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Priority areas for the development of field fodder production in view of the climate crisis

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► **Abstract.** This article covers the topical issue of the general impact of climate change on Ukrainian agriculture and on the field fodder production industry specifically, as well as the problems of adapting agriculture to modern environmental conditions. The authors set out to substantiate promising ways of developing modern field fodder production considering climate change. For this, the study employed the abstract-logical method, system analysis, methods of systematisation and classification, and a range of economic and statistical research methods (comparison, series of dynamics, method of structural groupings). Both negative and positive manifestations of the climate crisis in crop production were highlighted, and possible measures to counteract risks and ways to use potential opportunities to develop field fodder production given the impact of climate change were systematised. Particular attention was paid to the global practices of agriculture in the face of climate change, namely, the components of a climate-smart crop production system. The study also described the main promising measures of adaptation of field fodder production to climate change: irrigation of agricultural land, arrangement of snow retention systems in the fields, rainwater harvesting, selection and introduction of new varieties of fodder crops, effective crop rotation, increase in sowing of drought-resistant

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fodder crops, optimisation of agricultural technologies to reduce losses of fodder crops at the stages of harvesting and storage, application of organic farming, the latest soil fertilisation technologies and the use of nanotechnology in soil cultivation. The findings of this study can be used by managers of specific agricultural enterprises, as well as by advisory services and government agencies in the field of agricultural policy implementation

► **Keywords:** fodder crops; climate change; irrigation; organic farming; sorghum

► Introduction

Many scientific studies have been conducted to investigate the state of the livestock and crop production sectors in various economic entities and to substantiate possible prospects for their development in the context of climate change. Ukrainian scientists are studying the impact of climate change on agriculture and proposing adaptive agricultural measures. S.P. Ivanyuta *et al.* (2020) consider the main manifestations of the impact of climate change on various sectors of the national economy and factors of fodder production: land and water resources, energy efficiency of agriculture. L. Melnichenko & A. Bondarenko (2021) focus on various adaptive mechanisms of agrocenoses to modern climatic conditions. V.M. Pysarenko *et al.* (2020) describe the best agricultural technologies that can be applied in conditions of moisture deficit. Y. Yarochnenko (2022) describes promising areas of energy-saving agricultural production. However, these and other studies reflect the specific features of adaptive farming in the field of crop or livestock production, while the issues of field fodder production and priority areas of development of this industry considering the climate crisis are understudied. V.F. Petrychenko *et al.* (2018), considering promising avenues of developing fodder production, focus on adaptive technologies for growing fodder crops and breeding new varieties, but they lack the consideration of the modern climatic reality.

Foreign scientists are also researching climate change adaptation at the level of agriculture in general, not in the field of fodder production. N.P. Simpson *et al.* (2023) offer detailed research on the risks associated with climate change. Specifically, these are the risks of lower crop yields, complete loss of crops, and higher production costs in the agricultural sector. W. Elnashar & A. Elyamany (2023) focus on the problems of water scarcity and the need for irrigation on agricultural land in the new climate conditions. The current trends in temperature and water supply, and the frequency of abnormal weather conditions that can affect agriculture were also described (IPCC, 2022).

Since the 2000s, significant environmental and climatic changes have been observed around the world, affecting not only the well-being of the population, but also changes in animal behaviour and territorial boundaries, and disruption of plant habitats. Climate change is also having a considerable impact on human economic activity. The effects of this impact are particularly pronounced in crop production and field fodder production, as crops are sensitive to natural and climatic factors.

Ukraine is facing the challenge of optimising its fodder production model and finding effective solutions to counteract the adverse impact of natural and climatic factors. This requires, on the one hand, the adoption of measures to achieve the goals of adaptation to climate change, and, on the other hand, the implementation of measures

aimed at reducing the adverse impact of field fodder production on the natural and climatic state of the environment. The purpose of this study was to identify promising ways to develop field fodder production in the context of climate change. This purpose requires completing a range of research objectives: to identify the positive and negative effects of climate change in field fodder production; to investigate the mechanisms of climate change impact on the industry; to propose measures to counteract the adverse impact of climate change in the field of fodder production and areas for the effective use of the positive impact of climate change.

► Materials and Methods

Proceeding from the purpose of this study and its objectives, the appropriate materials and the best research methods were employed. The research materials can be systematised into several main groups: regulatory sources, specifically, the Law of Ukraine "On Land Lease" (Law of Ukraine No. 161-XIV..., 1998), the Strategy for the Restoration and Development of Irrigation and Drainage Systems in Ukraine until 2030 (Decree No. 688-p..., 2019), etc., data from theoretical and practical scientific research (monographs, publications in specialised literature, Internet publications), statistics on climate change, trends in the decline in fodder crop yields (Agriculture, forestry and fisheries, n.d.), forecast data provided by experts from specialised organisations (Ivanyuta *et al.*, 2020). Essential research materials included statistical data on the share of irrigated land in Ukraine and in some countries of the world (both Asian and European), on the area of sorghum crops in Europe and in Ukraine (Agriculture, forestry and fisheries, n.d.). An equally essential group of materials included the findings of scientific experimental studies and practical observations that allow comparing the yield of individual fodder crops with each other when grown under the same weather and climate conditions, the yield of the same crop when grown at different temperatures and water availability, etc.

