Climate-Smart Agriculture for Ukraine: Winter Wheat Breeding for Food Security and Climate Adaptation

November 2024

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U.S. Geological Survey

Acknowledgements

The authors thank all contributors who were essential in the development and facilitation of the research conducted for this report. Particular thanks are extended to Ethan Taylor of the Department of Interior's International Technical Assistance Program for facilitating the report team's meeting with Ukraine's Ministry of Agrarian Policy and Food, and Dr. Aparna Bamzai-Dodson of the North Central Climate Adaptation Science Center for selecting the climate-smart agriculture framework as the research lens for this report and assisting in identifying potential climate-smart agriculture case studies.

This study was initiated and funded by the U.S. Department of State in 2022 to support the U.S. Embassy in Kyiv, Ukraine by providing technical assistance to Ukraine's Ministry of Agrarian Policy and Food and the State Agency of Water Resources. A key objective of this support is to build capacity at national, regional, and local levels for science-and-data-informed decision-making in water resource management for agricultural production. Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

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Abbreviations

CH_4	Methane
CO_2	Carbon dioxide
K_2O	Potassium oxide
N	Nitrogen
N_2O	Nitrous oxide
P_2O_5	Phosphate
ARS	Agricultural Research Service of the U.S. Department of Agriculture
CAP	Common Agricultural Policy of the European Union
CSA	Climate-smart Agriculture
EPA	U.S. Environmental Protection Agency
EIP-AGRI	European Innovation Partnership for Agricultural Productivity and Sustainability
EU	European Union
Euro-CORDEX	European Coordinated Regional Downscaling Experiment
FAO	Food and Agriculture Organization of the United Nations
FAOSTAT	Statistics Division of FAO
GDP	Gross domestic product
GHG	Greenhouse gases
HWW	Hard winter wheat
KIIS	Kyiv International Institute of Sociology
KSU	Kansas State University
MENRU	Ministry of Environmental Protection and Natural Resources of Ukraine
MINAGRO	Ministry of Agrarian Policy and Food of Ukraine
NASS	National Agricultural Statistics Service of the U.S. Department of Agriculture
NUE	Nitrogen use efficiency
RCP	Representative Concentration Pathways
UHMC	Ukrainian Hydrometeorological Center
UHMI	Ukrainian Hydrometeorological Institute
UN	United Nations
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey

Executive Summary

Since the onset of the COVID-19 pandemic in early 2020, people have experienced food insecurity challenges because of increased prices of staple food commodities and loss of income or livelihood. Globally, countries with limited capacity to adapt have struggled to recover from pandemic-related disruptions and are further challenged to address adverse effects of climate change on agricultural production (United Nations [UN], 2022). Ukraine, a key agricultural exporter of staple food commodities, has a vital role in contributing to global food security, in particular through its wheat exports to countries in the Middle East, North Africa, and Europe (Martyshev and others, 2023). However, Ukraine's role as a stable source of global wheat has been disrupted by the ongoing Russia-Ukraine war—a conflict which began in February of 2022.

Given the fragile state of global and local markets and food systems, and the increasing risk climate change poses to agricultural production globally, Ukraine has prioritized adopting efficient agricultural practices to contribute to stabilizing crop yields and to increase its capacity to export wheat and other staple crops. According to Ukraine's Ministry of Agrarian Policy and Food (MINAGRO), along with addressing climate change, a contributing driver for this prioritization is the desire to join the European Union (EU) and the need to meet the requirements for the EU's Common Agricultural Policy (CAP) for acceptance as a union member state (Markiyan Dmytrasevych, a former deputy minister of MINAGRO, oral commun., 2023). As a result, MINAGRO is considering climate-smart agricultural practices to secure future crop yields and build resilience within its agricultural sector, especially as the war has impeded millions of tons of crops from reaching domestic and global markets.

Purpose of Study

The purpose of this report is to provide Ukrainian agricultural policy- and decision makers and others in technical and development assistance roles with an overview of relevant climate, environmental, and agricultural policy and market factors, and projections on climate and environmental resources that could influence the implementation of climate-smart agricultural practices in Ukraine.

Using the climate-smart agriculture (CSA) framework—developed by the UN Food and Agriculture Organization (FAO)—as a guide for this investigation, this report:

- Provides an overview of Ukraine, including a general description of topographic and hydrologic features and demographic characteristics, and a background on the agricultural sector (governance, market, land use, fertilizer use, and water use).
- Summarizes historical climate trends and projections and identifies potential climate change challenges and considerations for Ukraine.
- Analyzes EU strategy and policy documents to identify the assessment criteria pertinent to Ukraine's successful development of a CAP Strategic Plan and admission into the EU as a member state.
- Describes a case study of a climate-smart agricultural practice (winter wheat breeding) and analyzes its potential to contribute to climate change adaptation and food security goals, and to satisfy EU assessment criteria for CAP Strategic Plans.

