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Evaluating Perennial Wheat as a Strategy for Biodiversity Conservation and Soil Fertility Improvement in Kazakhstan

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ABSTRACT

This study sought to establish the agro-biological foundations for the cultivation of perennial wheat in agricultural agrocenoses in the South and South-East of Kazakhstan, aiming to preserve soil fertility. To achieve this objective, a three-year field study was conducted, during which the morphological characteristics, growth, development, and yield formation of wheat were systematically examined. Field condition trials revealed an average seed similarity of 70.55% for perennial wheat. Optimal planting times were identified as the end of September to beginning of October for autumn and mid-April for spring. The ideal plant spacing was found to be up to 15 cm within rows and up to 30 cm between rows. In its first year of cultivation, perennial wheat demonstrated the capability to compete with weeds, an efficacy that improved in subsequent years, concurrently suppressing the growth of undesirable vegetation. Notably, the cultivation of perennial wheat contributed to the maintenance of initial agrophysical soil properties and a reduction in erosion on irrigated soils. These findings underscore the potential role of perennial wheat cultivation in preserving soil fertility, mitigating erosion, and managing weed competition. The implications of this research could be significant for sustainable agricultural practices, not only in Kazakhstan but also in other regions with similar environmental conditions.

1. INTRODUCTION

In the global grain repository, perennial grains are increasingly considered as sustainable alternatives to traditional annual crops. Although annual crops form a substantial portion of the global food supply, their cultivation is not without drawbacks. Extensive cultivation of annual cereal crops has been associated with detrimental environmental impacts, including soil fertility degradation, water scarcity, elevated toxic gas emissions, and biodiversity loss [1-3].

In contrast, perennial grasses, capable of producing crops for several consecutive years post-sowing, are posited to pose fewer environmental challenges than their annual counterparts. These perennials have been shown to enhance soil quality through the augmentation of soil organic matter and nutrients, increasing stability, and minimizing leaching [4]. They also exhibit potential in rehabilitating soils degraded by overcultivation. However, the potential disadvantages of perennial crops cannot be overlooked, including lower crop yields compared to annual crops and the lack of pest control options via crop rotation [5]. The development of perennial crops has typically been achieved through the domestication of wild plants and hybridization of annual crop species with their wild relatives [6].

Intermediate wheat grains are generally characterized by a higher protein content than annual wheat, largely attributed to the smaller grain size of the former. Protein concentrations of various intermediate wheat cultivars have been found to range from 18% to 25%, contrasted with 12% for hard red wheat used as a control [7]. The unique flavor profile of intermediate wheat grass, making it a desirable ingredient in bread and beer, coupled with growing consumer interest in organic and alternative grains, may catalyze market opportunities for farmers interested in cultivating perennial crops [8].

Functionally diverse perennial crops offer numerous potential benefits for plant protection and have been identified as a sustainable alternative to conventional agriculture [9, 10]. When advocating for diversity within a field, it's critical to align with specific disease reduction objectives [11, 12].

The research question steering this study is: "Can the cultivation of perennial wheat in the South and South-East of Kazakhstan form an effective agro-biological foundation for preserving soil fertility and reducing erosion, and what are the optimal conditions for its growth and yield?" The study aims to evaluate the morphological features, growth, development, and yield formation of perennial wheat, and to explore its capacity to compete with weeds and maintain the agrophysical properties of the soil. The hypothesis under scrutiny is that perennial wheat cultivation in the region can offer a sustainable alternative to traditional annual crops, contributing to enhanced soil fertility and erosion reduction in irrigated agricultural systems.

2. LITERATURE REVIEW

2.1 Benefits of perennial crops

Perennial crops are currently being developed, but little is known about farmers' interest in these new crops. Perennial crops derived from large-scale hybrid crosses of existing annual sand wild perennials tend to yield higher than perennials derived from domesticated wild plants and are comparable to annual crops' increase productivity [13].

Year-round vegetation cover improves the physical and chemical properties of the soil, as well as increases the organic matter content in the soil, protecting the soil and water. Infiltration and water retention have increased, and runoff and soil erosion have decreased [14, 15]. The practice of growing perennial crops is of particular interest, especially on slopes and sensitive soil types, near coastal areas and along field edges [16, 17].