In preparing this study, the method of analysis was primarily used, which elaborates on theoretical provisions on climate change and its impact on various spheres of society, specifically, on the agricultural sector, and examines possible areas of investment. Using the synthesis method, the areas of further development strategy of field fodder production were formed and the main ideas and vectors of development of scientific thought on the impact of climate change on agriculture and vice versa were formulated. The theoretical and methodological provisions of the subject under study were summarised using a systematic analysis. Agro-climatic processes are considered as a single interdependent system of elements: on the one hand, the cultivation of fodder crops and their yields are

closely dependent on weather and climate conditions; on the other hand, field fodder production affects the climate. The mechanisms of climate change impact on field fodder production were studied using the methods of systematisation and classification, which allowed identifying direct and indirect, as well as positive and negative impacts. Similarly, the areas of meeting the growing demand for fodder were systematised, with extensive and intensive ways of doing so identified. Statistical data were processed and analysed using economic and statistical research methods (comparison, time series, method of structural groupings). Thus, the comparison method made it possible to identify the most productive fodder crops when grown under dry conditions. The comparison also helped to assess the fodder value of certain crops, such as maize and sorghum. The time series method helped to track changes in statistical data over the relevant period of time. The method of structural groupings made it possible to characterise the share of certain aggregates (e.g., the share of irrigated land among

all agricultural land in Ukraine and the world). For effective perception of statistical data and research results, tabular and graphical methods of visualisation of materials were used. The abstract and logical method was used to interpret the data in the statistical tables.

► Results and Discussion

The impact of climate change on field fodder production is quite complex and multidirectional, and it is possible to form positive and negative aspects of such an impact. Depending on the concrete situation, either the negative or the positive impact of climate change may prevail. However, scientists have already proven that the negative effects of climate change are more pronounced (Table 1).

Table 1 shows the direct effects of climate change on the field fodder industry. However, there is also an indirect impact that takes place through other sectors of agriculture. The primary mechanisms of such influences are summarised in Figure 1.

Table 1. Positive and negative effects of climate change in field fodder production

Negative manifestations	Positive manifestations
Decreased fertility and deterioration of soil conditions	longer growing season for growing fodder crops
Reduced yields of fodder crops	shifting the growing areas of heat-loving fodder crops to the north
increased activity of agricultural pests, increased frequency of fodder crop diseases	better conditions for wintering biennial and perennial fodder crops
frequent droughts and floods	increase in the yield of cereal fodder crops under the influence of an increase in the concentration of carbon dioxide in the atmosphere

Source: compiled by the authors of this study using data from L. Melnichenko & A. Bondarenko (2021)

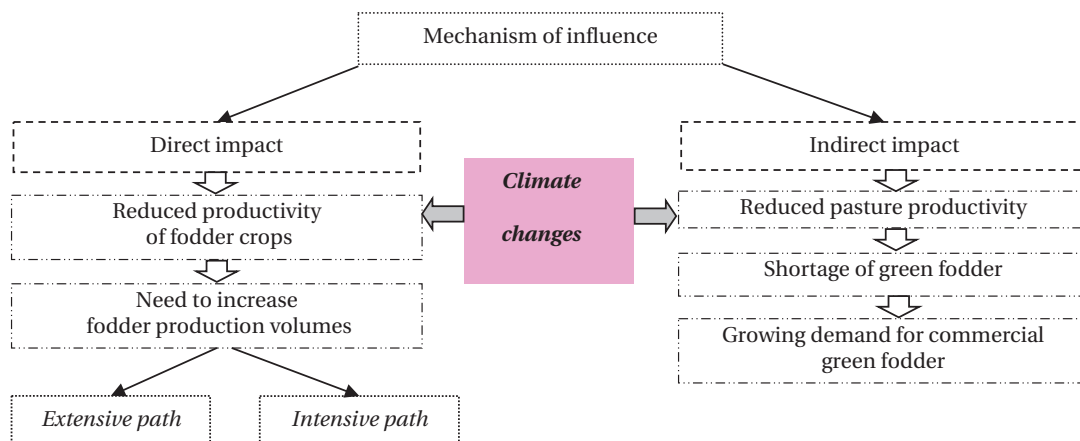


Figure 1. Mechanisms of climate change impact on the field fodder industry

Source: compiled by the authors of this study based on research by L. Melnichenko & A. Bondarenko (2021); Y. Yarochnenko (2022)

As presented in Figure 1, from an economic perspective, the impact of climate change on commercial field forage production is positive, as it creates additional demand for fodder. This is due to a possible shortage of green fodder in livestock production. According to research by Y. Yarochnenko (2022), small agricultural enterprises use more than 30% of green fodder in the overall feeding structure, while large agricultural enterprises use about 15%. Based on these data, it can be concluded that

the emergence of a shortage of this fodder component will increase the demand for commercial fodder and stimulate commercial field fodder production.

In such circumstances, agricultural enterprises are faced with the task of choosing a path for further development:

- 1) The extensive path requires an increase in the area under fodder crops;
- 2) The intensive path involves achieving the goals of increasing the yield of fodder crops (using new varieties,

new crops, optimisation of nutrition and moisture for fodder crops, etc.)

The extensive way of further development of fodder production has its obstacles at various levels of management: at the level of an individual enterprise, region or state, an increase in the area of farmland under fodder crops will lead to a loss of sown area for grain crops, which are traditionally the most profitable, in high demand,

and exported outside Ukraine, forming its solvency. That is why the extensive development of fodder production is not promising at present. Accordingly, measures to intensify field fodder production are needed. They can be aimed at reducing the negative impact of climate change or at more efficiently harnessing its positive effects on the industry under study. The most popular and effective ways to reduce the adverse impact are summarised in Table 2.

