. Biogeochem. Cycles. 2008. 22, No 1–19. (in English).

20 Glover J.D., Reganold J.P., Bell L.W., Borevitz J. et al. Increased food and ecosystem security via perennial grains. Science. 2010. No 328. P. 1638–1639. (in English).

21. Barylnik K. G., Kuznetsova L. I., Lavrenteva N. S., Savkina O. A., Chikida N. N. (2016). Comparative characteristic of bakery properties of wheat and wheat-couch grass hybrid Materials of the VI International Scientific and Technical Conference "Kazakhstan-Refrigeration Equipment 2016". March 1, 2016. pp.19–23. (in Russian).

22. Peresypkin V.F. Diseases of crops. Moscow : Kolos, 1979: 122-124. (in Ukrainian) 23. Uteush Yu.A., Lobas M.G. (1996) Feed resources of florii of Ukraine. Introduction, biology, vikoristan, foundations of virological education, economic docility in culture. Kyiv: Naukova Dumka, 220 p. (in Ukrainian).

24. Gritsaenko ZM, Gritsaenko AA, Karpenko VP Methods of biological and agrochemical studies of plants and soils. Kyiv .: NICHLAVA CJSC. 2003. 320 p. (in Ukrainian).

25. Dospekhov B.A. (1985). Field-experiment method. Moscow: Agropromizdat, 1985. 351 p. (in Russian).

3. AGROBIOLOGICAL CHARACTERISTICS OF SPELT WHEAT AND INTERMEDIATE WHEATGRASS IN THE CONDITIONS OF THE RIGHT-BANK FOREST-STEPPE OF UKRAINE

The main areas of agriculture are the production of high quality products, and the restoration of soil fertility with the use of prairie restoration with perennial cereal crops is a priority task in the United Nations strategy (Agriculture, Forestry and Fishery Statistics, 2016). Currently, spelt wheat is used in organic farming (Poltoretskyi et al., 2018). Intermediate wheatgrass is a promising crop for prairie restoration (Crews et al., 2018).

Western European agriculture is characterized by a high level of productivity of grain crops production. Such productivity is largely the result of specialization and intensification of farms. However, this type of management has led to environmental problems and greater dependence on adverse environmental factors (Duchene et al., 2019).

Spelt wheat is now a world-famous crop used for the production of high quality products. It is able to form the yield in the conditions where soft wheat does not produce it. It is characterized by complex resistance to adverse environmental factors (Hospodarenko et al., 2018), so it attracts the attention of researchers as a crop capable of providing high quality grain.

Interest in the transition to a perennial type of cereal crops cultivation is due to moisture deficit and high temperatures during the vegetation period (Rezzouk et al, 2020). Extreme heat can cause changes in agricultural production and increase the risk of food security (Parker et al, 2020). The study of agronomic and physiological characteristics connected with the formation of the yield amount is an important component in the selection programs for the creation of high-yielding species of grain crops (Chairi et al, 2020).

Perennial crops significantly predominate over annuals, as they have a longer vegetation period, permanent soil cover, reduce leaching of nutrients into deeper soil layers, emit more carbon into the soil, increase the resistance of the topsoil to erosion.

Intermediate wheatgrass is one of the promising perennial crops (Oliveira et al, 2019).

Intermediate wheatgrass is an ecologically stable perennial crop. A population of intermediate wheatgrass (Kernza species) has now created in the United States by hybridizing of seven parent components of this crop, including soft wheat. It is known that this species forms a large root system that is able to absorb nutrients from hard-to-reach forms. Grain of intermediate wheatgrass is suitable for processing. It has proven to have reduced shedding, high threshing and high resistance to lodging under test conditions in the United States. The grain yield of this species was 696 kg/ha. The plants formed the highest productivity during the first two years of growing. The grain yield of the third growing year was lower (Bajgain et al., 2020). In other researches, intermediate wheatgrass had great advantages while growing as a perennial crop for four years with grazing of farm animals. In addition, this crop is a good precursor for soybean and corn (Hendrickson, 2014). Other scientists also studied intermediate wheatgrass as a fodder crop. In researches, the yield of the vegetative mass of plants varied from 7790 to 9200 kg/ha (Jungers et al., 2018). Observations by other scientists suggested that the species of intermediate wheatgrass – Kernza can be used as a fodder and food crop. In spring and autumn, the vegetative mass is used for fattening farm animals, and crops are used to obtain grain after regrowth in summer (Favre et al., 2019).

Intermediate wheatgrass is a promising crop for use in food technology. It was found that the grain of this crop could be used for the production of products with a low glycemic index in the result of the study of the kinetics of starch hydrolysis (Zhong et al, 2019). However, these studies did not indicate how the elements of agrobiological indicators of plants were formed. In addition, the tests were conducted in the United States, which weather conditions were significantly different from the Forest-Steppe of Ukraine. It was not specified what protein content in the grain could be formed by plants of intermediate wheatgrass. Only detailed research on the impact of perennial crops on soil fertility would allow assessing the prospects of new species of perennial cereal crops to keep food security and a number of ecosystem services, especially in the context of climate change (Oliveira et al, 2019).

Materials and methods

The study was conducted during 2017–2019 in the conditions of the Right-Bank Forest-Steppe of Ukraine at Uman National University of Horticulture. Kalancha (Ukraine) – a cultivar of soft winter wheat (*Triticum aestivum* L.), Zoria Ukrainy (Ukraine) – spelt wheat (*Triticum spelta* L.), Khors (Ukraine) and Kernza (USA) – intermediate wheatgrass (*Elytrigia intermedia* (Host) Nevski) were used in the experiment. Kernza cultivar was obtained by hybridization of *Triticum aestivum* L. / *Elytrigia intermedia* (Host) Nevski.

The experimental plot was located in Mankivka natural-and-agricultural district of the Middle-Dnieper-Buh district of the Forest-Steppe Right-Bank province of the Forest-Steppe zone with geographical coordinates of 48° 46'56,47" of north latitude and 30° 14'48,51" of east longitude by Greenwich. Height above sea level was 245 m.

The climate of the region is temperate continental, with an average annual air temperature of 7.4 °C. Periods with an average daily air temperature of more than 5 °C last 205–215 days, more than 10 °C – 161–170, and with a temperature above 15 °C – 106–110 days. The sums of active temperatures are 2580–2900 °C and hydrothermal index is 1.0–1.2. The relative humidity is 64–88 %, according to the Uman weather station. In spring-summer period it decreases to 60–70 %, and in autumn-winter period it increases to 80–85 %. Average rainfall is 633 mm during the year and from 334 to 412 mm during the period with temperatures above 10 °C. Soil – chernozen podzolized heavy-loamed with high natural fertility, favourable for the growth and development of plants by neutral reaction of soil solution, good physical properties and nutritional regime. Humus content is 3.2–3.4 %.

Weather conditions in the research years differed (Table 1). They were more favourable in 2018 for all cereal crops, as there were 35.8 mm of precipitation during the period of active stem growth. In addition, there were 65.6 mm of precipitation in March. The air temperature was also in the optimal range (9+16 ºC) (Table 2).

Table 1. The amount of precipitation during the vegetation period of cereal crops, mm

Month	Year of research								
	2017			2018			2019		
	Decade								
	I	II	III	I	II	III	I	II	III
March	1.7	17.0	7.1	20.9	36.9	7.8	4.9	7.1	4.3
April	42.5	10.4	0.4	0.0	0.1	17.4	0.1	12.9	9.4
May	2.9	20.4	23.1	0.8	17.5	0.0	5.4	7.2	23.0
June	1.4	30.4	9.2	9.8	32.1	40.5	53.1	0.4	16.3
July	11.4	27.7	20.1	7.7	34.2	51.0	1.7	27.1	5.0

In 2017, there were 23.7 mm of precipitation during the period of active stem growth, and there were 78.7 mm of precipitation during the phase of spring tillering. However, the air temperature at the beginning of this phase of the development was unfavourable. In 2019, there were only 14.8 mm of precipitation during the period of stem elongation – the beginning of earing phase of soft wheat. Spelt wheat plants were in more favourable conditions than soft wheat because they had a longer stem growth period. There were 67.9 mm of precipitation during this vegetation period of spelt wheat.

Conditions of moistening in the period of earing phase – phase of milk ripeness of grain were better in 2018–2019, and worse in 2017 – 64.1 mm of precipitation. The air temperature during this period was optimal for all cereal crops (18–22 ºC for the earing phase and 22–25 ºC for the phase of milk ripeness of the grain) during the years of research.

Table 2. Average air temperature during the vegetation period of cereal crops, ºC

Month	Year of research								
	2017			2018			2019		
	Decade								
	I	II	III	I	II	III	I	II	III

March	5.7	4.2	7.7	-4.3	-0.8	0.4	4.6	4.7	4.3
April	11.1	7.6	10.6	10.3	14.8	15.3	9.2	7.3	12.4
May	14.2	12.7	17.3	19.8	15.6	18.4	12.8	18.7	19.2
June	19.2	18.8	22.0	19.3	22.1	19.2	20.7	24.3	22.3
July	19.2	20.0	22.4	19.1	20.6	22.3	20.3	17.3	22.1

Phenological observations were carried out in accordance with the Methodology of state species testing of agricultural crops (2000). The height was determined by measuring the stem length of cereal crops, the value of vegetative mass – by choosing the plants from two running meters with the following weighing, moisture of vegetative mass – by thermogravimetric method, grain yield – by sections by sheaf threshing, protein content – by the method of infrared spectroscopy using Infratek 1241. The stability index was determined by the formula:

$$SE = \frac{HE}{LE},$$

where HE – the greatest manifestation of the feature;

LE – the smallest manifestation of the feature.

The plants height and the dynamics of dry weight growth were determined at the beginning of the stem elongation phase of cereal plants, thenearing phase and the phase of milk ripeness of grain. The experiment was repeated three times.

Grouping of the variation coefficient was done according to the following gradations: 0–10% – insignificant, 10–20 – small, 20–40 – medium, 40–60 – large, ≥ 60% – very large. Statistical data processing was performed using Microsoft Excel 2010 and STATISTICA 8. Interpretation of the influence level by partial coefficient (thumb rule – Cohen): 0.02–0.13 – weak, 0.13–0.26 – medium, ≥0.26 – high. The "null hypothesis" was confirmed or refuted during the performing of variance analysis. The value of the coefficient "p" was determined for this purpose, which showed the probability of the corresponding hypothesis. In cases where $p<0.05$ "the null hypothesis" was refuted and the influence of the factor was significant (Tsarenko et al., 2000).