2.2 Challenges of perennial crops

Livestock can graze vegetative growth early in the season until stalks and grains develop, and for late vegetative regrowth after grain harvest, instead of collecting forage and crop residues [18]. In addition to direct economic benefits, grazing and harvesting perennial crops for fodder can help control pests. Removal of vegetation by grazing or harvesting limits weed seed production and reduces weed populations commonly found in arable crops [19].

Perennial wheat has been proposed to solve the long-standing problem of soil erosion in annual agricultural systems, while at the same time supporting rural communities and providing farmers with climate-resistant crops [20]. Perennial grass agrosenosis in combination with legumes has economic and ecological advantages [21]. Currently, many countries have projects to create hybrids or perennial varieties of cereals, such as wheat, rice, sorghum, oats and barley [22].

Most perennial crops require changes in harvesting and grain handling techniques to meet appropriate demand, and consumer farm policies and legislation need to be put in place. Perennial wheat develops a wider root system than annuals, helping access nutrients and water stored in deeper soil layers [23-25].

Perennial wheat cultivars bred to date yield on average 30% less than annual wheat cultivars, so there are several issues that need to be addressed. Where yield decline may reflect plant death rather than internal deficiencies in germplasm yield [26]. Forage and food are one of several realistic and possibly economically viable options in favor of implementing a sustainable approach to cereal farming [25]. It is clear that annual crops are more vulnerable than perennial crops to soil erosion due to the lack of a continuous soil cover [27].

2.3 Perennial wheat research and development

Final purpose of developing perennial wheat should be to act as a breeding goal while developing and improving this new crop [28]. The USA conducted six selection cycles based on ear efficiency, grain size and light threshing in the gray wheatgrass population, as a result of which the grain yield per unit area raised by 77%, and the weight of one grain – by 23% [29]. It is still undetermined whether the crossing of legumes and perennial cereals can improve or reduce the production of perennial crops in the long term [30-32]. The root system of perennial *Thinopyrum intermedium* is more than twice as deep as that of annual wheat, because the larger root system provides the plant with stress tolerance [29, 33, 34].

In addition to using intermediate wheatgrass grains as food, this crop can also provide significant ecosystem conservation services, such as improving carbon sequestration, reducing nutrient runoff and leaching into groundwater, and reducing soil erosion [4, 35].

Therefore, a large number of studies conducted in various soil and climatic conditions around the world suggest that perennial crops could be an alternative to annual crops due to the problems of climate warming, environmental threats and increasing energy intensity of cereal production. They are more resistant to many negative biotic and abiotic environmental factors, thus maintaining soil cover for years, reducing water and nutrient loss, and absorbing more carbon and thereby reduce greenhouse gas emissions from agriculture [36]. In this regard, research on the growth and development of perennial wheat and the development of effective cultivation methods associated with different agroecological zones are relevant and promising areas of agriculture in the South and South-East of Kazakhstan.

The purpose of the research was to develop agro-biological foundations for the management of perennial wheat in the agricultural culture of the South and South-East of Kazakhstan to preserve soil fertility. Morphological features of perennial wheat plants, growth and development features, crop formation and quality in various agroecological conditions of Kazakhstan have been studied.

3. MATERIALS AND METHODS

3.1 Plant material and field trials

In 2020-2022, field trials were conducted on the most promising breeding lines of perennial wheat obtained by the Land Institute as a result of interspecific crossing of wheatgrass *Thinopyrum intermedium* (Host) Barkworth & D. R. Dewey and wheat (*Triticum aestivum* L.) for the first time in conditions of Kazakhstan.

3.2 Greenhouse experiments

The features of the growth and development of perennial wheat were studied in two greenhouses of Al-Farabi Kazakh National University, Mukhtar Auezov South Kazakhstan University and in field conditions in various agroecological zones of the south in the city of Shymkent and in the Almaty region of the Karasai district of South-East Kazakhstan.

The objects of the study were the variety SOVA and 5 lines of perennial wheat. The "SOVA" variety is also intended for regenerative agriculture, the period of use without replanting is up to seven years. A dual–purpose variety – for grain and green mass, the average grain yield is 9.2 c/ha, green mass is 210.0 c/ha and hay is 71.0 c/ha. Research programs and methods for 2020-2022 have been developed. Perennial wheat was grown according to the method.