Table 2. Ways to counteract the adverse impact of climate change in the fodder industry

Adverse impact	Countermeasures
1	2
Decrease in soil fertility	1) measures to improve soil fertility: - application of the latest soil fertilisation technologies; - use of nanotechnologies for soil cultivation; - state control of soil quality. 2) growing fodder crops that are less demanding on soil fertility
Reduction in overall crop productivity	1) optimisation of breeding work: - breeding fodder crops with high productivity and adapted to modern climatic conditions; - use of varieties previously grown in more arid regions; 2) growing new fodder crops; 3) reduction of losses of fodder crops during harvesting and storage
Increased spread of crop pests and diseases	1) growing crops and varieties resistant to pests and diseases; 2) application of pest and disease control measures
Increased frequency of extreme events related to water resources	1) growing drought-resistant crops and varieties; 2) installation of irrigation systems; 3) arranging snow retention systems on the fields and rainwater collection

Source: developed by the authors of this study based on research by S. Baliuk *et al.* (2017); Y. Yarochnenko (2022)

As for the issue of soil fertilisation, there are two opinions in scientific sources on the feasibility of applying different soil fertilisation schemes in the context of climate change:

1. *The first opinion is to optimise the application of mineral fertilisers.* For instance, this idea is supported by S. Baliuk *et al.* (2017). Scientists note that in the context of climate change, it is necessary to increase the volume of phosphorus and potash fertilisers rather than nitrogen fertilisers. Rising temperatures and decreasing humidity, which currently accompany climate change, limit the rate of nutrient movement in fodder crops, while slowing the growth of their root system. And in conditions of water shortage, it is the branched root system that contributes to the normal development of plants. For its formation, the presence of mobile forms of phosphorus in the soil is important. Therefore, the application of phosphate fertilisers helps to optimise the root nutrition of fodder crops, which considerably increases their access to soil moisture and improves water consumption of crops even under conditions of unstable moisture. As a result, the adverse impact of climate change is reduced, and the productivity of fodder crops stays high. These effects of phosphate and potash fertilisers were proven experimentally. Practical experiments have shown that the amount of bound water, which determines the resistance of crops to high temperatures and drought, increases by 12-50% when phosphate-potassium fertilisers are applied to the soil. Scientific research suggests that phosphorus fertilisers contribute to better root development, while potassium fertilisers improve moisture use in conditions of moisture

deficit through more intensive development of both leaves and roots of forage crops (Baliuk *et al.*, 2017).

2. *The second opinion is that in the context of climate change, it is necessary to minimise mineral fertilisers and replace them with organic ones.* For instance, many countries, especially Germany, France, the Netherlands, Poland, etc., are already actively practising a system of agriculture called CSA (Climate Smart Agriculture) (Ivanyuta *et al.*, 2020). This system is aimed not only at adapting agribusiness to the new conditions associated with climate change, but also at minimising the adverse impact of agriculture on the environment. Achieving these goals involves a system of measures, including special methods of mechanical soil cultivation, optimisation of waste management, revegetation, soil reclamation on pastures, optimisation of manure storage and use, energy saving measures, decarbonisation, transition to growing more drought-resistant and high-yielding crop varieties, silvicultural reclamation, etc. The most common use of CSAs is in organic production (Ivanyuta *et al.*, 2020). V. Radulescu *et al.* (2021) also discuss the prospects for the development of this agricultural technology. Scientists note the growing demand for organic agricultural products and, at the same time, the positive impact of organic farming on the climate. Specifically, this technology involves the use of organic fertilisers. The main mechanism of this farming system's impact on the general adaptation to climate change in agriculture, and fodder production specifically, is associated with an increase in the water resistance coefficient of structural units. According to V.M. Pysarenko *et al.* (2020), in the case of an

organic farming system, it reaches 10%, while in an intensive farming system it is only 5.2%. The main effects of organic farming in field fodder production are determined by the effects described in the study by L. Datsko (2018): an increase in humus content; improvement of soil structure and reduction of soil acidity; saturation of soils with macro- and microelements, phytohormones, enzymes, and amino acids; and improvement of plant access to carbon dioxide. Apart from changing approaches to fertilisation to counteract the negative impact of climate change, it is important to use efficient crop rotations with fodder crops in them, as most of them can restore soil fertility by increasing humus content, improve soil nutrient and moisture supply, and improve physical properties and soil structure. Grow How company experts note that green manure is the most effective in this aspect, as it provides increased biological activity, loosening of the topsoil, reducing its acidity, increasing sunlight reflection and, accordingly, preventing overheating of the earth (Soil moisture: How to measure and preserve, 2021).

A considerable part of agricultural land in Ukraine is currently leased under the Law of Ukraine "On Land Lease" (Law of Ukraine No 161-XIV..., 1998). Lessees are not interested in investing in measures to restore and maintain land fertility. In most cases, the indicators of soil fertility changes during the term of the lease are not monitored. Therefore, the factual user of the leased land plot (the lessee) is not motivated to improve soil fertility, especially if they plan to lease and use the land for a short time (several years). As a result, after the lease expires, the lessor (most often a citizen, land plot or share owner) receives extremely depleted land with extremely low soil fertility. Sustainable agricultural land use requires information on the quality of agricultural land and soil fertility. For instance, currently in Ukraine, land leases are carried out without the obligatory accompaniment of an agrochemical passport for a land plot. The absence of a passport for an agricultural land plot has a negative impact on the efficiency of land use. The depletion of land should be punishable by fines, and the improvement of its condition should be stimulated by benefits, etc. That is why N.A. Sprynchuk (2011) emphasises the need for mandatory control over land quality by the state, as this will have a generally positive impact on the condition of soils. Combining information about soil conditions and field forage production is possible using intelligent digital technologies that surpass human capabilities. As noted by N.P. Simpson *et al.* (2023), risk and uncertainty are increasing, and climate change, limited availability and cost of resources, and market volatility are constraining decision-making by both policy makers and farmers. These trends are leading to a new era in which digital technologies make it possible to control both the condition of the soil and the condition of agricultural plants, and their combination creates the possibility of obtaining stable yields.