Results and discussion

The calendar dates of the coming-in of the plant development phases varied significantly depending on the crop and the research year. Plant development phases in spelt wheat came much later than in soft wheat. In 2017, the stem elongation phase of spelt wheat came 4–5 days earlier compared to 2018 and 2019 due to more favourable weather conditions (Table 3). The earing phase and phase of milk ripeness of grain came almost at the same time over the years of research. The calendar dates in the studied species of intermediate wheatgrass differed significantly from soft wheat and spelt wheat, because the crop was grown as a perennial one. In the first year of growth, the plants of intermediate wheatgrass developed more slowly compared to other studied wheat species. Therefore, in 2017, the phase of stem elongation in intermediate wheatgrass plants came 30 days later compared to soft wheat. However, the phases of earing and milk ripeness of grain of intermediate wheatgrass came almost at the same time compared to spelt wheat. In 2018, the phase of stem elongation in intermediate wheatgrass came 8–10 days, and in 2019 – 21–23 days earlier compared to soft wheat.

The phases of earing and milk ripening of grain in these years of research came almost at the same dates as soft wheat. It should be noted that the dates of occurring of the development phases while growing intermediate wheatgrass at the second and third years were almost the same. In addition, there was no large difference in the occurring of the development stages between the species of intermediate wheatgrass.

Table 3. Calendar dates of occurring of the main phases of plants development of cereal crops

Species	Year of research								
	2017			2018			2019		
	1	2	3	1	2	3	1	2	3
Kalancha	10.04	17.05	05.06	15.04	20.05	18.06	25.04	22.05	03.06
Zoria Ukrainy	26.04	06.06	20.06	01.05	04.06	22.06	05.05	08.06	23.06

Kernza	10.05	03.06	15.06	05.04	24.05	03.06	02.04	22.05	01.06
Khors	10.05	04.06	17.06	07.04	26.05	05.06	04.04	25.05	03.06

Note. 1 – the beginning of the stem elongation phase, 2 – earing phase, 3 – phase of milk ripeness of grain.

On average, for three years of research, the plant height of spelt wheat and intermediate wheatgrass plants of the Khors species in the stem elongation phase was at the level of soft wheat (Table 4). However, in Kernza species of intermediate wheatgrass it was 53% higher than soft wheat.

The height of spelt wheat plants in the earing phase was 3.4 times higher than in the stem elongation phase. Plants of intermediate wheatgrass of Khors species – in 3.6, Kernza species – in 2.4 times higher. Plants of spelt wheat were 1.6 times, intermediate wheatgrass were 1.5–1.6 times higher than soft wheat plants.

The increase in plant height of all cereal crops in the phase of milk ripeness of grain was smaller compared to the earing phase. Thus, the plants of spelt wheat were 1.4 times, intermediate wheatgrass – 1.5 times higher compared to the earing phase. Plants of spelt wheat were 1.6 times larger than soft wheat and 1.6–1.8 times higher than intermediate wheatgrass.

Table 4. Dynamics of plant height of different cereal crops, cm

Species (factor A)	Year of research (factor B)			Average over three years
	2017	2018	2019	
Stem elongation (factor C)				
Kalancha	27 ± 2^1	39 ± 3^1	23 ± 2^1	30 ± 8^3
Zoria Ukrainy	28 ± 2^1	42 ± 2^1	25 ± 2^1	32 ± 9^3
Kernza	23 ± 2^1	57 ± 5^1	57 ± 5^1	46 ± 20^3
Khors	21 ± 2^1	33 ± 2^1	29 ± 1^1	28 ± 6^3
Earing				
Kalancha	58 ± 2^1	88 ± 3^1	54 ± 2^1	67 ± 19^2
Zoria Ukrainy	110 ± 2^1	113 ± 2^1	107 ± 2^1	110 ± 3^2

Kernza	98 ± 4[1]	113 ± 3[1]	117 ± 2[1]	109 ± 10[2]
Khors	96 ± 3[1]	105 ± 2[1]	105 ± 2[1]	102 ± 5[2]
Milk ripeness of grain				
Kalancha	89 ± 3[1]	109 ± 2[1]	77 ± 2[1]	92 ± 16[3]
Zoria Ukrainy	144 ± 3[1]	168 ± 2[1]	137 ± 2[1]	150 ± 9[3]
Kernza	113 ± 2[1]	183 ± 26[2]	196 ± 21[2]	164 ± 45[3]
Khors	107 ± 3[1]	162 ± 20[2]	181 ± 19[2]	150 ± 39[3]

$p=0{,}003$

Note. 1 – insignificant, 2 – small, 3 – average variation.

Better humidification conditions and higher air temperature in 2018 contributed to the formation of the tallest plants of spelt wheat in the phase of stem elongation. This tendency was also observed in the phases of earing and milk ripeness of grain. Plants of intermediate wheatgrass of both varieties were the smallest in 2017. However, in 2018–2019, this indicator changed less from weather conditions. Thus, the difference in height of soft wheat plants in the phase of milk ripeness was 32 cm, and only 13–19 cm in intermediate wheatgrass depending on the year of research.

The results of statistical processing confirmed the significantly strong influence of "species of cereal crop", "year of research" and "plant development phase" factors on the formation of plant height of cereal crops (Fig. 1). It should be noted that the partial coefficient between the studied factors and plant height was the highest – and it was from 0.98 to 0.99. The partial coefficient between the interaction of factors and plant height was less, but their influence was strong. It was obvious that the connection between "species of cereal crop", "year of research" and "plant development phase" factors was weaker or absent, so the influence of AB, AC, BC and ABC was lower compared to A, B, C.

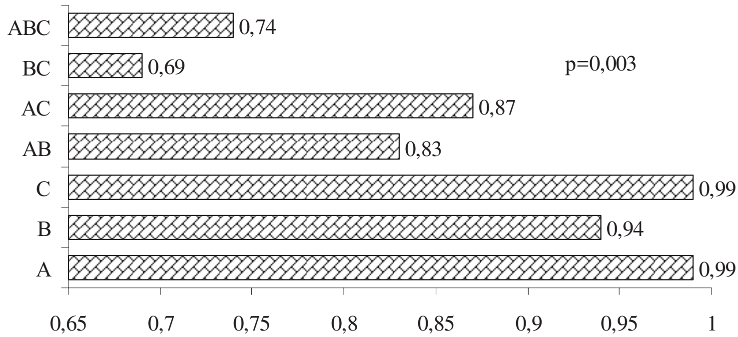

Fig. 1. The level of factors influence on the plant height of cereal crops: A – "species of cereal crop" factor, B – "year of research" factor, C – "development phase" factor

It was found that spelt wheat and intermediate wheatgrass were significantly inferior to soft wheat in the result of studying the dynamics of dry mass formation by plants of the studied cereal crops (Table 5). On average, over three years of research, this indicator in spelt wheat was 1.4 times and in intermediate wheatgrass was 1.2 times less compared to soft wheat in the phase of stem elongation. Plants of spelt wheat accumulated dry weight 1.4 times less than soft wheat in the phases of earing and milk ripeness of grain. Plants of intermediate wheatgrass accumulated dry weight 8–10% less in the earing phase and 1.3 times in the phase of milk ripeness of grain.

Table 5. Dynamics of dry mass formation by plants of different cereal crops, 10^3 kg/ha

Species	Year of research[1]			Average over three years
	2017	2018	2019	
Stem elongation				
Kalancha	3,71 ± 0,04[1]	3,83 ± 0,05[1]	2,51 ± 0,05[1]	3,35 ± 0,16[1]
Zoria Ukrainy	2,36 ± 0,05[1]	2,43 ± 0,04[1]	2,24 ± 0,04[1]	2,34 ± 0,10[1]
Kernza	2,13 ± 0,04[1]	3,17 ± 0,05[1]	3,10 ± 0,04[1]	2,80 ± 0,58[2]
Khors	2,06 ± 0,05[1]	3,10 ± 0,03[1]	3,03 ± 0,02[1]	2,73 ± 0,58[2]

Earing				
Kalancha	5,22 ± 0,051	5,34 ± 0,03[1]	4,08 ± 0,08[1]	4,88 ± 0,13[1]
Zoria Ukrainy	3,45 ± 0,07[1]	3,57 ± 0,04[1]	3,33 ± 0,05[1]	3,45 ± 0,12[1]
Kernza	3,17 ± 0,06[1]	5,23 ± 0,05[1]	5,11 ± 0,03[1]	4,50 ± 1,16[2]
Khors	3,06 ± 0,04[1]	5,13 ± 0,04[1]	5,08 ± 0,04[1]	4,42 ± 1,18[2]
Milk ripeness of grain				
Kalancha	6,41 ± 0,06[1]	6,56 ± 0,08[1]	5,24 ± 0,04[1]	6,07 ± 0,16[1]
Zoria Ukrainy	4,36 ± 0,06[1]	4,51 ± 0,05[1]	4,27 ± 0,04[1]	4,38 ± 0,12[1]
Kernza	3,50 ± 0,05[1]	5,60 ± 0,08[1]	5,33 ± 0,03[1]	4,81 ± 1,14[2]
Khors	3,33 ± 0,05[1]	5,51 ± 0,07[1]	5,24 ± 0,03[1]	4,69 ± 1,19[2]

$p=0,004$

Note. 1 – insignificant, 2 – average variation.

More favourable weather conditions in 2018 contributed to the accumulation of more dry weight of all cereal crops. It should be noted that plants of intermediate wheatgrass accumulated the least dry matter compared to wheat in the first year of growth. In 2018–2019, the difference in the accumulation of dry matter by intermediate wheatgrass was insignificant. Thus, the difference between a favourable and a less favourable year of research in the phase of milk ripeness in spelt wheat was 0.24×10^3 kg/ha, and 0.27×10^3 kg/ha in intermediate wheatgrass. This indicator was 1.32×10^3 kg/ha in soft wheat.

The results of statistical calculations confirmed significantly ($p\geq0.05$) the strong influence of the studied factors on the dry mass formation by plants of cereal crops, as the partial coefficient varied from 0.87 to 0.99 (Fig. 2).