Methods

This report employed the following methods:

- Literature review:
    - The report team reviewed literature and other publicly available sources of data and information related to agriculture, water resources, and the ongoing Russia-Ukraine war.
    - The report team reviewed and documented literature summarizing future climate projections and potential climate change implications for Ukraine.
- Stakeholder engagement:
    - On March 17, 2023, the report team met virtually with Markiyan Dmytrasevych, a former deputy minister of MINAGRO, to discuss the organization's goals and needs regarding agricultural production and planning.
- Climate trend analysis:
    - The report team summarized historical climate data for the purposes of identifying observed changes in annual temperature and precipitation.
- Document analysis:
    - Using the CSA framework, the report team reviewed and analyzed EU policy and strategy documents for the purpose of identifying core strategic and substantive goals regarding climate, agriculture, and the environment.
- Case study analysis:
    - The report team analyzed one case study of a climate-smart agricultural practice (crop breeding of winter wheat varieties). The Kansas State University (KSU) Wheat Breeding Program was selected as the case study unit of analysis for this report because of (1) the relative importance of winter wheat as a Ukrainian export crop, and (2) similar climate and landscapes in Kansas compared to those in much of Ukraine.

Findings

The key findings of this report are as follows:

- A review of observed climate data found that the mean annual temperature in Ukraine has increased since the 1950s, and climate projections for Ukraine indicate this pattern of increasing temperatures will continue into the future.
- Climate models for Ukraine forecast an increase in heat waves, drought events, and aridity in the Steppe region in southern and eastern Ukraine. This region of the country is where most agricultural land is located and where most wheat is grown. However, climate studies have also indicated that winter wheat yield may increase in Ukraine because of more moderate temperatures at the beginning and end of the winter wheat season that may extend the growing season.
- In 2014, Ukraine's nitrogen use efficiency (NUE) score was 120.05 percent. NUE scores of more than 100 percent are an indicator of "nitrogen mining" where crops deplete soils of nitrogen (N) because of a lack of sufficient N in the soil for the quantity of crops grown in an area.
- According to MINAGRO, since the start of the Russia-Ukraine war, Ukrainian agricultural producers have lacked access to affordable fertilizer and quality seeds have been harder to obtain, factors which have negatively affected the success of sowing (Markiyan Dmytrasevych, a former deputy minister of MINAGRO, oral commun., 2023).
- The document analysis of EU strategies and policies on climate, agriculture, and the environment identified three major overarching goals:
    - Food security and food quality
    - Reduction of environmental and climate footprint by reducing use of resources and increasing efficiency, in particular in the agricultural sector
    - Preservation of landscapes and biodiversity
- The case study analysis found that winter wheat breeding programs have the potential to satisfy EU CAP requirements and to meaningfully contribute to climate-change mitigation, climate-

change adaptation, crop productivity, and the nutritional value of food. However, winter wheat breeding programs, such as the KSU Wheat Breeding Program that develops winter wheat varieties for bread and noodle making, have found addressing the need for low-input crops that would require less fertilizer compared to traditional wheat varieties to be challenging, and tradeoffs between flour quality, yield, and lowered input requirements are expected (Dr. Allan Fritz, KSU, written commun., 2024).

Conclusions

This report finds that investing in domestic winter wheat breeding programs in Ukraine could be a meaningful approach for advancing climate-change mitigation and adaptation in Ukraine's agricultural sector. Domestic winter wheat breeding programs focusing on genetic markers for heat and drought tolerance could stabilize crop yields in areas where winter wheat crops may be subject to drier and hotter conditions, thereby enabling continued production in existing agricultural lands rather than requiring agricultural expansion into non-agricultural lands. Likewise, focusing on genetic markers to develop varieties with lower fertilizer requirements may aid in ameliorating existing nitrogen-depleted soils and lessen dependency on high volumes of fertilizers. Additionally, investing in domestic winter wheat breeding programs may help ensure a stable domestic supply of winter wheat seeds and varieties suitable for Ukraine's climate and soils, and regional variation. Lastly, winter wheat breeding programs satisfy numerous EU goals pertaining to climate change, agriculture, and the environment.

1. Introduction

With the global population projected to reach 9.7 billion by the year 2050 (United Nations Population Division, 2022), global and local food systems will inevitably become strained to feed such a large population. Population growth requires greater agricultural productivity to meet increasing demands, particularly in major staple crops, such as corn, rice, and wheat. Subsequently, the increased global demand for staple crops could require substantial increases in the inputs required to generate and sustain higher crop yields. Simultaneously, inputs required for crop growth (land, water, soil, fertilizers, seeds, pesticides, and so forth) are projected to become less available in quantity, quality, or both because of resource depletion and adverse effects from climate change. Anticipated changes in climate include increases in mean temperature, changes in precipitation patterns, and increase in frequency and intensity of extreme events, including droughts (Condon and others, 2004; U.S. Environmental Protection Agency [EPA], 2023; FAO, 2013; Fess and others, 2011). Increases in temperature and precipitation variability will make agriculture and food planning challenging, while decreases in water availability may make production of staple crops no longer possible in some areas (FAO, 2013). Furthermore, although increases in crop yields commensurate with population growth have been possible in the past, undernourishment and malnourishment still remain a problem as the nutritional value of crop varieties and food products has not sufficiently improved (FAO, 2013). Thus, at the intersection of climate change and agriculture, not only is productivity of concern but also the quality of food produced and its nutritional value.