The prospects for counteracting the negative impacts of climate change in field fodder production are also significant in the field of breeding. It is relevant to develop new varieties and hybrids of fodder crops that are highly resistant to temperature fluctuations and moisture deficit. The authors of this study agree with S. Baliuk *et al.* (2017) that for early crops, the rapid growth of the root system

and aboveground biomass becomes a particularly vital feature, which creates opportunities for the rapid development of fodder crops during the period when the soil still has sufficient moisture content. According to M. Aksaniuk (2021), the specialists of the Institute of Plant Breeding and Genetics have been conducting adaptive crop breeding for a long time. Over the past 15 years, they have developed and entered 183 varieties and hybrids of winter wheat, winter and spring barley, sunflower and maize, peas and soybeans, chickpeas and sorghum, alfalfa and sainfoin into the state register. These data indicate that breeding is quite active not only for grain crops, but also in fodder production. Many of the new varieties are not only characterised by high yields and short ripening periods but are also drought and frost resistant. They are being successfully tested in Ukraine and in other countries (Spain, Romania, France, Turkey, Georgia).

Using the results of breeding work to develop early-ripening varieties that are highly resistant to sudden changes in temperature, moisture deficit or excess, one can harvest twice a year. Thus, after harvesting winter barley or wheat in July, it is recommended to sow early maturing hybrids of soybeans, sunflower, millet, and fodder crops. This practice has long been used by agribusinesses in Israel, Turkey, and other countries with challenging climatic conditions. In these countries, agriculture requires irrigation, and it is the harvesting of crops twice a year that makes it profitable (Aksaniuk, 2021).

Agrotechnical measures should also be an essential part of counteracting the negative impact of climate change in field fodder production. To adapt to climate change, agricultural enterprises must introduce modern technologies and methods of growing fodder crops. First of all, this concerns measures to accumulate and save water from precipitation and soil moisture, as water regime is a major factor of fertility, which is primarily affected by climate change. At the same time, as noted by S. Baliuk *et al.* (2017), it is considered a difficult to control factor, as it depends on natural features: the amount of precipitation (which can be considerably reduced in the context of climate change), soil properties in terms of moisture retention (deteriorates with a decrease in humus, disruption of soil structure), unproductive water losses through evaporation, and increased surface or infiltration runoff.

The main measure to counteract droughts and other extreme effects of climate change related to water resources is the development of irrigation systems. This is an agricultural technology that has a direct impact on the negative environmental factor in the context of climate change, compensating for the shortage of natural moisture, ensuring sufficient water supply by redistributing water from places of its availability to agricultural land. Therewith, irrigation becomes effective only in combination with other agrotechnical measures: the use of appropriate tillage systems, adherence to best fertilisation schemes, chemical reclamation, weed and pest control, etc. S.P. Ivanyuta *et al.* (2020) acknowledge that in the context of climate change, an increase in the area of irrigated land is necessary for climate-optimised agriculture. Such recommendations are relevant for temperate countries, including Ukraine, which may face water shortages as a result of climate change. Therefore, with the support of the World Bank

and the Food and Agriculture Organisation of the United Nations (FAO), the Strategy for the Restoration and Development of Irrigation and Drainage Systems in Ukraine until 2030 was developed for Ukraine (Decree No. 688-p..., 2019). It is intended to create an effective mechanism for the provision of irrigation and drainage services to ensure efficient agriculture in the country (Baliuk *et al.*, 2017).

T. Zinchuk *et al.* (2021) emphasises the multidirectional trends of land reclamation processes in Ukraine and in the world. Thus, considering the climate change, the area of irrigated land on a global scale is growing by 1% annually, while in Ukraine this figure has decreased by 70% over the

past 20 years. And this is despite the fact that irrigation is one of the primary factors that reduces the dependence of agribusiness on natural moisture supply and creates conditions for increasing crop yields. According to the scientist, the efficiency of the yield increase from growing oil-seeds under irrigation compared to the average is 6.9 c/ha. In the case of soybean cultivation under irrigation, the yield increase is the highest – 9.4 c/ha, while sunflower is 4.9 c/ha. As of 2022, the area of irrigated land in the world is about 300 million ha. The share of irrigated land in some Asian countries exceeds 40%, while in Ukraine this figure reaches only 1.1% (Fig. 2).

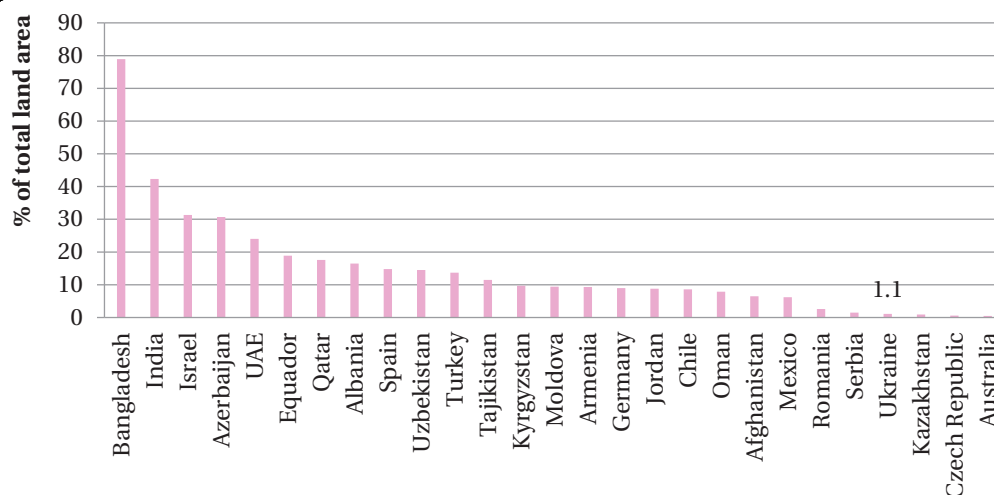


Figure 2. Share of irrigated land in selected countries in 2022

Source: compiled by the authors of this study based on data Agricultural irrigated land (% of total agricultural land) (n.d.)