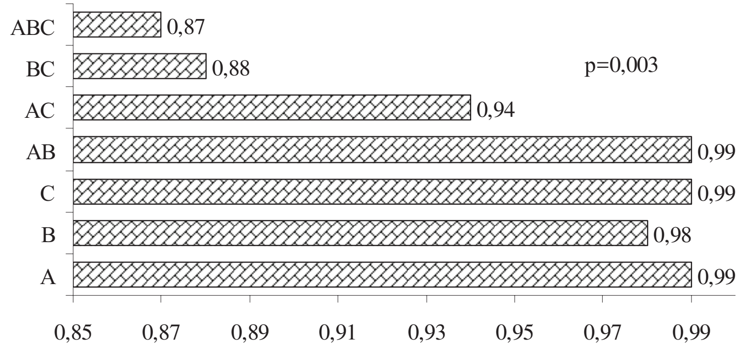

Fig. 2. The level of factors influence on the dry mass formation by plants of cereal crops:

A – "species of cereal crop" factor, B – "year of research" factor, C – "development phase" factor

Spelt wheat and intermediate wheatgrass by grain yield were significantly inferior to soft wheat (Table 6). On average, over three years of research, this indicator in spelt wheat was 1.4 times and in intermediate wheatgrass it was 6.6–8.0 times lower than in soft wheat. Better moisture supply of plants contributed to the formation of higher grain yield of spelt wheat and intermediate wheatgrass. The yield of grain in intermediate wheatgrass was the lowest in 2017.

It should be noted that spelt wheat and intermediate wheatgrass were characterized by the formation of a stable grain yield, as the stability index was 1.1–1.0. Despite the high grain yield in soft wheat, the stability of its formation was lower.

On average, over three years of research, the protein content of grain in spelt wheat was 1.8 times higher than in soft wheat (Table 7). This indicator in the grain of intermediate wheatgrass was 1.9–2.0 times higher. It should be noted that the protein content in the grain of spelt wheat and intermediate wheatgrass changed little depending on the weather conditions of the year of research.

Table 6. Yield of grain in different cereal crops, 10^3 kg/ha

Species	Year of research[1]			Average over three years	Stability index
	2017	2018	2019		
Kalancha	8,34 ± 0,10[1]	8,73 ± 0,11[1]	7,02 ± 0,06[1]	8,03 ± 0,27[1]	1,2
Zoria Ukrainy	5,54 ± 0,06[1]	5,72 ± 0,06[1]	5,47 ± 0,06[1]	5,58 ± 0,13[1]	1,0
Kernza	1,06 ± 0,04[1]	1,32 ± 0,04[1]	1,28 ± 0,04[1]	1,22 ± 0,14[2]	1,0[3]
Khors	0,78 ± 0,04[1]	1,12 ± 0,03[1]	1,05 ± 0,04[1]	0,98 ± 0,18[2]	1,1[3]

p=0,002

Note: 1 – insignificant, 2 – small variation. 3 – stability index was calculated for 2018–2019.

Spelt wheat and intermediate wheatgrass were significantly inferior to soft wheat in terms of dry mass and grain yield in the conditions of the Right-Bank Forest-Steppe of Ukraine. However, they were significantly dominated by the protein content in the grain. It should be noted that spelt wheat and intermediate wheatgrass had the highest stability in formation of dry mass and grain yield. However, these indicators in intermediate wheatgrass in the first year of growth were lower compared to the plants of the second and third year. This might be caused by the peculiarities of the development of intermediate wheatgrass. It was known that the root system was intensively formed in the first year of growth. The vegetative mass of sowing in the first year was less compared to the second and third year of growing of intermediate wheatgrass (Duchene, 2020). Therefore, the plants of intermediate wheatgrass were less responsive to adverse environmental factors than soft wheat in the second and third years of growth. Despite the fact that the species of intermediate wheatgrass – Kernza was created by the hybridization of *Triticum aestivum* L. / *Elytrigia intermedia* (Host) Nevski, the grain yield was only 1.06–1.32×10^3 kg/ha. The protein content in the grain was very high, which indicated the need for further selection improvement of this crop.

Table 7. Protein content in the grain of different cereal crops, %

Species	Year of research*	Average over

	2017	2018	2019	three years
Kalancha	12,6 ± 0,2	12,0 ± 0,2	11,7 ± 0,2	12,1 ± 0,5
Zoria Ukrainy	21,6 ± 0,2	22,4 ± 0,2	22,2 ± 0,2	22,1 ± 0,4
Kernza	24,1 ± 0,2	25,1 ± 0,2	24,5 ± 0,1	24,6 ± 0,5
Khors	22,3 ± 0,2	22,6 ± 0,2	22,4 ± 0,2	22,4 ± 0,2

p=0,003

Note. * – insignificant variation.

Spelt wheat in the conditions of the Right-Bank Forest-Steppe of Ukraine has more advantages in comparison with intermediate wheatgrass as it forms higher yield capacity of high-protein grain. Such advantages of spelt wheat compared to soft wheat were also confirmed by the studies by domestic (Moskalets et al, 2019) and foreign scientists (Koenig et al, 2015). However, intermediate wheatgrass is a promising crop for cultivation in the field crop rotation for two years to improve the soil structure and its microbiological activity in the layer up to 100 cm (Duchene, 2020). Today it is also relevant in the conditions of moisture deficit and high air temperature (Dong-Su et al, 2020).

Conclusions

The main agrobiological properties of spelt wheat and intermediate wheatgrass were studied. It was found that spelt wheat and intermediate wheatgrass had a high stability of crop formation and its quality in the conditions of the Right-Bank Forest-Steppe of Ukraine. The main stages of development in spelt wheat occurred on average 10–15 days later than in soft wheat. Plants of intermediate wheatgrass in the first year of growing had slower growth. The main phases of development in the plants of intermediate wheatgrass of the second and third year of growth occurred like in soft wheat. It was studied that these crops significantly prevailed over soft wheat in plant height. The height of the plants was over 100 cm in the earing phase. Plants of spelt wheat and intermediate wheatgrass had a high index of stability in formation of dry mass and grain yield. It should be noted that intermediate wheatgrass formed a high vegetative mass even in the earing phase. The vegetative mass in spelt wheat was formed during the phase of earing – full ripeness of grain. These crops were significantly superior to soft wheat in terms of protein content, so it was recommended to involve them in the selection programs to create species with high productivity. However, spelt wheat was less and intermediate wheatgrass was more inferior to soft wheat in terms of grain yield. The strong influence of "species of cereal crop", "year of research" and "development phase" factors on the formation of height and dry mass by the plants of cereal crops was established significantly ($p \geq 0.05$).

References

Hendrickson, J. R. (2014). Tillage and grazing impact on annual crop yields following conversion from perennial grass to annual crops. *Crop Management, 13*(1), 613–627. doi: 10.2134/CM-2013-0081-RS.

Bajgain, P., Zhang, X., Jungers, J., DeHaan, L., Heim, B., Sheaffer, C., Wyse, D., Anderson, J. (2020). 'MN‐Clearwater', the first food‐grade intermediate wheatgrass (Kernza perennial grain) cultivar. *Journal of Plant Registrations*. Retrieved from https://acsess.onlinelibrary.wiley.com/doi/full/10.1002/plr2.20042. doi.org/10.1002/plr2.20042.

Zhong, Y., Mogoginta, J., Gayin, J., Annor, G. (2019). Starch hydrolysis kinetics of intermediate wheatgrass (*Thinopyrum intermedium*) flour and its effects on the unit chain profile of its resistant starch fraction. *Cereal Chemistry, 96*(3). 564–574. doi: 10.1002/cche.10156.

Oliveira, G., Brunsell, N. A., & Crews, T. (2019). Carbon and water relations in perennial Kernza (*Thinopyrum intermedium*): An overview. *Plant Science, 295*, 270–279. doi.org/10.1016/j.plantsci.2019.110279.

Parker, L. E., McElrone, A. J., & Ostoja, S. M. (2020). Extreme heat effects on perennial crops and strategies for sustaining future production. *Plant Science, 295*, 388–397. doi: 10.1016/j.plantsci.2019.110397.

Chairi, F., Sanchez-Bragado, R., Dolores, & M. S. (2020). Agronomic and physiological traits related to the genetic advance of semi-dwarf durum wheat: the case of Spain. *Plant Science, 295*, 201–210. doi: 10.1016/j.plantsci.2019.110210.

Rezzouk, F. Z., Gracia-Romero, A., & Kefauver, S. C. (2020). Remote sensing techniques and stable isotopes as phenotyping tools to assess wheat yield performance: effects of growing temperature and vernalization. *Plant Science, 295*, 277–281. doi: 10.1016/j.plantsci.2019.110281.

Jungers, J., Frahm, C.S., & Tautges, N. (2018). Growth, development, and biomass partitioning of the perennial grain crop *Thinopyrum intermedium*: growth, development, and biomass partitioning of a perennial grain crop. Annals of *Applied Biology, 172*(3), 346–354. doi.org/10.1111/aab.12425.

Favre, J. R., Castiblanco, T. M., & Combs, D. K. (2019). Forage nutritive value and predicted fiber digestibility of Kernza intermediate wheatgrass in monoculture and in mixture with red clover during the first production year. *Animal Feed Science and Technology, 258*. 285–298. doi: 10.1016/j.anifeedsci.2019.114298.

Duchene, O., Celette, F., & Ryan, M. R. (2019). Integrating multipurpose perennial grains crops in Western European farming systems. *Agriculture, Ecosystems & Environment, 10*(9), 101–124. doi.org/10.3390/agronomy10091254.

Agriculture, Forestry and Fishery Statistics – 2016 Edition. [(accessed on 10 September 2018)]; Available online: https://ec.europa.eu/eurostat/web/products-statistical-books/-/KS-FK-16-001.

Crews, T., Carton, W., & Olsson, L. (2018). Is the future of agriculture perennial? Imperatives and opportunities to reinvent agriculture by shifting from annual monocultures to perennial polycultures. *Glob. Sust., 1*, 1–18. doi.org/10.1017/sus.2018.11.

Poltoretskyi, S., Hospodarenko, H., & Liubych, V. (2018). Toward the theory of origin and distribution history of *Triticum spelta* L. *Ukrainian Journal of Ecology, 8*(2), 263–268.