Just as agriculture is both susceptible to and influenced by climate change, so is the climate susceptible to agricultural production and agricultural-related processes. Agriculture and agricultural-related processes, such as development of inputs, transport, processing, retail, consumption of products, and waste, are substantial contributors to anthropogenic climate change. Greenhouse gases (GHG) directly emitted by agriculture largely consist of methane (CH_4) from livestock and nitrous oxide (N_2O) from nitrogen (N) fertilizer application. However, carbon dioxide (CO_2) emissions from agricultural-related processes have been more difficult to quantify. One of the more impactful sources of CO_2 emissions is land conversion for agriculture (Lynch and others, 2021). From the mean total of GHG emissions recorded from 2007 to 2016, land conversions for agricultural purposes accounted for an estimated 10 percent of the total anthropogenic emissions for that time period (Mbow and others, 2022).

Agricultural inputs also affect the environment and contribute to the depletion of natural resources, such as soil, minerals, and water. Land conversion and agricultural land use can have detrimental effects on surrounding water resources and ecosystems, and regional climate. Fertilizer and pesticide use can degrade the water quality of nearby water resources as they move from the original point of application. In fact, in the United States, agriculture is the leading cause of impaired rivers and lakes (U.S. Geological Survey [USGS], 2019). In an overview of water quality studies conducted across the United States between 1991 and 2001, the USGS found that the presence of at least one pesticide was detected in 94 percent of all water samples, 90 percent of all fish samples from streams, and in roughly 55 percent of samples from shallow wells near agricultural areas (Hamilton and others, 2004). In the Mississippi River Basin, land conversions for agriculture contributed to an approximate 500 percent increase (from less than 1 to greater than 6 metric tons) in nitrogen fertilizer application when comparing 1950–70 to 1980–96. The substantial increase in nitrogen fertilizer use in the basin was the primary contributing factor to a seasonal bottom water hypoxia event in the Gulf of Mexico. In Denmark, a four-year study of 130 stations at river mouths found agriculture to be responsible for more than two-thirds of yearly riverine nitrogen transport (Scanlon and others 2007). Additionally, excessive use of pesticides and fertilizer, and depletion of soil nutrients and moisture from unsustainable agricultural practices and land clearing can lead to soil degradation, erosion, and changes in soil composition (World Wildlife Fund, [undated]). Similarly, reserves for phosphorous, a macronutrient required to produce phosphate (P_2O_5) fertilizer, are declining and are projected to become difficult to source in less than a century (Fess and others, 2011).

In addition to climate change, natural resources depletion, and environmental degradation, global and local food systems have been disrupted by the COVID-19 pandemic beginning in early 2020 and the Russia-Ukraine war which started in February of 2022 (United Nations [UN], 2022). In 2021, an estimated 2.3 billion people worldwide experienced at least moderate food insecurity, 924 million of which experienced severe food insecurity (FAO and others, 2022). In 2022, estimates by FAO and others projected that as many as 7.6 million to 13.1 million additional people may experience undernourishment because of the Russia-Ukraine war. Uncertainty around ongoing and emerging geopolitical conflicts, and potential future pandemic or other disruptions indicate a pressing need to strengthen food systems and build resilient agricultural sectors.

Ukrainian Agriculture

Ukraine is one of the world's top agricultural producers and exporters and plays a critical role in supplying oilseeds and grains to the global market. Agriculture accounts for an estimated 20 percent of the country's gross domestic product (GDP) and an estimated 40 percent of total export revenue (Nivievskyi and others, 2022). Ukraine primarily grows wheat, sunflower, corn, barley, soybeans, potatoes, and rapeseed. Winter wheat, spring barley, and corn are the country's principal grain crops. Within the wheat crop sector, winter wheat is the dominant crop accounting for about 97 percent of Ukraine's total wheat production (U.S. Department of Agriculture [USDA], 2022).

Prior to the start of the Russia-Ukraine war, Ukraine accounted for approximately 12–14 percent of globally traded grain, with 93 percent of this grain exported to the Middle East, North Africa, and Europe (Martyshev and others, 2023). After the start of the conflict, grain production dropped by 25 percent and grain exports decreased by 15 percent (Brown and others, 2023). Agricultural losses due to the war amounted to approximately 75 percent of Ukraine's agricultural output (or $34.25 billion) (Martyshev and others, 2023).

In addition to conflict-related risks and losses, adverse effects from climate change make Ukraine increasingly susceptible to droughts, increased temperatures, heat waves, and extreme precipitation events resulting in floods and erosion of topsoil (World Bank, 2021). However, Ukraine may benefit from more moderate temperatures that could extend the winter wheat season, potentially increasing overall wheat yields. Further explanation of the projected effects of climate change on agriculture are discussed later in this report (refer to "Implications of Climate Change for Agriculture in Ukraine" section in Chapter 3).

Ukraine's Admission into the European Union

On March 17, 2023, in a meeting with Markiyan Dmytrasevych, a former deputy minister of MINAGRO, the authors of this report were briefed on Ukraine's plans to pursue admission into the EU as an official member state. To be admitted successfully, Ukraine must implement an agricultural strategy that is in accordance with the current EU strategic direction and policy goals and requirements set for the agricultural sectors of member states within the union. Within the EU, the principle agricultural policy is the Common Agricultural Policy (CAP)—a policy that predates the modern EU established in the early 1990s. The CAP establishes the policy and regulatory objectives of agricultural sectors of EU member states (refer to "The European Union's Strategy on Climate Change, Agriculture, and the Environment" section in Chapter 4). Every four years the European Council, an executive body of the EU responsible for setting policy agendas, develops new strategic targets for the CAP as well as additional policies which influence the assessment of CAP Strategic Plans. CAP Strategic Plans are agricultural comprehensive plans developed by member states which are evaluated by the EU for strategic cohesion and to assess implementation progress via performance, context, and result indicators (European Commission, Directorate-General for Agriculture and Rural Development, [undated] b). In preparation for entering the EU, Ukraine would be responsible for developing a CAP strategic plan of its own.