In Ukraine, the area of available irrigated land, according to the State Agency of Water Resources, is about 2.17 million ha, of which only a quarter – 505 thousand ha – is actually irrigated (State water cadastre...,

n.d.). In 2020-2022, irrigation volumes decreased significantly: while in 2020, 1,452 million m³ of water was used for these purposes, in 2022, only 143 million m³ was used (Fig. 3).

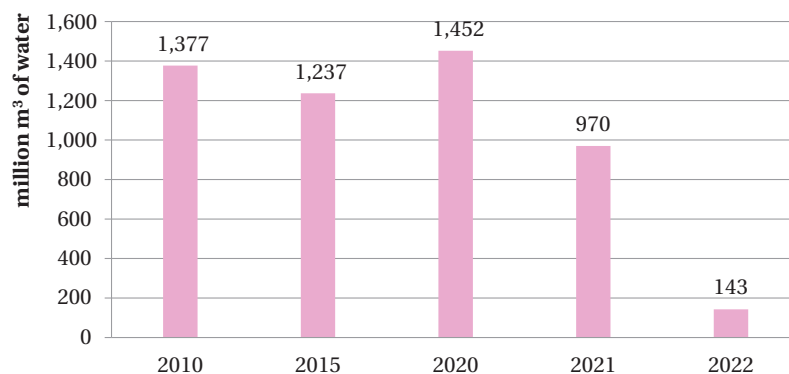


Figure 3. Water consumption for irrigation in Ukraine in 2010-2022

Source: compiled by the authors of this study based on Environment (n.d.)

Therefore, irrigation of land is quite relevant for Ukrainian farmers. But this requires considerable investment. The expansion of irrigated areas will cost the farmer about USD 2.6 thousand per hectare. Even with the losses farmers face as a result of droughts, they are not ready to invest in irrigation facilities, as about 90% of farmers grow crops on leased land while the moratorium on land

sales continues. Without confidence in the possibility of extending leases or purchasing land in the strategic period, agribusinesses are not ready to invest in long-term irrigation projects (Zinchuk *et al.*, 2021). Accordingly, it is more promising for lessees and most landowners in Ukraine to use the positive impact of climate change on the development of field fodder production (Table 3).

Table 3. Ways to utilise the positive impact of climate change in the fodder industry

Positive impact	Effective use of the factor
increase in the length of the growing season	1) growing two harvests of agricultural crops; 2) shifting the timing of agrotechnical measures; 3) growing new fodder crops
Extension of the zone for growing heat-loving crops to the north	Growing varieties of fodder crops previously used in the southern territories
Optimisation of the physiological state of field crops in winter	Optimisation of crop care in winter

Source: compiled by the authors of this study based on research by L. Melnichenko & A. Bondarenko (2021); Y. Yarochnenko (2022)

As Table 3 suggests, one of the most positive impacts of climate change on field fodder production is the increase in the length of the growing season. As noted by N. Honcharova & H. Meluta (2022), in Ukraine in 2022, compared to the 2000s, the duration of the active growing season has already increased by an average of 10 days. The forecasts until 2030 suggest that the period of growth and development of heat-loving crops will be extended by another 10 days. The Polissya and Forest-Steppe regions are warming faster than the steppe regions. Winter temperatures increased by 1.5-2°C, and the depth of soil freezing decreased to 20-70 cm, which is a favourable factor for the absorption of winter precipitation and the formation of sufficient soil moisture in spring. To make more efficient use of the growing season length factor, it is possible to, firstly, expand sown areas for species and varieties of fodder crops with a short growing season, which will allow for two to three harvests of individual crops; secondly, shift the sowing dates of spring crops to earlier and winter crops to later dates, which will ensure efficient use of soil moisture reserves by crops and create prospects for soil optimisation between spring and winter crops; thirdly, grow new fodder crops with a long growing season.

As noted by L. Hrustek (2020), agriculture, including field forage production, is faced with the challenge of growing more, polluting less, and distributing better (supply chain optimisation). Given the climate crisis, special attention should be paid to finding new fodder crops that can be grown in new climatic conditions. According to forecasts, climate change in the coming years will be manifested by a decrease in air temperature in the cold season and an increase in the warm season. Therewith, the amount of precipitation will decrease. It is expected that over the next 40-50 years, the climate in southeastern Ukraine will become more continental, which will be manifested by a decrease in humidity. Given these trends, a decline in the profitability of growing some conventional crops can be predicted. To solve this problem, M. Prybuzkyi (2018) recommends selecting crops that are characterised by high drought resistance, productivity, and versatility of use.

L.O. Udova *et al.* (2014), following Stanford University researchers, point out that global warming will result in a decline in grain yields (specifically, wheat and barley) in European crop production over the next decades. By 2040, the figure is expected to decline by more than 20%. Maize is also expected to fall by at least 10%. Scientists argue that wheat and barley are more sensitive to rising temperatures in the face of climate change, while growing corn using irrigation technologies or using adapted

varieties will reduce the negative impact of warming on crop productivity. According to R. Vignola *et al.* (2022), ecosystem-based adaptation (EbA) methods effectively address the problem of climate change in the cultivation of crops (maize, legumes, etc.). Optimisation goals can be achieved by building on the biodiversity of ecosystem resources and processes that may be available to farmers (e.g., the use of trees in agroforestry systems). FAO experts recommend active planting of forest strips to retain additional moisture, reduce the heating of the Earth's surface, preserve the fertile soil layer, etc.