Hospodarenko, H. M., Karpenko, V. P., & Liubych, V. V. (2018). Characterization of amino acid content of grain of new wheat varieties and lines. *Agric. Sci. Pract., 5*(3), 12–18. doi.org/10.15407/agrisp5.03.012.

Tsarenko, O., Zlobin, Y., & Panchenko, S. (2000). *Computer methods in agriculture and biology*. Sumy: LLC (Elita-Star). 200 p.

Duchene, O., Celette, F., & Ryan, M. R. (2020). Introducing perennial grain in grain crops rotation: the role of rooting pattern in soil quality management. *Agronomy, 10*(9), 12–54. doi.org/10.3390/agronomy10091254.

Moskalets, V. V., Vovkohon, A. H., Kliuchevych, M. M., Moskalets, T. Z., Sliusarenko, A. O., Liubych, V. V., Martyniuk, A. T., Pushka, O. S., Pushka, I. M., Nevlad, V. I. (2019). Biochemical and molecular-genetic markers of adaptability and quality of genotypes in cultural and wild cereal plants. *Ukrainian Journal of Ecology, 9*(4), 704–708.

Dong-Su, Yu., Kwon, Oh-C., & Hong-Gie, K. (2020). A simple program improving uncertainly average temperature and growing degree days based on RCP scenario. *Journal of Climate Change Research, 11*(2), 113–122. doi.org/10.15531/KSCCR.2020.11.2.113.

Koenig, A., Konitzer, K., & Wieser, H. (2015). Classification of spelt cultivars based on differences in storage protein compositions from wheat. *Food Chemistry, 168*, 176–182. doi: 10.1016/j.foodchem.2014.07.040.

Livandovsky, A.A., Khomenko, T.M. (2016). *Methods of examination of varieties of cereals, cereals and legumes for suitability for distribution in Ukraine*. Kyiv: Alefa, 81 p.

4. MICROBIOTA IN THE RHIZOSPHERE OF CEREAL CROPS

The microbiota of the rhizosphere plays an important role because they produce vitamins, amino acids, heteroauxins, enzymes that affect plant development. Besides, this group of microorganisms takes part in the control for the coming of nutrients from the soil into the root system, inhibits the development of harmful microflora, stimulates endosymbiosis of plants with microorganisms [1].

Modern agricultural technologies cause ecosystem soil erosion, greenhouse gas emissions and water pollution despite the increase in production of plant raw material [2]. Spelt wheat is now a famous crop in the world which is used to produce high quality products [3]. Intermediate wheatgrass is good for food and fodder purposes (green fodder, silage, haylage, hay). In addition, these crops are of low maintenance to growing conditions, able to form yield, especially in the conditions where soft wheat does not form it [4]. They require less fertilizer, help to prevent water flow, are more resistant to drought compared to annual cereal crops due to the long vegetation period of perennial cereal crops and deep root system [5]. Restoration of soil fertility with the use of prairie restoration with perennial cereal crops is a priority task in the United Nations strategy [6].

Plant species, as well as soil type, had a significant impact on the structure and function of microbial populations connected with the rhizosphere. In addition, these factors could affect in different ways the number of microorganisms depending on biotic and abiotic conditions [7, 8]. It is known [9] that spelt wheat had advantages over soft wheat in organic agrotechnologies. However, there was no data on the formation of the microbiota of the rhizosphere of spelt wheat in these studies.

The results of a study of other scientists [10, 11] showed that wild perennial grasses contained different groups of fungi in the rhizosphere depending on the season, in particular ascomycetes were the most. However, these researchers did not study the number of individual ecological and trophic groups of microorganisms.

Analysis of the literature showed a significant impact of the activity of microorganisms on the productivity of agricultural crops and soil fertility. However, researches of the number of the microbiota of spelt wheat and intermediate wheatgrass remains insufficiently studied. The study of this issue will give the possibility to partially identify the plants adaptability to the environmental conditions taking into account the importance of the microbiota in the synthesis of biochemical components used by the plant. The greater the number of the microbiota, the higher the plants adaptability was. It was manifested in the formation of more stable yields and grain quality in spelt wheat, and in the yield of the vegetative mass in intermediate wheatgrass. Therefore, it is topical to study the influence of growing spelt wheat and intermediate wheatgrass on the formation of the microbiota in their rhizosphere, which is important for the characteristics of the plants adaptability and ecological and functional characteristics of the soil.

The purpose is to study the number of individual groups of microbiota in dynamics in the rhizosphere of different cereal crops (soft wheat, spelt wheat, intermediate wheatgrass) depending on the weather conditions and the phase of plants development.

Materials and methods. Studies of the number of different ecological and trophic groups of microorganisms were performed in the field and laboratory conditions in the Uman National University of Horticulture during 2017–2019. Kalancha (Ukraine) – a cultivar of soft winter wheat (*Triticum aestivum* L.), Zoria Ukrainy (Ukraine) – spelt wheat (*Triticum spelta* L.), Khors (Ukraine) and Kernza (USA) – intermediate wheatgrass (*Elytrigia intermedia* (Host) Nevski) were used in the experiment. Kernza cultivar was obtained by hybridization of *Triticum aestivum* L. / *Elytrigia intermedia* (Host) Nevski.

The number of microorganisms was determined in the stem elongation phase, earing phase, phase of milk ripeness of grain, in particular ammonifying – on agarized medium of meat-and-peptone agar, nitrifying – on the liquid medium of S. N. Winogradsky, cellulosolytic – on the liquid medium of A. A. Imsheneckii and L. I. Solntseva. The number of ammonifying microorganisms was expressed in colony-forming units (CFU). The number of nitrifying and cellulosolytic microorganisms was expressed in $N \cdot 10^3$ cells/g of soil. Studies of nitrogen-fixing microorganisms of the *Azotobacter* genus were performed on Ashby medium, and their number was expressed in % of soil lumps surrounded by colonies. Determination of the number of microorganisms was performed three times. Grouping of the variation coefficient was done according to the following gradations: 0–10 % – insignificant, 10–20 – small, 20–40 – medium, 40–60 – large, ≥ 60 % – very large. Statistical data processing was performed using Microsoft Excel 2010 and STATISTICA 8. Interpretation of the influence level by partial coefficient (thumb rule – Cohen): 0.02–0.13 – weak, 0.13–0.26 – medium, ≥0.26 – high. The "null hypothesis" was confirmed or refuted during the performing of variance analysis. The value of the coefficient "p" was determined for this purpose, which showed the probability of the corresponding hypothesis. In cases where $p<0.05$ "the null hypothesis" was refuted and the influence of the factor was significant.

The experimental plot was located in Mankivka natural-and-agricultural district of the Middle-Dnieper-Buh district of the Forest-Steppe Right-Bank province of the Forest-Steppe zone with geographical coordinates of 48° 46'56,47" of north latitude and 30° 14'48,51" of east longitude by Greenwich. Height above sea level was 245 m. The soil of the experimental field was podzolized chernozem.

In terms of rainfall, the supply of cereal crops was satisfactory. Soil samples were taken 10 days after the phase of plant development. Therefore, rainfall and average air temperature were given for the first half of each phase of plant development. There were 199.9 mm of rainfall or 28 % less than the average long-term index (277 mm) during the period of April – July 2017. There were 211.1 mm in 2018, 194.7 mm in 2019 or less by 24 % and 30 %, respectively. The distribution of rainfall during the plant development of wheat plants was different. The supply of soft wheat plants with water in 2017 and 2018 was higher than in 2019 (Table 1).

Table 1

Weather conditions of the first half of the development phase of plants of different cereal crops

Indicator	Date of phase beginning		
	stem elongation	Earing	milk ripeness of grain
2017			

Kalancha	15.04	20.05	18.06
Rainfall, mm[1]	*13,7*	*23,1*	*9,2*
Temperature, ºC[2]	*10,6*	*19,2*	*22,0*
Zoria Ukrainy	01.05	02.06	13.06
Rainfall, mm[1]	*23,3*	*24,5*	*30,4*
Temperature, ºC[2]	*14,2*	*19,2*	*18,8*
Kernza	10.05	03.06	15.06
Khors	10.05	04.06	17.06
Rainfall, mm[1]	*20,4*	*30,4*	*9,2*
Temperature, ºC[2]	*12,7*	*19,2*	*22,0*
2018			
Kalancha	10.04	17.05	05.06
Rainfall, mm[1]	*17,4*	*17,5*	*32,1*
Temperature, ºC[2]	*14,8*	*15,6*	*19,3*
Zoria Ukrainy	26.04	06.06	21.06
Rainfall, mm[1]	*35,7*	*32,6*	*40,5*
Temperature, ºC[2]	*19,8*	*19,6*	*22,1*
Kernza	05.04	24.05	03.06
Khors	07.04	26.05	05.06
Rainfall, mm[1]	*43,8*	*9,8*	*32,1*
Temperature, ºC[2]	*14,8*	*18,4*	*22,1*
2019			
Kalancha	25.04	22.05	03.06
Rainfall, mm[1]	*5,4*	*23,0*	*0,4*
Temperature, ºC[2]	*9,2*	*12,4*	*12,8*
Zoria Ukrainy	05.05	08.06	23.06
Rainfall, mm[1]	*12,6*	*53,4*	*16,3*
Temperature, ºC[2]	*18,7*	*24,3*	*22,3*
Kernza	02.04	22.05	01.06
Khors	04.04	25.05	03.06
Rainfall, mm[1]	*22,3*	*23,1*	*53,1*
Temperature, ºC[2]	*12,4*	*19,2*	*20,7*

Note. 1 – amount of rainfall, 2 – average air temperature for the first half of the phase.

2017–2018 were better for spelt wheat, as there were 23.3 to 40.5 mm of rainfalls during the period of stem elongation – milk ripeness of the grain. In 2019, 53.4 mm of rainfall fell only in the earing phase, and 12.6–16.3 mm in other phases of plant development. The beginning of the vegetation period in 2017–2018 was sufficiently supplied with water for intermediate wheatgrass and 22.3–53.1 mm of rainfall fell during the entire vegetation period in 2019.

Air temperature also affected the development of wheat plants. The air temperature was optimal in 2017 and 2018 except spelt wheat, in which stem elongation phase took place at a temperature of 19.8 ºC which was higher than optimal (9–16 ºC) in 2018 and 2019. Temperature for soft wheat in the phases of earing (18–20 ºC) and milk ripeness of grain (22–25 ºC) was lower than optimal in 2019. It was higher than optimal in the earing phase for spelt wheat. It should be noted that the temperature was optimal in the phases of earing and milk ripeness of grain for the microbiota in the rhizosphere of cereal crops.