In addition to EU admission, the deputy minister informed the authors of this report of other related and pressing concerns. For instance, as a consequence of the ongoing Russia-Ukraine war and subsequent crises in Ukraine, the quality of sowing decreased because of the rise in cost of fertilizer (which had become three to five times more expensive) and the lower quality and quantity of available seeds. Moreover, the deputy minister communicated that the Ukrainian government is unlikely to pursue or support new programs which do not already align with existing priorities owing to limited institutional capacity and financial resources, except in the case where external support (from the EU, World Bank, the U.S., and so forth) could facilitate its implementation.

Given recent support by the EU (refer to the "Climate-Smart Agriculture and the European Union" section in this chapter) and the World Bank (World Bank, 2021) for the implementation of climate-smart agricultural practices in Ukraine and elsewhere, this report presents a summary of strategy documents and policies supportive of and relevant to implementing climate-smart agriculture for winter wheat. Additionally, this report describes and analyzes a case study where one such climate-smart agricultural practice, winter wheat breeding, has been implemented successfully (refer to Chapter 5 of this report, "Winter Wheat Breeding") and could potentially serve as a means by which Ukraine's winter wheat sector can become more resilient to climate change, environmental degradation, and conflict or other disruptions.

Climate-Smart Agriculture and the European Union

The CSA framework is a concept which was developed by the FAO in 2010 (FAO, 2013). Its usefulness for identifying climate-compatible agricultural practices and pathways toward innovation has been recognized by the EU. In February of 2021, the European Commission's European Innovation Partnership for Agricultural Productivity and Sustainability (EIP-AGRI) published the "Climate-smart agriculture: Solutions for resilient farming and forestry" brochure – an overview of instances of climate-smart agriculture emerging from EU member states at that time. Most case studies presented in the brochure focused on sustainable livestock and soil management practices which contribute to food security (through increased crop yield or productivity), climate adaptation, and contributing to climate change mitigation by increasing carbon sink potential and resource efficiency (EIP-AGRI, 2021). However, the brochure does not present any case studies of staple crops, such as wheat; as a short document providing a broad overview, it was not designed to present in-depth case studies.

This report seeks to fill a gap by focusing on winter wheat because of its importance in Ukraine's role globally as a major producer and exporter of wheat. Additionally, this report provides an in-depth case study of winter wheat breeding as a potential pathway to increase efficiency and resiliency in the production of winter wheat. Moreover, this report highlights additional EU agricultural strategies and policies relevant for Ukraine's successful admission as a new EU member state.

2. Climate-Smart Agriculture as a Framework

The CSA framework has been utilized by governmental and non-governmental entities alike with different reaches from global to local, including the World Bank, USDA, Environmental Defense Fund, Rainforest Alliance, Ceres, Concern Worldwide, the Commonwealth of Massachusetts, California Institute for Water Resources, and the California Department of Food and Agriculture. According to Lipper and others (2014), CSA is employed by governmental and non-governmental entities to promote coordination between diverse groups of actors through “four main action areas”: (1) building evidence, (2) increasing local institutional effectiveness, (3) generating cohesion between climate and agricultural policies, and (4) linking financing available for climate and agricultural initiatives and sectors. CSA is intended to contribute to sustainable development goals by addressing the adverse effects of food insecurity and climate change through its three main pillars: (1) climate change adaptation, (2) climate change mitigation, and (3) productivity. The first pillar has the objective of adapting and building resilience to the projected effects of climate change. The second pillar aims to reduce or remove GHG emissions where possible. The third pillar seeks to sustainably increase yield and nutritional value of food (FAO, 2013).

Two joint principles guide actions undertaken through the CSA approach. The first guiding principle is the more efficient use of natural resources. Increasing efficiency entails reducing the inputs required to produce food – meaning using less land, water and other inputs, such as fertilizers. Additionally, increasing efficiency entails increasing food production while reducing the emissions intensity of food. The second guiding principle is increasing resiliency to changes or shocks by preparing for variability in precipitation and temperature attributable to climate change and for changes in the quality and quantity of natural resources due to environmental degradation. Resilience is defined as the “capacity of systems, communities, households or individuals to prevent, mitigate or cope with risk and recover from shock” (FAO, 2013, p. 19). Within the CSA framework, the FAO dovetails resilience to adaptive capacity, or the ability to recover from shocks and to ensure “plasticity” of a system, as an essential aspect of resilience (FAO, 2013).