3.3 Field experiments and sowing conditions

1-Autumn sowing: In 2020, the study was started in September, 350 seeds of the variety "SOVA" were sown under greenhouse conditions, in April 2021-2022 years.

Phenological observations of perennial wheat were carried out daily. Under greenhouse conditions, a Sulphur-containing new fertilizer synthesized by chemists of Al-Farabi Kazakh National University was used as fertilizer. 2-Spring sowing in 2021 in 4 variants treated with Sulphur-containing preparations, 1-Control, 2-Tiovit, 3-Sulphur-containing solution, 4-Diatomite solution, 3-Autumn sowing in Mukhtar Auezov South Kazakhstan University, 2021.

To determine the timing of sowing: In the field, in October 2020 and 2021, in early spring in early April and late spring in May, sowing of perennial wheat was carried out on September 26-27, 2020 in the field of Karasay district of Almaty region. 1-autumn sowing, manual sowing methods. Scheme of experience: Ordinary: 15×5 – 4 rows, 15×10 – 8 rows Wide-row: 30×5 – 4 rows, 30×10 – 4 rows.

2-sowing in the spring of 2021, early on April 4 and late on April 24, 3-autumn sowing, 2021. 2-sowing was carried out in the field in the experimental area of the city of Shymkent, on October 8, 2021, the distance between rows 15, 30, 45 cm, between plants 5 and 10 cm. 3-sowing in the spring of 2022 in the South-East of Kazakhstan.

The optimal sowing methods and timings were determined by considering several factors, including soil temperature, moisture levels, and regional climate conditions. Daily weather patterns and historical climate data were consulted to identify suitable sowing windows for perennial wheat. Soil samples were taken regularly to assess moisture content and nutrient levels, informing the selection of appropriate fertilization regimes. Germination rates, growth patterns, and yield formation were analyzed under various sowing conditions to identify effective combinations of sowing dates and plant spacings. A comparative analysis of manual and machine sowing methods was conducted, evaluating their impact on seedling establishment and plant development. Findings were further validated through consultation with local agricultural experts and farmers, who provided valuable insights into sowing practices for perennial wheat in the region.

3.4 Soil analysis

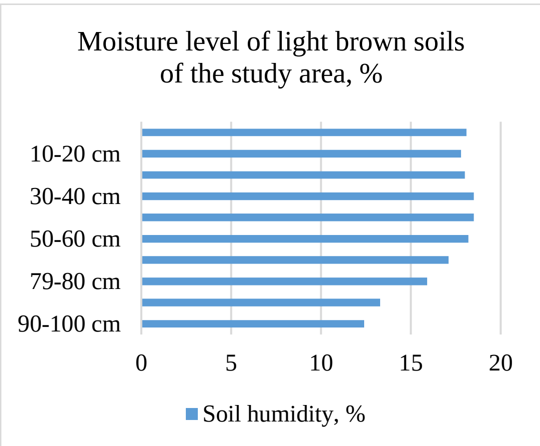

Figure 1. Humidity level of light brown soil in the studied area

To characterize the initial conditions of the experimental site, soil samples were selected and soil pesticide and agrophysical analyzes were performed to determine common and labile humus, mobility and total morphology of foothill light chestnut nutrient elements (N, P, K) contents were determined in field irrigated soils of Karasay district, Almaty region. Water storage in the metric layer of soil at the experimental site was determined (12 definitions). Soil moisture was determined by an isothermal gravimetric method in which soil samples were dried to a constant weight. Soil sampling is done in layers of 10 cm to a depth of 1 meter. The sampling repetition is 3 times (Figure 1).