Results. The number of ammonifying microorganisms in the rhizosphere of cereal crops varied depending on a complex of factors. As a result of the analysis of variance, it was found that the number of ammonifying microorganisms in the rhizosphere of spelt wheat was significantly higher compared to soft wheat during 2017–2019 (Fig. 1). The dynamics of the number of ammonifying microorganisms in the rhizosphere of intermediate wheatgrass was different. In the first year of growing season, this figure was significantly lower than for soft wheat and spelt wheat. In the second and third years of intermediate wheatgrass plant growth, the number of ammonifying microorganisms of the soil rhizosphere was significantly higher during all stages of growth.

Better distribution of rainfall and optimal temperature in 2018 contributed to the formation of the highest number of ammonifying microorganisms in the rhizosphere of soft wheat. In the less favorable 2019, this indicator was 1.4–1.5 times and 1.2–1.3 times lower in 2017 compared to 2018. Another trend was found for spelt wheat. The highest number of ammonifying microorganisms was in 2018 in the stem elongation phase because 35.7 mm of rainfall fell. More rainfall during the phases of earing – milk ripeness of grain in 2018–2019 contributed to the formation of the highest number of this group of microorganisms – from 211 to 228×10^3 CFU/g of soil. This indicator was 1.1–1.2 times lower in the less favourable 2017 compared to 2019. Insufficient rainfall in the stem elongation phase in 2019 contributed to the lowest number of ammonifying microorganisms. The lowest number of this group of microorganisms was in 2017 in the rhizosphere of intermediate wheatgrass, as the development of the root system and aboveground mass was weak. This indicator was the highest in 2018, 2019. It should be noted that the number of ammonifying microorganisms exceeded the indicator of soft wheat and spelt wheat by 1.5–1.8 times in these years of research.

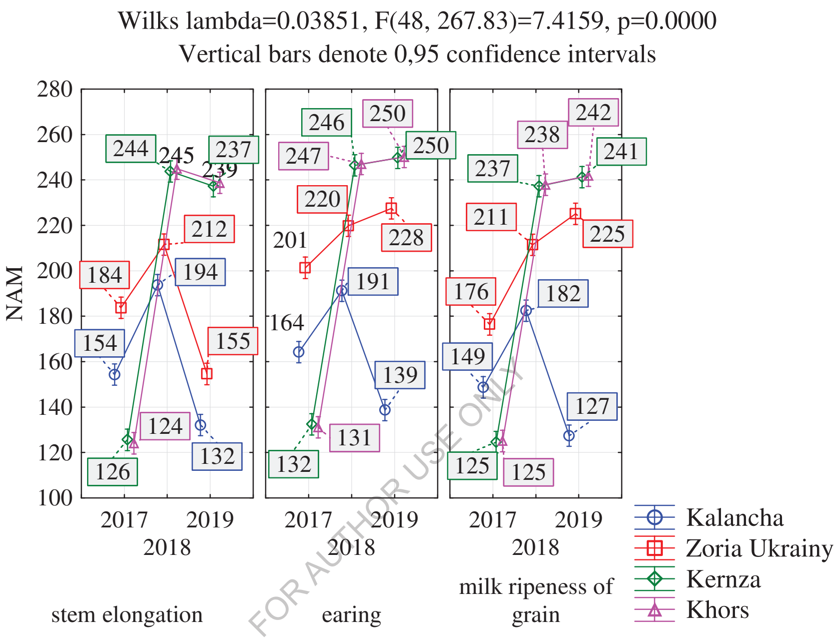

Fig. 1 The number of ammonifying microorganisms in the rhizosphere of cereal crops, 10^3 CFU/g of soil

Statistically significant (p≤0.05) studied factors influenced the formation of the number of ammonifying microorganisms (Fig. 2).

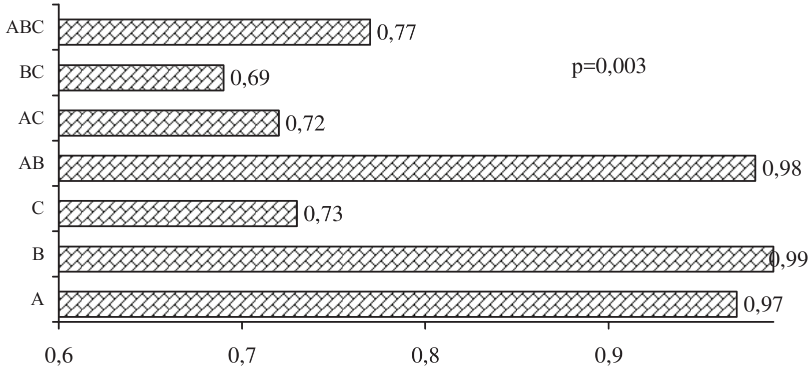

Fig. 2 The level of factors influence on the number of ammonifying microorganisms in the rhizosphere of cereal crops: A –"species of cereal crop" factor, B – "year of study" factor, C – " plant development phase" factor

The force of influence was high. It should be noted that the "species of cereal crop" and "year of study" factors influenced the number of ammonifying microorganisms the most. Obviously, there was a connection between "species of cereal crop" and "year of study". This connection with the "development phase" factor was weaker or absent, so the influence of ABC was lower compared to A and B.

In the rhizosphere of spelt wheat, the number of nitrifying microorganisms in stem elongation stage did not differ significantly from soft wheat (Fig. 3). On average, it was statistically significant ($p \leq 0.05$) that the number of nitrifying microorganisms in the rhizosphere of spelt wheat was 17–26 % higher than in soft wheat during the earing phase in 2018–2019. In the milk stage of grain, a significantly higher number of nitrifying microorganisms was only in 2019.

Intermediate wheatgrass had significantly lower number of nitrifying microorganisms in the stem elongation and earing stages compared to soft wheat. In the milk stage of grain, this figure was at the level of soft wheat. During the second and third years of intermediate wheatgrass growth, the number of nitrifying microorganisms was significantly ($p \leq 0.05$) higher than that of soft wheat. In the stem elongation stage, the number of nitrifying microorganisms of soil rhizosphere was 28–38%, in the earing stage – 26–29, in the milk stage of grain – 16–37% higher compared to the control (Kalancha soft wheat) depending on the year of study.

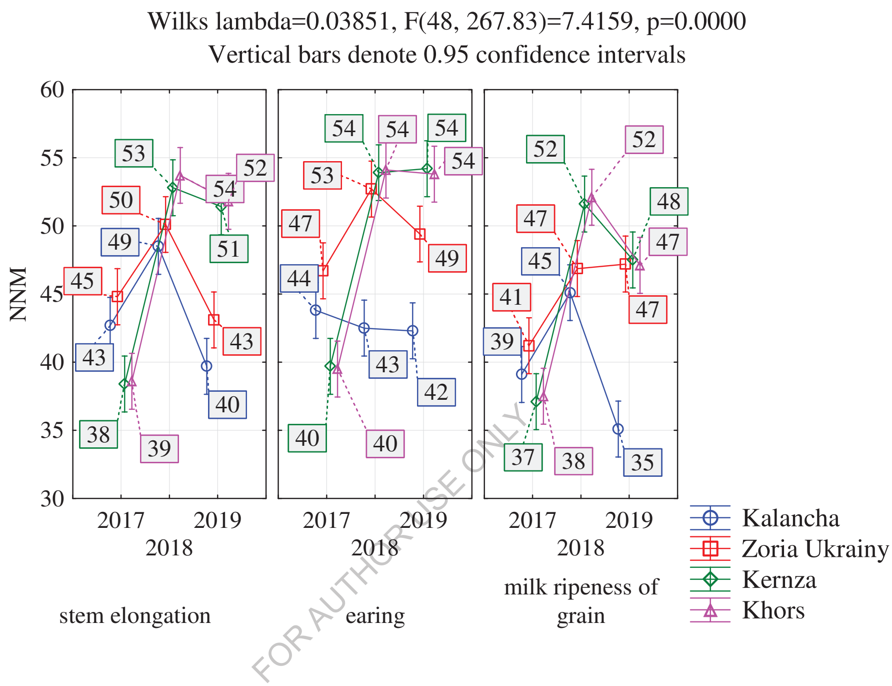

Fig. 3 The number of nitrifying microorganisms in the rhizosphere of cereal crops, 10^3/g of soil

The number of nitrifying microorganisms in the rhizosphere of soft wheat and spelt wheat was the highest in a favourable 2018 year. The number index was the highest in 2018–2019 in the rhizosphere of intermediate wheatgrass.

The results of statistical processing confirmed the significantly strong influence of "species of cereal crop", "year of study" and "plant growth phase" factors on the formation of the number of nitrifying microorganisms. It should be noted that the influence of weather conditions and characteristics of the species of cereal crop and the interaction of these factors was the highest – 0.71–0.88. The "plant development phase" factor had less effect on the number of nitrifying microorganisms. Therefore, its interaction with other factors had less effect on this indicator.

The number of cellulosolytic microorganisms in the rhizosphere of soft wheat and spelt wheat was the highest in the favourable 2018 year. It was the lowest in less favourable 2019. This indicator was the highest in 2018, 2019 in intermediate wheatgrass, because the supply of plants with moisture was also high during this period.

In the stem elongation stage, the number of cellulosolytic microorganisms of the soil rhizosphere of spelt wheat did not change significantly from this indicator of soft wheat (Fig. 4). However, in the earing and milk stages, the number of this group of microorganisms was significantly ($p \leq 0.05$) higher than that of soft wheat. Thus, in the earing stage of spelt wheat, the number of cellulosolytic microorganisms of soil rhizosphere was 11–16 % higher compared to soft wheat depending on the year of study. In the milk stage, respectively, by 14–24%. The dynamics of the number of cellulosolytic microorganisms changed from the weather conditions of spelt wheat growing season. In 2017 and 2019, this indicator did not change significantly in stem elongation and earing stages. However, better humidity and comfort temperature for the growth of spelt wheat plants in 2018 contributed to the formation of a significantly larger number of cellulosolytic microorganisms in the earing stage compared to the stem elogation one. In addition, in the milk stage, this figure did not decrease significantly compared to the earing one. In 2017 and 2019, the number of cellulosolytic microorganisms in the milk stage of grain was 9 and 20% lower, respectively, compared to the earing one.