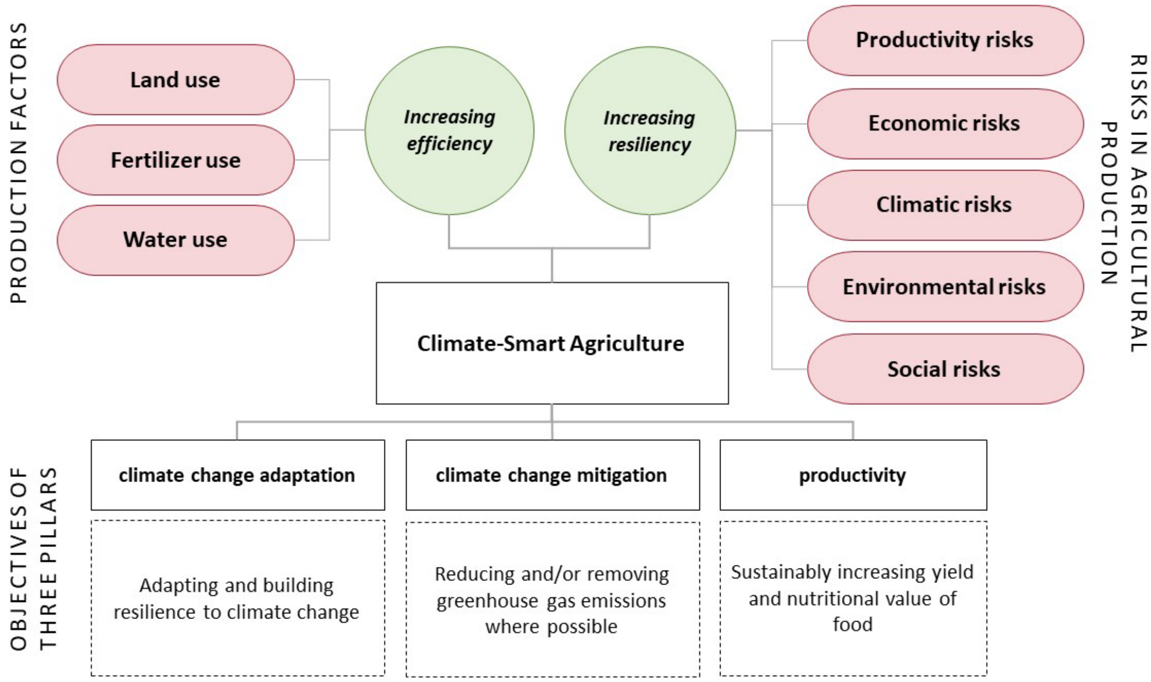

Figure 1. *Diagram of the Climate-smart Agriculture (CSA) framework including the three pillars (climate change adaptation, climate change mitigation, and productivity) and the two guiding principles (increasing efficiency and increasing resiliency) covered in this report (United Nations Food and Agriculture Organization (FAO), 2013).*

Increasing Efficiency

The CSA framework identifies several agricultural production factors that influence efficiency (FAO, 2013). Only three production factors (land use, fertilizer use, and water use) are included in the scope of this report.

Agricultural land use, and more specifically land conversions because of agricultural expansion, is an important driver of deforestation and loss of grasslands. Land conversion is not only detrimental to the local landscapes and ecosystems, but also increases CO_2 emissions. A reduction in agricultural expansion through increasing the yield potential of crops and sustainably intensifying production on existing cultivated land could have a major climate change mitigation effect. It may also reduce the potential adverse effects of agricultural processes to local resources and ecosystems (FAO, 2013).

The often excessive or inefficient use of fertilizer is not only costly and energy intensive, but also a source of high CO_2 emissions and N_2O in production and transport, and of N_2O emissions when applied to fields directly (EPA, 2005). Although crops need macronutrient inputs (for example, nitrogen, potassium, and phosphorus) for increased productivity, high-input agricultural systems require heavy use of fertilizers with mostly inorganic mineral macronutrients which contribute to GHG emissions and to degraded water quality near sites where field application occurs (EPA, 2005). At present, concern over excessive fertilizer use globally is due to both the manner in which excess nitrogen and phosphorus readily contaminate water resources as well as the declining global reserves of phosphorus mines which, in 2011, were projected to only last between 50 to 130 years (Fess and others, 2011).

The inefficient use of water resources in agriculture is of particular concern as a result of the consumptive water use and energy use required by irrigation systems (FAO, 2013). However, even in rain-fed systems, the urgency to increase efficiency in water use is evident given the projected population growth, and decreased water availability (Condon and others, 2004).

Increasing efficiency in the three production factors described in this section (land use, fertilizer use, and water use) will serve as the first guiding principle in this report to find intersections with outlined strategies and policy directives generated by the EU. Increasing efficiency in the three production factors also serves as indicators in determining if winter wheat breeding is a suitable approach to addressing the climate change adaptation, climate change mitigation, and productivity goals outlined by the CSA framework.

Increasing Resiliency

As outlined in the CSA framework, increasing resiliency requires reducing exposure, sensitivity, or both to risks in agricultural production while increasing adaptive capacity (FAO, 2013). Risks in agricultural production are found in different spheres, systems, and scales within those systems which interact with or influence food production and its outputs (EPA, 2023; FAO, 2013; National Research Council (US) Committee on Biosciences, 1985; USDA Economic Research Service, 2023b). These include natural spheres (such as environment and climate), human-actor spheres and processes (such as governance structures, policy actions, and production processes), and the intersection of both natural and human-actor spheres (for instance where yield, or productivity, is concerned). Of the many risks that are present in agricultural production, this report will focus on the following risks:

- *Productivity risks*
  - Crop yield (the uncertain natural growth processes of crops)
  - Pests and disease (competition and detrimental effects from viruses, bacteria, fungi, and insects)
- *Economic risks*
  - Variations in access to inputs (fertilizers, seeds, pesticides) in quantity or quality
- *Climatic risks*
  - Increased probability of severe drought or heatwaves
  - Increase in mean temperature
  - Changes in precipitation
- *Environmental risks*
  - Land use, conversion, and availability
  - Water use and availability
  - Soil degradation
- *Social risks*
  - Uncertainties surrounding government actions (policy changes, tax laws, regulations of chemical uses, and so forth)

Increasing resiliency to the agricultural production risks outlined herein will serve as the second guiding principle in this report to find intersections with outlined strategies and policy directives generated by the EU as well as serving as indicators to determine if winter wheat breeding is a suitable approach to addressing the three pillars outlined by the CSA framework (climate adaptation, climate mitigation, and productivity).