3.5 Phenological observations

Seeds of perennial wheat are prepared for sowing and drip irrigation systems. A multi-factor experience of plants and micro-fields is laid out, with 12 options (regular 15 cm, wide row 30 cm, wide row 45 cm). In 2021 and 2022, perennial wheat was sown on April 3rd and April 24th. Field germination and plant density of perennial wheat were considered. Field germination of seeds was accounted for by counting its 4 fixing sites of 0.25 m^2 in every plot of full seedlings. The start of the shoot was marked on 30 April and the full shoot on 6 May. Phenological observations were made on plant growth, biomass accumulation, and leaf formation in perennial wheat. Laboratory research analyzes of soils and plants were performed in accredited analytical laboratories of the Kazakh Research Institute of Agriculture and Plant Growing.

3.6 Laboratory analyses

The soil cover at the experimental site is foothill, and the dark light chestnuts formed on the loess-like loam have a distinct fertile profile. According to the mechanical composition of the soil, it refers to coarse dust medium loam, with a physical clay content of 29-32% and coarse dust of 40-50%. Soil supply of hydrolysable nitrogen is average, mobile phosphorus is low, and exchangeable potassium is average. The upper horizon contains up to 2.57% humus.

The soil cover at the experimental site is foothill light chestnut formed on loess-like loam, with a distinctly fertile profile. A characteristic feature of light chestnut soils is their high carbonate content, and their boiling is characterized by HCl from the surface. According to the mechanical composition of the soil, it refers to coarse medium loam, with a physical clay content of 39-42%, coarse dust of 45-51%, and silt of 12-17%. Soil supply of hydrolysable nitrogen is average, mobile phosphorus is low, and exchangeable potassium is average. The upper horizon contains up to 2.02% humus, 0.12-0.14% of total nitrogen.

4. RESULTS

During the study in greenhouse conditions, the germination of seeds in laboratory, greenhouse and field conditions was determined. By years 2020-2022 and seasons (spring and autumn), laboratory germination varied from 65.9 to 85.7%. In greenhouse conditions, when growing with various sulfur-containing fertilizers, in three repetitions, the average percentage of germination of perennial wheat seeds varied from 79.55% to 83.42%, and field germination was less from 65.7 to 75.4%. In greenhouse conditions, new types of fertilizers were used for the growth and development of perennial wheat. Table 1 shows the average percentage of germination.

During the study of the growth and development of perennial wheat varieties sown in 2021, it was found that the

SOVA variety gave abundant green mass in greenhouse conditions. Also, the normal growth rates of perennial wheat sown in 2021 have been determined in both conditions. In greenhouse conditions, the volume of green mass increases. During the phenological observations of autumn sowing in the greenhouse conditions of Shymkent, the features of the ontogenesis of perennial wheat plants were analyzed, mass flowering at the end of May were determined. In the field conditions of Shymkent at the end of March, the passage of the seedling phase was observed, the stage of three leaves at the end of May, perennial wheat passes the tillering phase. Pheno-observation of spring sowing in the field in the Almaty region showed that 10 days after sowing, seedlings up to 8 cm in length appeared. At the end of May, there were phases of tillering development. When determining the accumulation of crude total biomass of plants grown the following year after mowing the primary aboveground part in greenhouse conditions, the biomass of one plant in the tillering phase was 57.78±6.9 g. At the same time, the average dry biomass of one plant was 30.8±2.3 g.

In greenhouse conditions: the total bushiness of 2-year-old perennial wheat was determined to establish the peculiarities of variability and the nature of inheritance of quantitative and qualitative characteristics, on average, the total bushiness was 8.9±2.6 stems per plant. The average number of leaves per plant is 44±3.2. The average leaf length was 39.55±2.7 cm and the leaf width ranged 1.1±0.3 cm. The leaf surface of plants of perennial wheat of the second year in greenhouse conditions of the Al-Farabi Kazakh National University was determined by the formula, the leaf area per plant averaged 381.23±8.8 m^2.