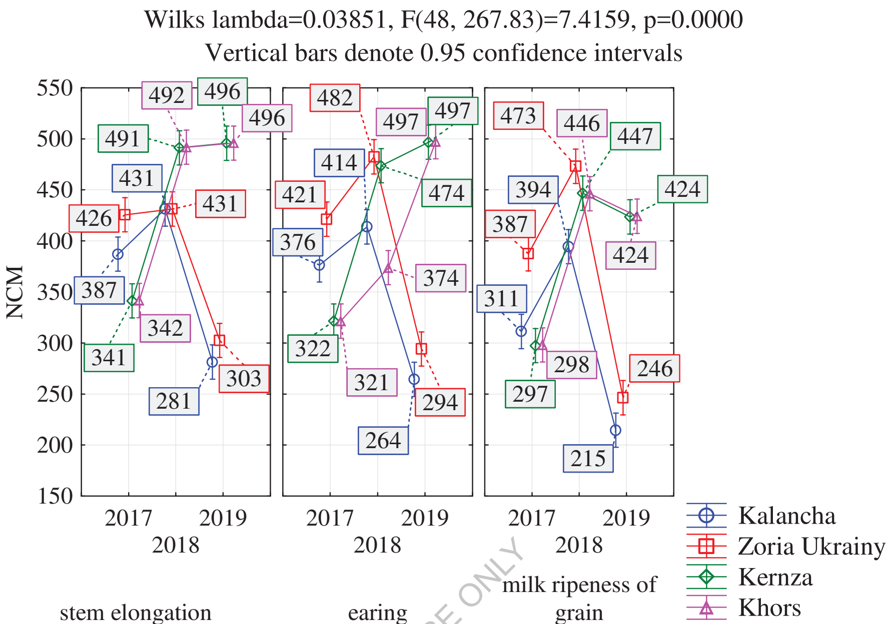

Fig. 4 The number of cellulosolytic microorganisms in the rhizosphere of cereal crops, 10^3/g of soil

The dynamics of the number of cellulosolytic microorganisms in the rhizosphere of intermediate wheatgrass differed significantly from spelt wheat. In the first year of plants growth of intermediate wheatgrass (2017), this figure was significantly lower in stem elongation and earing stages. During the milk stage, it was at the level of soft wheat, as the indicator of cellulosolytic microorganisms in the soil rhizosphere decreased insignificantly. In the second and third years of intermediate wheatgrass growing, the number of this group of microorganisms was significantly higher than that of soft wheat. Thus, in the stem elongation stage, the number of cellulosolytic microorganisms of the soil rhizosphere of intermediate wheatgrass was 14–77%, in the earing stage 14–88, in the milk stage 13–97% higher compared to soft wheat depending on the study year. It should be noted that the number of this group of microorganisms was high during the growing season of intermediate wheatgrass compared to soft wheat. The number of cellulosolytic microorganisms of the soil rhizosphere of intermediate wheatgrass in the earing stage was at the level of stem elongation, because the decrease was insignificant. In the milk stage only in 2019, the number of this group of microorganisms was significantly lower compared to the earing one. Thus, it could be affirmed that the number of cellulosolytic microorganisms significantly depended on the studied factors. It should be noted that there was a stronger connection between A and B factors compared to C factor. Therefore, the interaction of AC, AB and ABC was smaller compared to AB.

On average, the number of soil lumps overgrown with bacteria of the *Azotobacter* genus of the rhizosphere of spelt wheat and intermediate wheatgrass was significantly higher compared to soft wheat over three years of research (Fig. 5).

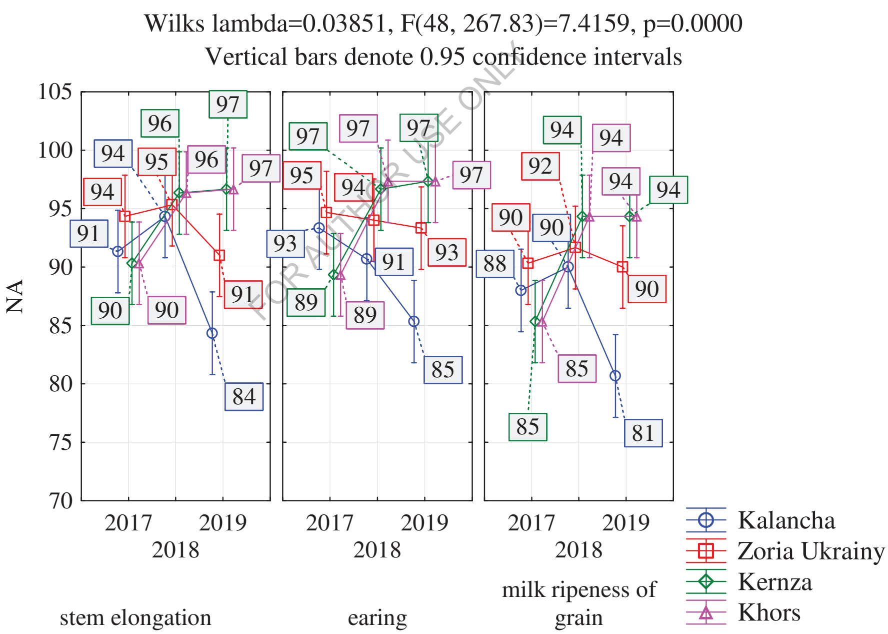

Fig. 5 The number of *Azotobacter* in the rhizosphere of cereal crops, % of overgrown lumps of soil

The number of overgrown soil lumps by bacteria of the *Azotobacter* genus almost did not change from the plant development phase in the rhizosphere of all cereal crops. The number of overgrown soil lumps of *Azotobacter* over the years of research changed significantly depending on the amount of rainfall during the growth of cereal crops. It should be noted that the number of overgrown soil lumps of this group of microorganisms was the highest in the rhizosphere of intermediate wheatgrass in 2018, 2019.

Reliable and strong influence of three factors on the number of overgrown lumps of soil by bacteria of the *Azotobacter* genus was statistically confirmed (Fig. 6). The interaction of the AC, BC and ABC factors was unreliable. It should be noted that this indicator changed less compared to other ecological and trophic groups of microorganisms.

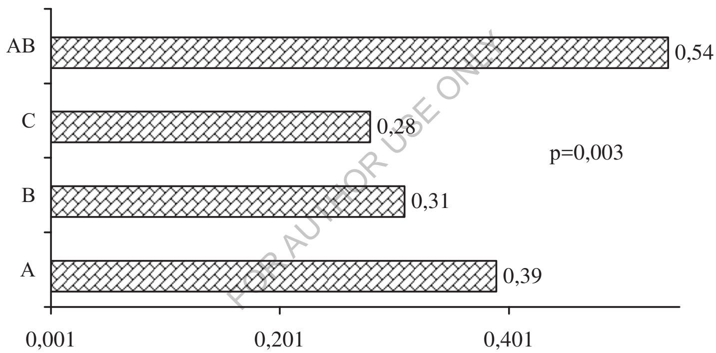

Fig. 6 The level of factors influence on the number of bacteria of the *Azotobacter* genus in the rhizosphere of cereal crops: A – "species of cereal crop" factor, B – "year of study" factor

It should be noted that the number of studied microorganisms in the soil rhizosphere of intermediate wheatgrass did not change significantly depending on the variety.

Discussion. It is known [12] that the number, biomass and taxonomic structure of the soil microbial complex depend on a number of factors. Lead-in of the soil into the active land use leads to significant changes in these indicators.

A high dependence of the functional structure of the soil microbiocenosis and the interaction between microorganisms of different groups on hydrothermal conditions was established. Unfavourable hydrothermal conditions had a significant effect on the functional structure of the chernozem microbiota, disturbing trophic connections between physiological groups of microorganisms. A decrease in strength or bonds breaking in the microbiocenosis was observed under elevated air temperatures and lack of or excess moisture in the soil. The soil of the natural ecosystem is characterized by balance and stability of the functional structure of the microbiocenosis as to the action of hydrothermal factors. A less stable functional structure of the soil microbiocenosis with a low number of connections and a high degree of correlation and a simplified structure of the pleiads in unfavourable weather conditions is specific for the agroecosystem [13]. It was obvious that the improvement of moisture conditions during the vegetation period of the studied crops, according to the results of our researches, contributed to the formation of a higher number of ammonifying, nitrifying, cellulosolytic microorganisms in the rhizosphere of cereal crops.

The influence of plants during the vegetation period on physiological processes and the general activity of microorganisms in the soil was due to root secretions, as well as due to the root system and terrestrial parts after extinction. In turn, the living conditions and productivity of plants depended on the structure and physiological activity of the complex of soil microorganisms [14]. In the studies of scientists [15], the number of microorganisms that absorbed organic and mineral nitrogen of the soil was the largest in the earing phase of winter wheat. It decreased in the following phases of development of winter wheat plants. The amount of root secretions depended on the growth of vegetative mass. This period in wheat was in the earing phase. Therefore, the maximum number of microorganisms (ammonifying, nitrifying, cellulosolytic) in the soil of the rhizosphere of soft wheat and spelt wheat was in the earing phase. The greater number of which in spelt wheat was due to the higher number of root secretions.

Intermediate wheatgrass in the first year of the vegetation period formed a small aboveground mass and root system. As a result, the number of root secretions was probably smaller and as a result the number of microorganisms of different ecological and trophic groups was the lowest. Intermediate wheatgrass plants formed a larger root system, so the number of ammonifying, nitrifying, cellulosolytic microorganisms was the highest compared to soft wheat after the first year of the vegetation period. This was confirmed by the results of researches by other scientists [16].

Conclusions. The formation of rhizoshere microbiota of spelt wheat and intermediate wheatgrass was first analyzed under the conditions of the Right-Bank forest-steppe of Ukraine. The number of main groups of microorganisms in the rhizosphere of these crops has been found to be significantly different from that of soft wheat. In the soil rhizosphere of spelt wheat, significantly more ammonifying and cellulosolytic microorganisms are formed compared to soft wheat. The conducted studies indicate the feasibility of growing and use of spelt wheat in breeding programs to create varieties of soft wheat with higher microbiological activity. The total count of nitrifying and the number of soil lumps covered with bacteria of *Azotobacter* genus did not change compared to soft wheat.