3. Climate and Agriculture in Ukraine

Ukraine has a total area of 603,550 square kilometers (sq km) and is bordered to the south by the Black Sea, to the southwest by Moldova and Romania, to the west by Hungary, Slovakia, and Poland, to the north by Belarus, and to the northeast by Russia. Ukraine is made up of 24 administrative divisions, or *oblasts*, in addition to two cities of special status (Kyiv and Sevastopol) and the Autonomous Republic of Crimea (World Factbook, 2021). The cities of Kyiv (distinct from Kyiv Oblast) and Sevastopol are both first-level administrative divisions, the same as oblasts, which is a legacy of the former Soviet Union.

Figure 2. *Map of Ukraine showing major cities and rivers as well as bordering countries and the Black Sea (map reproduced from the World Factbook, 2021, which provides the following copyright notice: "the World Factbook is in the public domain. Accordingly, it may be copied freely without permission of the Central Intelligence Agency [CIA])."*

Most of Ukraine lies within four main watersheds (named herein for their main-stem rivers from west to east): the Dniester, the Pivdennyy Buh (Southern Bug), the Dnipro (Dnieper), and the Siverskyy Donets. The Dnipro River watershed makes up the central third of the country. The Dnipro River is the largest river in the country by volume and is vital for trade, electricity generation, and irrigation (FAO, 2015; Kubijovyč and Teslia, [undated]; Maryna and Taisiia, 2024).

In 2022, Ukraine had an estimated population of 43.3 million. At the time of the 2001 census, the population was made up of 78 percent Ukrainian, 17 percent Russian, and 5 percent other ethnicities. About 70 percent of the population lives in urban areas and 30 percent live in rural areas (World Factbook, 2021). In 2021, 2.7 million people were employed in agriculture, forestry, and commercial fishing, which is 17.3 percent of the total employed population of 15.6 million (State Statistics Service of Ukraine, 2022). Ukraine's agri-food sector is critical to its economy, accounting for as much as 20 percent of GDP in the 1990s, as low as 6.5 percent in 2007, and a more stable approximate 10 percent of

GDP in the late 2010s. When accounting for industry related to agriculture, roughly 20 percent of Ukraine's GDP is derived from agriculture and food (Nivievskyi and others, 2022).

Climate of Ukraine

The climate for much of Ukraine, including most of the northwest regions, is characterized as cold with no dry season and a warm summer (Beck and others, 2018). Eastern and central regions of Ukraine are similar, but with even warmer summers. Southern Ukraine is classified as more arid. The Carpathian Mountains to the west create their own climate region, with typically no warm season observed at higher altitudes.

Gridded data at a 0.1° x 0.1° resolution from the Ukrainian Hydrometeorological Institute (UHMI) spanning 1950 to 2020 shows Ukraine's annual mean temperature has been increasing during the past few decades (Osadchyi and others, 2022). The annual mean temperature during 2019 and 2020 increased by more than 2 °C compared to the mean annual temperature during 1950–80 (Figure 3). Although temperatures have been increasing across all regions of Ukraine, the fastest rates of increase are occurring in central and northwestern Ukraine, with estimated annual temperatures increasing at a rate of 27 percent between 1980 and 2020 (Figure 3; Table 1). The UHMI data from 1950 through 2020 indicate 2020 (10.7 °C; +2.4 °C from baseline) and 2019 (10.5 °C; +2.2 °C from baseline) were the hottest years on record (Figure 3).