There are also prospects for increasing maize production, subject to best agronomic practices. In countries experiencing climate change (USA, China, India), full-melt film water collection along ridge furrows is used. According to T.-I. Fan *et al.* (2023), the technology is a staple in maize cultivation in arid regions of many countries and is generally widely used to cope with hot climates.

Maize (as well as fodder beet) is a typical plant of the second group, which is characterised by resistance to hot temperatures. Under such conditions, they are more efficient in photosynthesis. In the context of climate change, which is accompanied by an increase in CO₂ concentration in the air, rising air, and soil temperatures, maize uses nitrogen more actively in photosynthesis. Scientific sources indicate that maize yields decline with increasing CO₂ concentrations in the atmosphere, but this is still more influenced by changes in the thermal regime. Up to a certain point, rising temperatures have a positive effect on maize productivity. Therefore, scientists predict an increase in the yield of this fodder crop when grown in Ukraine in the near future (To protect arable land in Ukraine..., 2021). In contrast, fodder beet is more sensitive to the amount of moisture in the air and soil. The need for it is especially high in March-April. A 10% change in soil moisture levels compared to optimal values causes a 20-25% decrease in fodder beet yields (Udova *et al.*, 2014). Therefore, the cultivation of this fodder crop must either be moved to the north or provided with an irrigation system.

In the context of climate warming, an essential area for the development of field fodder production is the increase in the sown area of fodder crops that are highly resistant to high temperatures and moisture deficit. Sorghum looks promising in this regard. Even in case of a severe drought, the crop does not perish, but only stops growing. After rainfall, the plant continues to grow. Due to its heat tolerance and resistance to drought, sorghum is grown on different continents: in India, the area under the crop reaches 12 million ha, in Africa – 21 million ha, and in the United States – 3.6 million ha (Prybuzkyi, 2018).

As a fodder crop, sorghum provides various types of fodder for farm animals. This includes grain, green fodder, silage, and hay. Accordingly, sorghum is considered an alternative to growing maize, which is traditionally the main silage crop for Ukrainian fodder production and a component of mixed fodder. Grain sorghum, sugar sorghum, and sorghum-sudangrass hybrid are used to feed livestock. Grain sorghum is used as a fodder, food, and industrial crop, and is included in fodder for pigs, cattle, poultry, and horses. The advantage of sorghum grain is its high nutritional value (nutritional value of 1 kg of grain is up to 1.3

fodder units). Its composition is as follows: up to 15% protein, up to 4.5% fat, up to 70% starch, up to 5% fibre, up to 2.5% lysine, and up to 1.9% methionine (Prybuzkyi, 2018). Considering these advantages of sorghum, Europe is implementing an action plan to promote this fodder crop. As a result, in 2018-2020, the area under sorghum in Europe increased, which led to an increase in its production. Although this figure declined in 2021-2022, in 2023 there was a trend towards an increase in the area under the crop again. In Ukraine, against the backdrop of the war, a negative trend is observed in 2022 (Fig. 4).

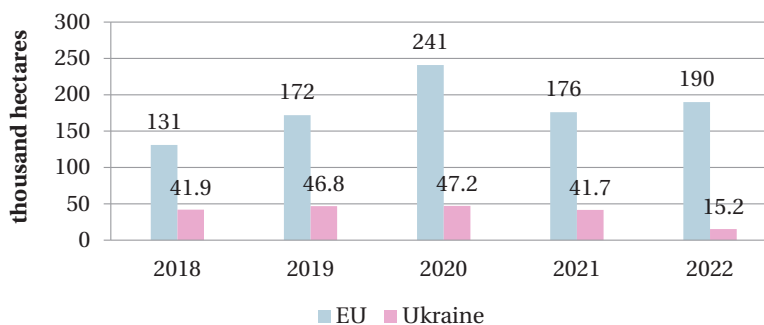


Figure 4. Sorghum planted areas and gross harvest in Europe and Ukraine in 2018-2022

Source: compiled by the authors of this study based on Productivity data. Sorghum is reliable (n.d.); USDA (2022); Agriculture, forestry, and fisheries (n.d.)

The development of fodder production in the context of climate change requires concrete optimisation measures that would offset the negative impact of external factors. At the same time, optimisation of agrotechnical measures can contribute to a more active use of the positive effects of climate change for field fodder production. This should also be considered, although most scientists focus only on the adaptation of agriculture to the negative factors of the climate crisis. Attention is also rarely paid to the opposite process – the risks of negative environmental impacts of fodder production. To minimise them, it is advisable to introduce energy efficiency measures, switch to renewable energy sources, improve the efficiency of waste recycling, etc. Globally and in Ukraine, such projects are promoted by governments, local authorities, and individual commercial entities. The activities of financial intermediaries that encourage investment in energy-saving technologies have a positive impact on the promotion of such measures in field fodder production. Ukrainian banks support environmental investment projects of agribusinesses by offering preferential lending rates, specifically under the government programme “Affordable Loans 5-7-9” (Strategy of the Ukraine’s..., 2023). Thus, field fodder production is dependent on the climate crisis, and with proper practical functioning of this industry, adverse environmental consequences and impact on climate change can be minimised.