Table 1. Germination of perennial wheat samples in greenhouse conditions

SOVA Years	2020	2021	2022	Average Percentage
Control	79.17%	73.50%	77.08%	76.58%
Tiovit	77.08%	87.50%	83.30%	82.63%
Sulfur solution	81.25%	77.08%	91.67%	83.33%
50% Diatomite solution	77.08%	79.17%	81.25%	79.17%

Table 2. Structural analysis of the yield of perennial wheat varieties in the field

Variety	SOVA	39-02-1	39-04-1	39-04-4	34-06-1	39-04-6
Plant Height (PH, cm)	110±3.8	96.3±4.2	89.9±3.8	91.1±5.5	90.2±4.9	86±3.8
Spike Length (SL, cm)	20.2±0.8	18.8±2.3	16.1±1.1	18.8±2.2	17.4±2.7	18.2±1.8
Number of Kernels per Spike (NKS, pcs)	17.4±0.9	13.4±0.7	13.7±0.8	16.6±0.3	16.1±0.6	16.8±0.4
Total Number of Stems (TN, pcs)	27.7±2.7	22.13±1.5	20.49±1.7	18.8±0.7	19.9±0.9	20±0.7
Number of Productive Spikes (NPS, pcs)	21.1±0.9	15.7±2.4	14.5±3.1	15.5±4.3	16.8±2.6	15.8±1.3
Thousand Kernel Weight (TKW, g)	12.5±0.01	27.8±0.02	23.6±0.03	20.3±0.01	10.7±0.04	15.6±0.03
Average Yield, (AY, c/ha)	10.5±0.9	11.6±0.7	9.3±2.1	10.4±1.2	5.7±2.2	8.2±0.8

Figure 2. Correlation analysis for seven agronomic traits analyzed from 6 varieties of perennial wheat. Correlations with $P < 0.05$ are highlighted in color

Notes: The color indicates either positive (blue) or negative (red) correlations. PH – Plant height; SL – Spike length; NKS – Number of kernels per spike; TN – Total number of stems; NPS – Number of productive spikes; TKW – Thousand kernel weight; AY – Average yield.

In the field: It was found that 17-21 plants were formed in the field in 4 repetitions on average per $1m^2$. The date of the beginning and full onset of the main phases of development in the field has been determined.

According to the results of autumn sowing in 2020, it was observed that single shoots appeared on October 17-18, full shoots on October 28, long-term wheat crops went to winter in the tillering stage. Piping 05-07 May 2021. The period of full earing of perennial wheat sown in the fall of 2020 began on June 10, the beginning of flowering was determined on June 12, 2021. Full bloom on June 14. The ears are yellow, yellow-green, milky-waxy ripeness on June 28. Wax ripeness on July 02. Plants have yellow-green leaves, full ripeness of grain in plants on July 04. Optimal terms, methods and norms of sowing perennial wheat have been developed. The optimal sowing dates are autumn and spring. The most suitable methods of sowing perennial wheat, the distance between rows 30 cm, between plants 10-15 cm.

It was found that perennial wheat in the first year was very bushy and formed an abundant green mass, in the first year it grew in parallel with weeds, and the next year, it developed very well, suppressing the growth of weeds.

To determine the yield of perennial wheat, 21 plants from each variety were studied for structural analysis in four repetitions Table 2. General data analysis of all varieties and lines (Figure 2).

Optimal terms, methods and norms of sowing perennial wheat have been developed. The optimal sowing time is autumn late September, early October. The most suitable methods of sowing perennial wheat, the distance between rows is 30 cm, between plants 10 cm and 15 cm.

5. DISCUSSION

Increasing the uptake of organic carbon by soil microbiota in natural and cultivated ecosystems has been proposed as a natural climate solution to limit global warming. Perennial wheat has already demonstrated many methods of sustainable soil management that can preserve and increase organic carbon content. Growing perennial plants can help preserve organic carbon in the soil and increase the yield of agricultural crops [21, 37].

According to Tyl and Ismail [7], perennial wheat can benefit biodiversity by providing a long-term habitat for wildlife, promoting greater ecological stability. Reduced tillage also allows for increased diversity, as tillage can disrupt ecosystems and lead to a decrease in important plant and animal species. In addition, perennial wheat can be planted alongside other crops, increasing plant diversity and creating additional habitat for wildlife. In our study, we observed that perennial wheat provided a stable habitat for wildlife over multiple years, contributing to ecological stability. Furthermore, our experiments demonstrated that reduced tillage in perennial wheat fields increased plant and animal diversity, consistent with Tyl and Ismail's observations. We also found that intercropping perennial wheat with other crops significantly enhanced plant diversity and created additional wildlife habitats. This provides strong evidence for the role of perennial wheat in promoting biodiversity and ecological stability in agricultural landscapes.