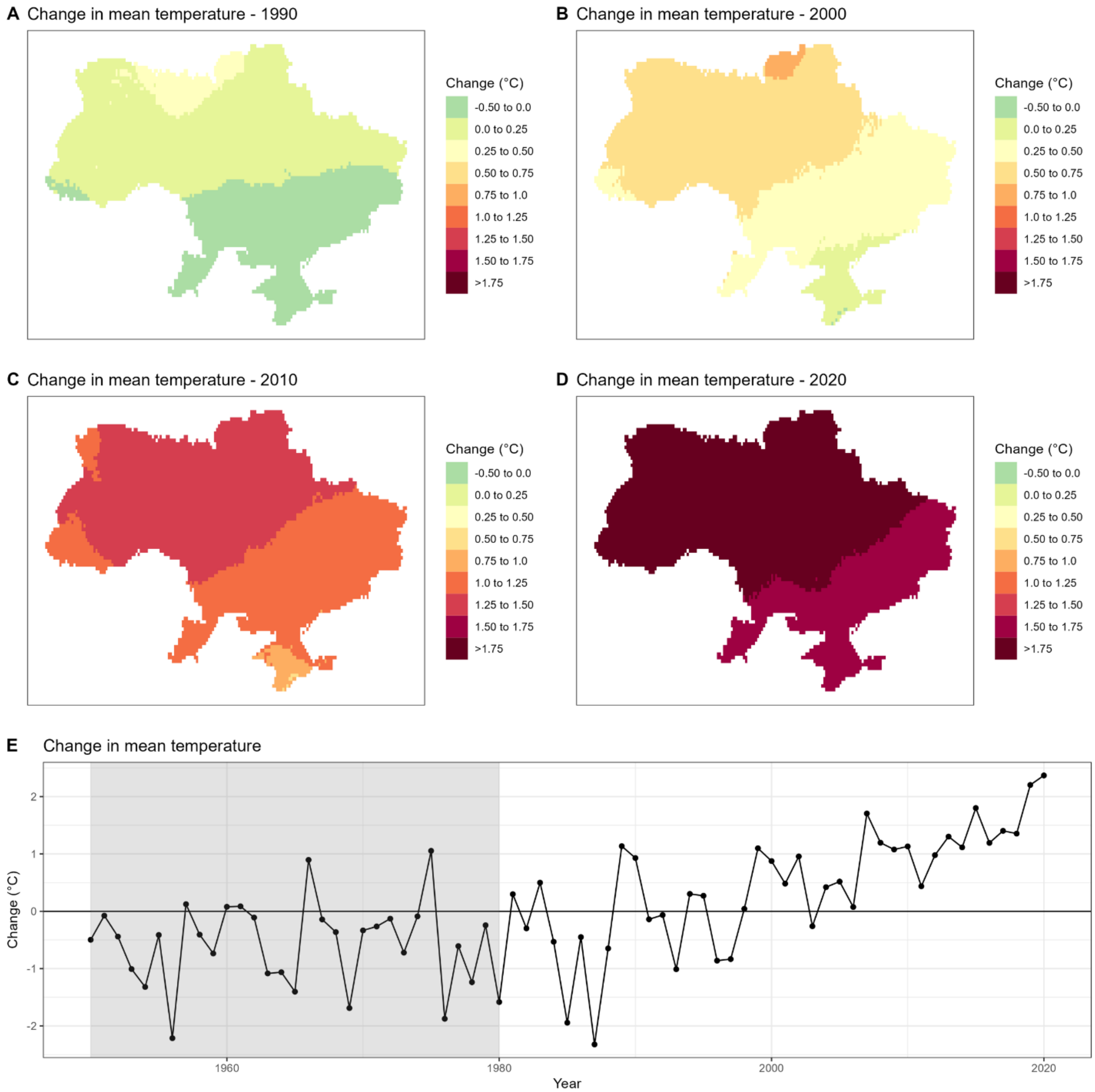

Figure 3. *Observed annual mean temperature change compared to the mean annual temperature from 1950 to 1980 (the baseline temperature). Changes in temperature are calculated as degree Celsius change from baseline. Panels A–D depict change estimates spatially by using 10-year means (for example, the 1990 change was calculated by using the mean annual temperature during 1980–90, the 2000 change was calculated by using the mean annual temperature during 1990–2000, and so forth) and panel E depicts change in annual mean temperature compared to baseline mean annual temperature, with baseline years (shaded gray). Data from Osadchyi and others (2022).*

Table 1. *Observed mean temperature change summarized by region, following Kyiv International Institute of Sociology (KIIS) regions (Refer to Appendix A for list of oblasts within KIIS regions). Mean annual temperature during 1950–80 was used as the baseline. Changes in temperature are calculated as degrees Celsius change from baseline with percent change from baseline in parentheses using 10-year*

mean annual temperatures (for example, 1990 change calculated with by using mean annual temperatures from 1980–90, 2000 change calculated by using mean annual temperatures during 1990–2000, and so forth). Data from Osadchyi and others (2022).

[°C, degrees Celsius; +, plus; %, percent]

Region	Baseline (°C) (1950-80)	1990 change (°C)	2000 change (°C)	2010 change (°C)	2020 change (°C)
Central	7.17	0.16 (+2.19%)	0.63 (+8.76%)	1.37 (+19.12%)	1.93 (+26.97%)
East	7.76	0.02 (+0.21%)	0.37 (+4.77%)	1.15 (+14.87%)	1.76 (+22.68%)
South	9.37	-0.12 (-1.30%)	0.33 (+3.57%)	1.10 (+11.73%)	1.70 (+18.13%)
West	6.85	0.18 (+2.67%)	0.63 (+9.27%)	1.27 (+18.59%)	1.87 (+27.37%)
Ukraine	7.78	0.07 (+0.90%)	0.51 (+6.56%)	1.25 (+16.07%)	1.83 (+23.53%)

Throughout the year, the greatest mean increases in temperatures were in January (+2.2 °C) and March (+1.8 °C); however, relying solely on monthly means as an indicator can overlook changes in minimum and maximum temperatures, which were also appreciable. On an annual basis, January through March were the months with the greatest increases in minimum and maximum monthly temperature. Although UHMI data only provide monthly temperature estimates, other reports on Ukraine have found an increase in total number of days with summer-like temperatures, and an increase in the number of frost-free days at the national scale using daily data from E-OBS v20.0e (World Bank, 2021).