► Conclusions

The study made it possible to describe and systematise the mechanisms of climate change impact on field fodder production. Among the consequences of this impact are negative ones (reduced fertility and deterioration of soil conditions; reduced yields of fodder crops; increased activity of agricultural pests, increased frequency of diseases

of fodder crops; frequent droughts and floods) and positive ones (longer growing season for fodder crops; shifting the growing zones for heat-loving fodder crops to the north; better conditions for wintering biennial and perennial fodder crops; increased yields of grain fodder crops due to the increase in carbon dioxide concentration in the atmosphere). The agrotechnical impact of climate change is mostly negative, but the economic consequences are manifested in an increase in demand for fodder crops, i.e., stimulating the development of field fodder production. The negative impacts will be counteracted by irrigation systems, growing new fodder crops or new varieties of already popular plants, using optimal crop rotations, planting forest belts, etc. Global experience shows the effectiveness of irrigated field fodder production, but in Ukraine the share of irrigated land is only 1.1%, while in Germany it is 9%, Moldova – 9.4%, Turkey – 13.7%, etc. Partial replacement of maize crops with drought-resistant sorghum is also promising in the face of climate change. In the EU, the area under this crop is about 200,000 ha, while in Ukraine, in the pre-war period, this figure exceeded 40,000 ha, but decreased considerably in 2022.

In turn, field fodder production also has a negative impact on the environment and climate. The mechanism of such impact can be direct (field destruction, waste pollution, etc.) and indirect (through livestock incentives). Therefore, the prospects for the development of fodder production in the new economic environment require not only adaptation to climate change, but also reduction of the industry’s negative impact on the environment. Modern technologies for processing organic waste from field fodder production with a focus on energy production or high-performance compost, ways to reduce fuel consumption in fodder production, etc., the use of smart

technologies, and robotisation of the industry need to be investigated. The problems of financing measures to adapt fodder production to new climate conditions also require more in-depth research.

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► Conflict of Interest

The authors of this study declare no conflict of interest.

► References

- [1] Agricultural irrigated land (% of total agricultural land). (n.d.). Retrieved from <https://data.worldbank.org/indicator/AG.LND.IRIG.AG.ZS>.
- [2] Agriculture, forestry and fisheries. (n.d.). Retrieved from https://www.ukrstat.gov.ua/druk/publicat/kat_u/publ7_u.htm.
- [3] Aksaniuk, M. (2021). "Anatolii Polovyi: "Climate change forces agrarians to choose: Technological renewal or abandonment". Retrieved from <https://ukurier.gov.ua/uk/articles/anatolij-polovij-klimatichni-zmini-diktuyut-agrari/>.
- [4] Baliuk, S., Vorotyntseva, L., & Zakharova, M. (2017). Sustainable management of soil resources for adaptation to climate change. *Visnyk of the Lviv University. Series Geography*, 51, 3-10. doi: 10.30970/vgg.2017.51.8732.
- [5] Datsko, L. (2018). *Seven advantages of organic fertilizers over mineral ones*. Retrieved from <https://integro.co.ua/sim-perevag-organichnyh-dobryv-pered-mineralnymy/>.
- [6] Decree No 688-p "On the Approval of the Irrigation and Drainage Strategy in Ukraine for the Period up to 2030". (2019, August). Retrieved from <https://zakon.rada.gov.ua/laws/show/688-2019-p#Text>.
- [7] Elnashar, W., & Elyamany, A. (2023). Managing risks of climate change on irrigation water in arid regions. *Water Resources Management*, 37, 2429-2446. doi: 10.1007/s11269-022-03267-1.
- [8] Environment. (n.d.). Retrieved from https://www.ukrstat.gov.ua/druk/publicat/kat_u/publnav_ser_u.htm.
- [9] Fan, T.-l., Li, S.-z., Zhao, G., Wang, S.-y., Zhang, J.-j., Wang, L., Dang, Y., & Cheng, W.-l. (2023). Response of dryland crops to climate change and drought-resistant and water-suitable planting technology: A case of spring maize. *Journal of Integrative Agriculture*, 22(7), 2067-2079. doi: 10.1016/j.jia.2022.08.044.
- [10] FAO. (2020). *Practical guide for implementing models of effective management of field protection forest strips*. Kyiv: FAO.
- [11] Honcharova, N., & Meluta H. (2022). [Impact of climate change and extreme climatic events on agricultural development in the Polissia region](#). In *Climate change and agriculture. Challenges for agricultural science and education: Materials of the V international scientific and practical conference* (pp. 40-43). Kyiv: Scientific and Methodological Center of the Ministry of Education and Science of Ukraine.
- [12] Hrustek, L. (2020). Sustainability driven by agriculture through digital transformation. *Sustainability*, 12(20), article number 8596. doi: 10.3390/su12208596.
- [13] IPCC. (2022). *Climate change 2022: Impacts, adaptation and vulnerability. Contribution of working group II to the sixth assessment report of the intergovernmental panel on climate change*. In H.-O. Pörtner et al. (Eds.). Cambridge: Cambridge University Press. doi: 10.1017/9781009325844.
- [14] Ivanyuta, S.P., Kolomiets, O.O., Malinovska, O.A., & Yakushenko, L.M. (2020). *Climate change: Consequences and adaptation measures*. Kyiv: NISS.
- [15] Law of Ukraine No 161-XIV "On the Land Lease". (1998, October). Retrieved from <https://zakon.rada.gov.ua/laws/show/161-14#Text>.
- [16] Melnichenko, L., & Bondarenko, A. (2021). [Impact of climate change on the functioning of agrocenoses](#). In *Climate change and agriculture. Challenges for agricultural science and education: Materials of the IV international scientific and practical conference* (pp. 63-65). Kyiv: Research and Methodological Center for VET.
- [17] Petrychenko, V.E., Kornijchuk, O.V., & Zadorozhna, I.S. (2018). Formation and development of fodder production in Ukraine. *Bulletin of Agricultural Science*, 11, 54-62. doi: 10.31073/agrovisnyk201811-08.
- [18] Productivity. Sorghum is reliable. (n.d.). Retrieved from <https://www.sorghum-id.com/uk/%D0%BF%D1%80%D0%BE%D0%B4%D1%83%D0%BA%D1%82%D0%B8%D0%B2%D0%BD%D1%96%D1%81%D1%82%D1%8C-%D1%81%D0%BE%D1%80%D0%B3%D0%BE-%D1%86%D0%B5-%D0%BD%D0%B0-%D0%B4%D1%96%D0%B9%D0%BD%D0%BE/>.
- [19] Prybuzkyi, M. (2018). *Sorghum in cattle feeding. The Ukrainian Farmer*, 6.
- [20] Pysarenko, V.M., Pysarenko, V.V., & Pysarenko, P.V. (2020). *Management of agrotechnologies under drought conditions*. Poltava: NGO "Poltava Agricultural Society".
- [21] Radulescu, V., Cetina, I., Cruceru, A.F., & Goldbach, D. (2021). Consumers' attitude and intention towards organic fruits and vegetables: Empirical study on romanian consumers. *Sustainability*, 13(16), article number 9440. doi: 10.3390/su13169440.
- [22] Simpson, N.P., et al. (2023). Adaptation to compound climate risks: A systematic global stocktake. *iScience*, 26(2), article number 105926. doi: 10.1016/j.isci.2023.105926.
- [23] Soil moisture: How to measure and preserve. (2021). Retrieved from <https://www.growhow.in.ua/voloha-hruntu-iaak-vymiriatiy-ta-zberehty/>.