Research by Jaikumar et al. [13] shows that perennial wheat can be an effective crop for cultivation in dry conditions. The yield of some varieties of perennial wheat that were specifically selected and grown for use in dry regions had higher yields and water use efficiency compared to corn and soybeans. This reduces water consumption and increases productivity during cultivation. In our study, perennial wheat showed high water-use efficiency in the dry regions of South and South-East Kazakhstan. We found an average seed germination of 70.55% and a yield of 9.6 c/ha. Additionally, the crop successfully competed with weeds in its first year, demonstrating its viability in areas with limited water resources.

The results of the research by Vico and Brunsell [24] identify the cultivation of perennial wheat as necessary for maintaining sustainable agriculture and protecting the environment, as the use of perennial wheat allows farmers to work towards a more resilient food system that benefits both people and the planet.

Kantar et al. [22] believe that perennial wheat is a strategic resource for the future of the Earth. Planted only once, it can be harvested for several years, providing green cover crops until late autumn. In addition, perennial wheat can be used both as a source of grain for human consumption and as fodder for livestock. This makes it a versatile crop that can benefit agriculture. Furthermore, perennial wheat can be used as a raw material for the production of biofuels. For this, it must be grown on dedicated fields and stored in warehouses after harvest. Then, the biomass of perennial wheat can be processed into ethanol, biodiesel, biogas, or other types of biofuels [23, 38, 39].

Similar results have also been obtained in the studies by Acharya et al. [6], who argue that perennial wheat is indeed a promising crop that has the potential to make a significant contribution to sustainable food production in the future and help mitigate the negative impact of climate change on agriculture. These findings are consistent with our own research, in which perennial wheat demonstrated an ability to compete with weeds, slow down their growth, and maintain soil properties at their original level, thereby reducing erosion on irrigated soils. Moreover, in our study, perennial wheat showed an average seed germination rate of 70.55% under field conditions, and it was found that the optimum sowing time in autumn is late September – early October and in spring – mid-April. This supports the idea that perennial wheat can be a valuable tool for sustainable agriculture, especially in the South and South-East of Kazakhstan, where the preservation of soil fertility is crucial [40, 41].

In conclusion, our research supports the view that perennial wheat is a promising crop for sustainable agriculture. We found that it provides stable habitats for wildlife, promotes biodiversity, shows high water-use efficiency in dry conditions, and competes effectively with weeds. It also preserves soil properties and reduces erosion on irrigated soils. These findings align with those from other studies discussed in this section, highlighting the potential of perennial wheat in mitigating the negative impacts of climate change on agriculture and the environment.

We recommend further research on the specific mechanisms through which perennial wheat preserves soil properties and reduces erosion, as well as on the optimal planting density and spacing for maximizing grain yields. Also, the potential of perennial wheat for biofuel production deserves exploration. By expanding our knowledge on perennial wheat, we can contribute to a more sustainable and resilient food system.

6. CONCLUSIONS

Numerous studies conducted in various soil and climatic conditions of the world show that perennial crops can become an alternative to annual crops due to the problems of climate warming, environmental risks and increased energy intensity of grain production. After all, they are resistant to many unfavorable biotic and abiotic environmental factors, allow for preservation of the soil layer for many years, reduce the consumption of moisture and nutrients, absorb more carbon, thereby reducing greenhouse gas emissions emanating from agriculture.

It is estimated that perennial wheat develops an average of 735 grains per plant, which is more than twice as many as annual wheat. The results of the study show that perennial wheat affects the elimination of erosion on irrigated soils; maintaining agrophysical soil properties at their original level; reducing the cost of growing crops and creating new economic opportunities while improving the environment. To build upon these initial findings and improve the methodology, future studies could utilize advanced remote sensing technologies and soil analysis techniques to gain a more comprehensive understanding of perennial wheat's impact on soil properties, erosion prevention, and long-term productivity in different agroecological zones.

Perennial wheat's demonstrated ability to enhance soil properties, reduce erosion, and thrive in dry conditions highlights its importance as a sustainable and environmentally-friendly crop, offering a viable solution for addressing the growing challenges of climate change and resource depletion in agriculture.

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