The microbiota of the rhizosphere of intermediate wheatgrass reached the maximum development in the second year of cultivation. The number of ammonifying, nitrifying and cellulosolytic microorganisms of soil rhizosphere of intermediate wheatgrass was significantly higher compared to soft wheat during all growth stages. The microbiota number of the rhizosphere of intermediate wheatgrass in the 2–3 year of cultivation was more resistant to adverse environmental factors compared to soft wheat. The soil microbiota of the rhizosphere did not change much depending on the phase of plant development during the vegetation period of cereal crops (spelt wheat, intermediate wheatgrass). The conducted statistical analysis showed that the influence of "species of cereal crop" and "year of study" factors had the greatest impact on the number of ammonifying, nitrifying and cellulosolytic microorganisms. The conducted studies confirm the practical application of intermediate wheatgrass to preserve and increase soil fertility. Intermediate wheatgrass can be grown for up to three years in one field, as microbiological activity reaches its maximum development.

1. Snisarenko TA, Alesina NV. [The influence of some environmental factors on the microbial composition of the rhizosphere and rhizoplana on the example of common oats (*Avena sativa*)]. Bulletin MRSU. 2014; 3: 46-51. Russian.

2. Musilova L, Ridl J, Polivkova M, Macek E, Uhlik O. Effects of Secondary Plant Metabolites on Microbial Populations: Changes in Community Structure and Metabolic Activity in Contaminated Environments. Int J Mol Sci. 2016; 17(8): 1205-1213.

3. Liubych V, Novikov V, Polianetska I, Usyk S, Petrenko V, Khomenko S, Zorunko V, Balabak O, Moskalets V, Moskalets T. Improvement of the process of hydrothermal treatment and peeling of spelt wheat grain during cereal production. Eastern European Journal of Enterprise Technologies. 2019; 3 (11 (99)): 40-51.

4. Crews T, Carton W, Olsson L. Is the future of agriculture perennial? Imperatives and opportunities to reinvent agriculture by shifting from annual monocultures to perennial polycultures. Glob. Sust. 2018; 1: 1-18.

5. Pimentel D, Cerasale D, Stanley R, Perlman R. Annual vs. perennial grain production. Agric. Ecosyst. Environ. 2012; 161: 1-9.

6. Agriculture, Forestry and Fishery Statistics - 2016 Edition. [(accessed on 10 September 2018)]; Available online: https://ec.europa.eu/eurostat/web/products-statistical-books/-/KS-FK-16-001.

7. Bakker H, Berendsen R, Doornbos R, Wintermans P, Pieterse C. The rhizosphere revisited: Root microbiomics. Front. Plant Sci. 2013; 4: 165-172.

8. Assainar S, Solaiman Z. Response of wheat to a multiple species microbial inoculant compared to fertilizer application. Front Plant Sci. 2018; 9: 1601-1612.

9. Naylor D, DeGraaf S, Purdom E, Coleman-Derr D. Drought and host selection influence bacterial community dynamics in the grass root microbiome. The ISME Journal. 2017; 11: 2691-2704.

10. Xun W., Li W, Huang T, Ren Y, Xiong W, Miao Y, Zhang R. Lon-term agronomic practices alter the composition of asymbiotic diazotrophic bacterial community and their nitrogen fixation genes in an acidic red soil. Biology and Fertility of Soils. 2018; 54: 329-339.

11. Zarraonaindia I, Owens S, Weisenhorn P, West K, Hampto-Marcell J, Lax S, Gilbert J. (2015). The soil microbiome influences grapevin-associated microbiota. MBio. 2015; 6: 2527-25634.

12. Tsyuk OA, Kyrylyuk VI, Yushchenko LP. Biochemical activity of typical chernozem in different farming systems. Mikrobiol. Z. 2017; 79(3): 65-71.

13. Demyanyuk OS, Sherstoboeva OV, Tkach ED. [Functional structure of microbial groups of deep chernozem under the influence of hydrothermal and trophic factors]. Mikrobiol. Z. 2018; 80(6): 94-108. Ukrainian.

14. Lin W, Wu L, Lin S, Zhang A, Zhou M, Lin R, Wang H, Chen J, Zhang Z, Lin R. Metaproteomic analysis of ratoon sugarcane rhizospheric soil. BMC Microbiol. 2013;13: 1-13.

15. Dragovoz IV, Volkogon MV, Yavorskaya VK. [Physiological activity of vermicompost components and creation of a complex growth regulator based on it].

Physiology and biochemistry of cultivated plants. 2006; 38(4): 292-300. Ukrainian.

16. Tsyuk OA, Kirilyuk VI, Yushchenko LP. [Biochemical activity of chernozem typical of different farming systems]. Mikrobiol. Z. 2017; 79(3): 65-71. Ukrainian.

5. INTRODUCING PERENNIAL GRAIN IN GRAIN CROPS ROTATION: THE ROLE OF ROOTING PATTERN IN SOIL QUALITY MANAGEMENT (O. Duchene, F. Celette et al., 2020)

The recent development of perennial grain breeding programs has highlighted the value of the wheat wild-relative ‘intermediate wheatgrass’ (*Thinopyrum intermedium* (Host) Barkworth & D.R. Dewey to support the transition to multifunctional agroecological systems. In addition to its ability to produce an interesting forage-grain dual income, its regrowth capacity for several years would achieve substantial production at minimal soil and environmental costs. In contrast to the recurrent use of annual crops, the use of intermediate wheatgrass has been suggested to sustain soil fertility through the development of an extensive root system beneficial to a range of soil functions. The extended lifetime of perennial grains improves the capacity to access soil resources through higher colonization of deep soil horizons and increased resource allocation towards belowground plant growth. The use of perennial crops is likely to have a range of effects on ecosystem processes and the provision of ecosystem services due to the large differences in plant traits between annuals and perennials. These includes the promotion of the soil organic carbon pool, better retention of nutrients, higher water storage capacity and uptakes, improved soil stabilization and aggregation, lower soil disturbance, and a shift of soil microbial communities (O. Duchene, F. Celette et al., 2020).

Greater investment in belowground biomasswith intermediatewheatgrass has been demonstrated several times, including greater root carbon and nitrogen content, and was associated with benefits observed on leaching reduction and enhanced soil microbiota. In spite of the increasing literature on perennial grains and intermediate wheatgrass, studies have not thoroughly investigated issues associated with rooting patterns. Data on intermediate wheatgrass often involve aging stands (>two years old) rather than new plantings (<two years old). Compared to long-term grasslands, the integration of a perennial grain into grain crop rotation may be potentially implemented over a short timeframe (2 to 3 years as a maximum). This would likely

lead to a smaller impact on soil processes and properties. Therefore, it remains uncertain if the short-term use of a perennial grain can effectively enable increased belowground productivity, influence soil microbiology, or allow the establishment of root-microbe symbiosis, which are needed to confer the benefits of intermediate wheatgrass on the soil. The value of integrating a perennial phase within a grain crop rotation is then strongly dependent on the rapidity of rooting system development and its capacity to sustain soil services.

The amount and timing of these benefits are currently the cornerstone to ensure desirable and profitable use of intermediate wheatgrass, especially as grain yields are much lower compared to annual counterparts and might counteract the potential benefits to the soil. The dynamic of perennial rooting systems in cropping systems is therefore critical to designing the 'safe operating space' that takes advantage of a maximum services while limiting drawbacks from disservices (e.g., grain yields penalties).

In studying rooting systems, morphological root traits (e.g., specific length, length density, tissue density, diameter, vertical distribution) are used and recognized as good indicators of plant–soil processes (e.g., exudation, water and nutrients uptakes, tissue decomposability) and are useful in discussing the ecosystem services likely to be provided by plant communities (e.g., soil aggregation, water retention, carbon storage) (Figure 1). Complementarily, soil microbial indicators have been used to inform about soil–root interactions. Microbial biomass, community structure and catabolic diversity are particularly used to investigate carbon and nitrogen cycles and used as proxies for inputs of litter and root-derived compounds to soil. Mycorrhizal fungi are beneficial root symbionts that participate in root system functioning and impact the soil through its hyphal network.

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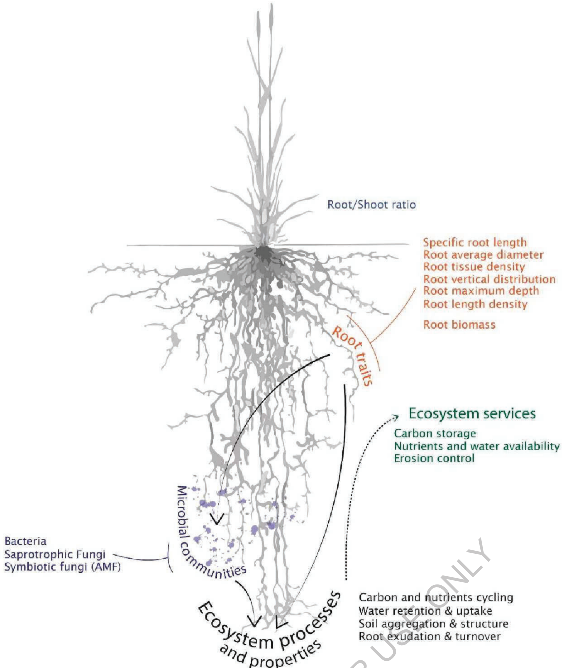


Figure 1. Influence of root traits and microbial indicators on soil ecosystem processes.

Here, we investigated root system development and changes in root traits of young stands of intermediate wheatgrass, from establishment to the next cropping season, comparing them to a continual annual grains crop rotation, to assess the potential to improve soil components within a limited period after establishment. We determined how rooting pattern, early root development, and a range of root traits differ in perennial and annual crops, in the topsoil to deeper soil layers.

We further tested the impact of root systems on soil microbial communities, including arbuscular mycorrhiza, through the evaluation of microbial indicators. More specifically, we hypothesized that intermediate wheatgrass would demonstrate, first, a denser and deeper rooting pattern as compared to annual grains, indicating higher belowground investments. Additionally, under young perennial plants there would already be an increase in microbial organism groups, indicating an improvement in soil functioning (O. Duchene, F. Celette et al., 2020).