- [24] Sprynchuk, N.A. (2011). *Investment support for the development of soil fertility conservation system* (PhD dissertation, National Scientific Center "Institute of Agrarian Economics", Kyiv, Ukraine).
- [25] State Water Cadastre: Accounting of surface water objects. (n.d.). Retrieved from <http://geoportal.davr.gov.ua:81>.
- [26] Strategy of the Ukraine's agricultural sector development. (2023). Retrieved from <https://minagro.gov.ua/en/investoram/strategy-ukraines-agricultural-sector-development>.
- [27] To protect arable land in Ukraine, it is necessary to create 660 thousand hectares of forest belts. (2021). Retrieved from <http://agro-business.com.ua/agrobusiness/item/21886-dlia-zakhystu-ornykh-zemel-v-ukraini-potribno-stvoryty-660-tysiach-ha-lisosmuh>.
- [28] Udova, L.O., Prokopenko, K.O., & Didkovska, L.I. (2014). *The impact of climate change on the development of agricultural production*. *Economy and Forecasting*, 3, 107-120.
- [29] USDA. (2022). *EU Grain Summer Update 2022 (E42022-0053)*. Madrid.
- [30] Vignola, R., Esquivel, M.J., Harvey C., Rapidel, B., Bautista-Solis, P., Alpizar, F., Donatti, C., & Avelino, J. (2022). Ecosystem-based practices for smallholders' adaptation to climate extremes: Evidence of benefits and knowledge gaps in Latin America. *Agronomy*, 12, article number 2535. doi: 10.3390/agronomy12102535.
- [31] Yarochno, Y. (2022). *Sustainable development: Environmental protection. Energy efficiency. Balanced natural resource management: Collective monograph*. In M. Malovanyi (Ed.). Kyiv. doi: 10.51500/7826-07-0.
- [32] Zinchuk, T., Kutsmus, N., Usiuk, T., Kovalchuk, O., & Zaburanna, L. (2021). Inclusive development of the world countries under conditions of globalisation: Models and arguments. *Scientific Horizons*, 24(6), 81-91. doi: 10.48077/scihor.24(6).2021.81-91.

Пріоритетні напрями розвитку польового кормовиробництва з урахуванням кліматичної кризи

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► **Анотація.** Стаття присвячена актуальній темі впливу кліматичних змін на сільське господарство України в цілому та на галузь польового кормовиробництва зокрема, а також проблемам адаптації сільського господарства до нових екологічних умов. Авторами було поставлено за мету обґрунтувати перспективні шляхи розвитку сучасного польового кормовиробництва з урахуванням кліматичних змін. Для цього використано абстрактно-логічний метод, системний аналіз, методи систематизації та класифікації, ряд економіко-статистичних методів дослідження (порівняння, ряди динаміки, метод структурних групувань). Було виділено як негативні, так і позитивні прояви кліматичної кризи у рослинництві, а також систематизовано можливі заходи протидії ризикам та шляхи використання потенційних можливостей розвитку польового кормовиробництва з урахуванням впливу змін клімату. Особливу увагу було звернено на світовий досвід ведення сільського господарства в умовах зміни клімату, зокрема, розглянуто складові системи «кліматично розумного»

рослинництва. Також у статті було охарактеризовано основні перспективні заходи адаптації польового кормовиробництва до кліматичних змін: зрошування сільськогосподарських земель, облаштування систем затримки снігу на полях, збору дощової води, селекцію та впровадження у практику нових сортів кормових культур, ефективні сівозміни, збільшення посівів посухостійких кормових культур, оптимізація агротехнологій з метою зменшення втрат кормових культур на етапах збирання врожаю та зберігання, застосування системи органічного землеробства, новітніх технологій удобрення ґрунтів, використання нанотехнологій обробітку ґрунтів. Результати проведеного дослідження можуть бути використані як менеджерами конкретних сільськогосподарських підприємств, так і дорадчими службами, державними органами в сфері реалізації аграрної політики

► **Ключові слова:** кормові культури; кліматичні зміни; зрошування; органічне землеробство; сорго