Higher root biomasswas observed under the perennial grain compared to annualwheat at 0–10 cm depth in June 2018 (first spring) (Figure 2). Perennial root expansion was observed during the regrowth period, with higher total root biomass compared to the values observed during first spring. Overall, between the end of the first and second spring growing seasons, perennial above and belowground biomass increased by 52% and 111%, respectively. Consequently, root biomass was higher under the perennial treatment in each soil layer, leading to more than three-fold higher total root biomass (5.3 tonnes more of dry roots hectare).

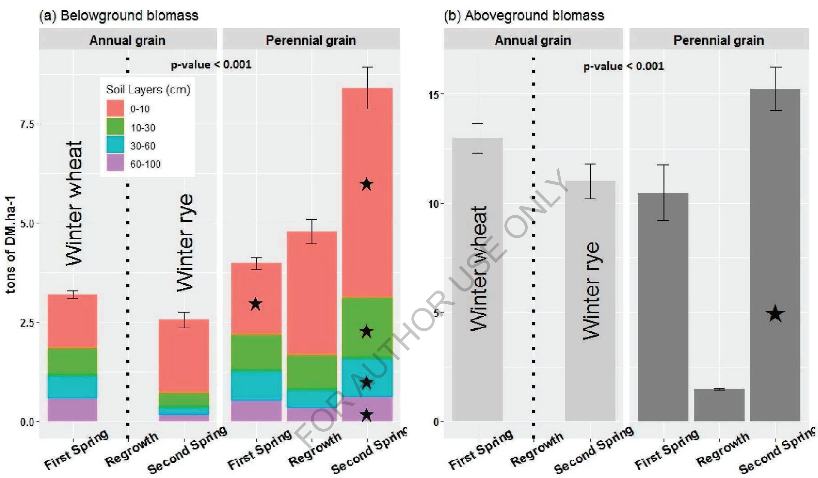


Figure 2. Mean root dry biomass (**a**) and aboveground dry biomass (**b**) measured under annual and perennials grains during two crop seasons. Statistical differences (post hoc analyses) between annual and perennial grains are indicated by ★. Error bars indicate standard errors, from 0 to 100 cm depth.

The % of soil colonized by roots (Figure 3a) and % of total root in each soil depth (Figure 3b) observed in the second spring growing season both indicated a significant effect of crop treatment. Except for the topsoil layer (0–10 cm), all soil layers had significantly higher colonization under perennial grain cultivation. The perennial root system showed a thorough soil colonization until 60cm, with 96 and 83% of colonized soil for the 10–30 and 30–60 cm soil layers, respectively, whereas the annual root system showed only 62 and 54% of soil colonized soil for the same layers. Similarly, for thedeeper soil layers of 60–100, 100–130 and 130–160 cm, the perennial root system colonized as much as 66, 58 and 54% of the observed soil profile, respectively, whereas the annual root system showed relatively low soil colonization of 35, 27 and 14%, respectively, at these depths. The maximum rooting depth of annual grain (141.5 cm − 6.8 SE) was less than that of the perennial grain, where the maximum rooting depth was >160cm in each soil profile replicate. The root vertical distribution indicates that the perennial root system showed a more even distribution as compared to the annual root system (Figure 3b). The annual root system had a stronger preferential allocation of annual roots in upper soil layers (on average, 68% of the annual root system is found between 0 and 60 cm, while it is only 47% for the perennial root system). In contrast, as much as 30% of the perennial root system was found in the deeper soil layers (100–160 cm), as compared to only 16% for the annual grains (O. Duchene, F. Celette et al., 2020).

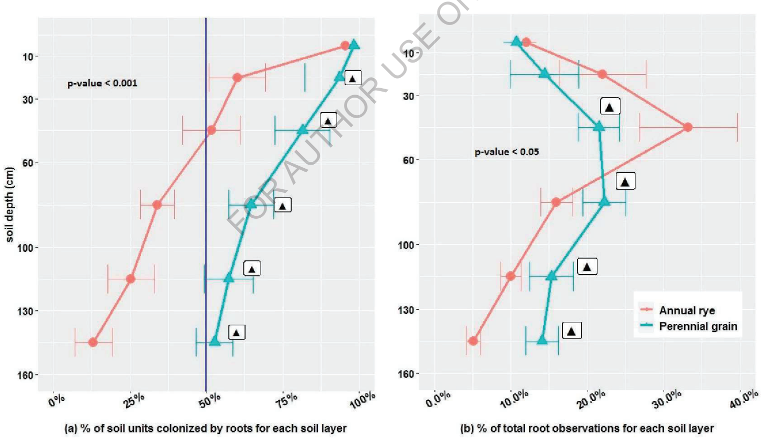
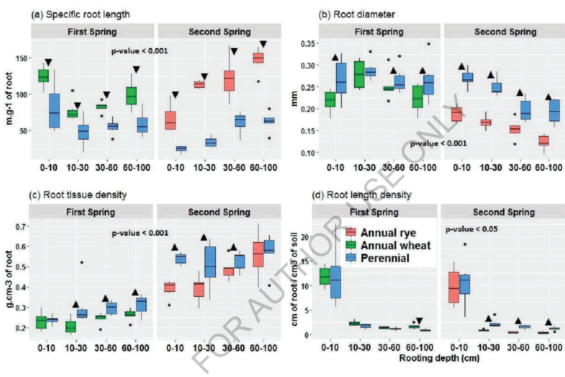


Figure 3. Mean root colonization of the soil profile observed at the second crop season, under intermediate wheatgrass and annual winter rye. Standard errors are represented by error bars. Statistical differences (post hoc analyses) between annual and perennial grains are indicated by ▲.

Specific root length (SRL), mean root diameter (RD) and root tissue density (RTD) all demonstrate the different rooting patterns between the annual and perennial grains, where annuals have higher SRL (Figure 4a) but a lower RD and RTD (Figure 4b,c). In general, SRL increased and RD and RTD decreased with soil depth. In comparison to SRL, RD and RTD, the root length density (RLD) is associated to a given volume of soil. Significant differences between annual and perennial grains were mainly observed in the second year (Figure 4d), as the higher RLD under the perennial grain (from 10 to 100 cm) was associated with increased root biomass (Figure 2). RLD was higher for each crop in the 0–10 cm soil layer due to the highest concentration of roots in the top layer (Figure 2). Differences between annual and perennial grains through volume-based root measures (root biomass, RLD) were associated with perennial growth duration (establishment–regrowth), while single root traits are associated with annual–perennial crop type, independent of growth.



Bacterial markers did not respond to the crop treatment (Figure 5a), while both the overall fungal markers (Figure 5b) and AMF markers did (Figure 5c,d). Fungal markers, including AMF, at 0–10 cm depth were higher under the perennial treatment in both first and second spring samplings compared to the annual crops, winter wheat and winter rye, respectively (Figure 5b–d).

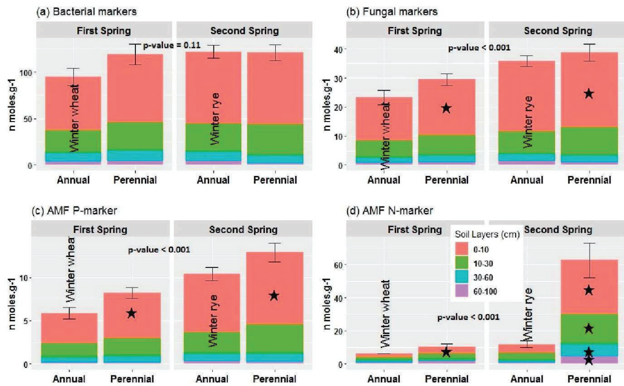


Figure 5. The PLFA and NLFA markers in annual wheat and intermediate wheatgrass, and between annual rye and the intermediate wheatgrass during the first and second growing seasons. Statistical differences (post hoc analyses) between annual and perennial grains are indicated by ★. Error bars indicate standard errors, from 0 to 100 cm depth.

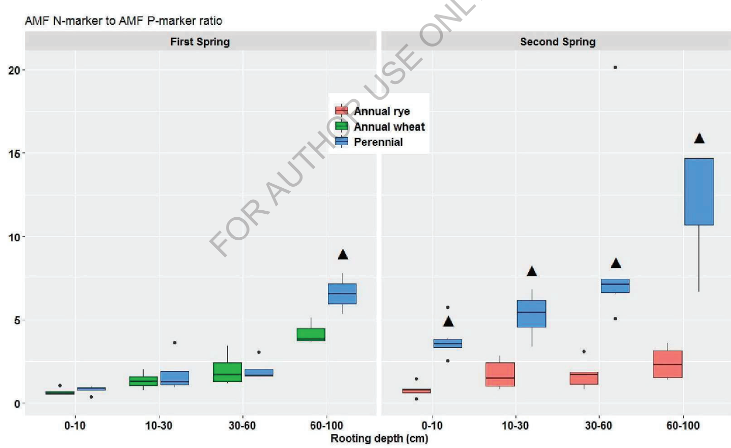


Figure 6. NLFA to PLFA marker ratio indicating (AMF). Statistical differences (post hoc analyses) are illustrated by ▲.

The abundance of AMF N-marker was higher for each soil layer from 0 to 100 cm depth in the second spring, showing five times greater abundance compared to the annual winter rye. The ratio between the two AMF markers (N-to P-marker) was significantly higher than the annual crop in all soil layers under intermediate wheatgrass in the second experimental year and in the deepest soil layer (60–100 cm) in the first experimental year (Figure 6). The ratio between the two markers generally increased with soil depth (p-value < 0.001) (O. Duchene, F. Celette et al., 2020).

Compared to annual crops, and within two years after establishment, stands of intermediate wheatgrass showed a denser and deeper rooting system profile. This highlights how perennial grains allocate more assimilates to belowground parts. Total root biomass produced by intermediate wheatgrass after two years was higher than the sum of the root biomass produced by both annual crops during the two growing seasons. Furthermore, the dense and deep root system observed with intermediate wheatgrass demonstrates the ability of the perennial grain to explore the entire soil profile and subsoil layers, permitting access to greater amounts of soil resources and suggesting a potential impact of its root functioning on a larger volume of soil. Intermediate wheatgrass was able to produce higher amounts of root biomass in the topsoil layer by the first spring, and then in the entire soil profile during the following growing season including the fall period, as compared to the annual grains succession (O. Duchene, F. Celette et al., 2020).