UHMI data show high variability and no clear pattern in total precipitation (snow and rainfall) at a national scale, similar to summaries in other reports (World Bank, 2021). Between 1980 and 2020, total annual precipitation was as high as 60 mm/year (1980) and as low as 39 mm/year (1994) (Figure 4). Historically, most of Ukraine's precipitation falls in June and July, with the least precipitation falling in February and March. Heavy rain events are frequently observed in the southern, western and central regions of Ukraine, and extreme snowfall is common in southern and western Ukraine (Balabukh and others, 2018). Although the total annual rainfall shows no clear change pattern, there is some evidence of temporal and spatial shifts in precipitation patterns. More specifically, the largest monthly decreases in precipitation were most frequently observed in July and August and in November and December, in contrast with increases in precipitation during June and September (Figure 5). Overall, precipitation totals equal to or slightly greater than long-term mean values were recorded in the southern and eastern regions of Ukraine, whereas precipitation totals less than long-term mean were recorded in central and western Ukraine (Figure 4; Table 2).

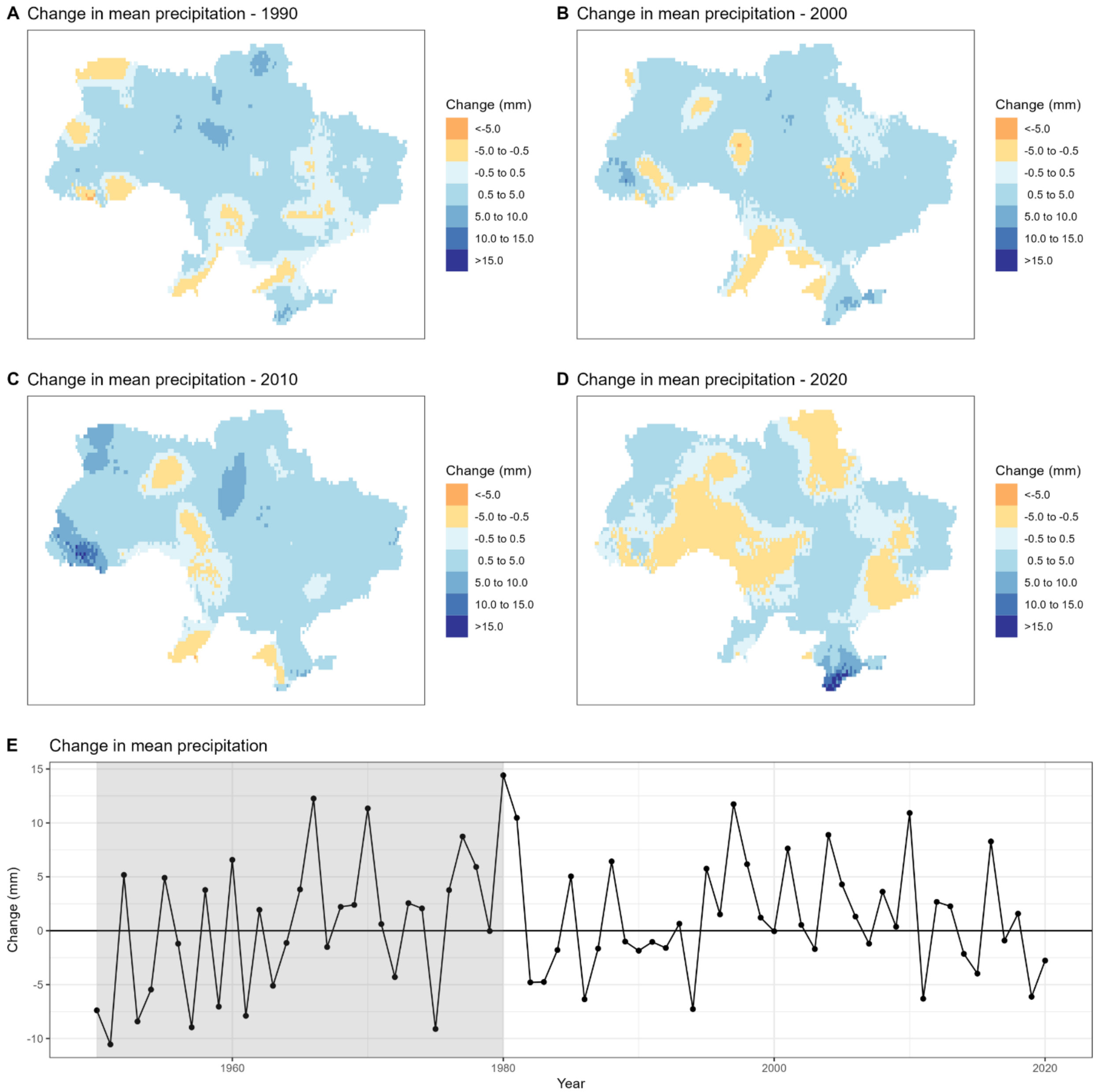

Figure 4. *Observed annual mean precipitation change. Mean annual precipitation during 1950–80 was used as the baseline. Changes in precipitation are calculated as millimeter change from baseline. Panels A–D show change estimates spatially using 10-year mean annual temperatures (for example, 1990 change calculated by using the mean annual precipitation during 1980–90, 2000 change calculated by using the mean annual precipitation during 1990–2000, and so forth) and panel E shows change in annual precipitation compared to baseline mean annual precipitation with baseline years shaded gray. Data from Osadchyi and others (2022).*

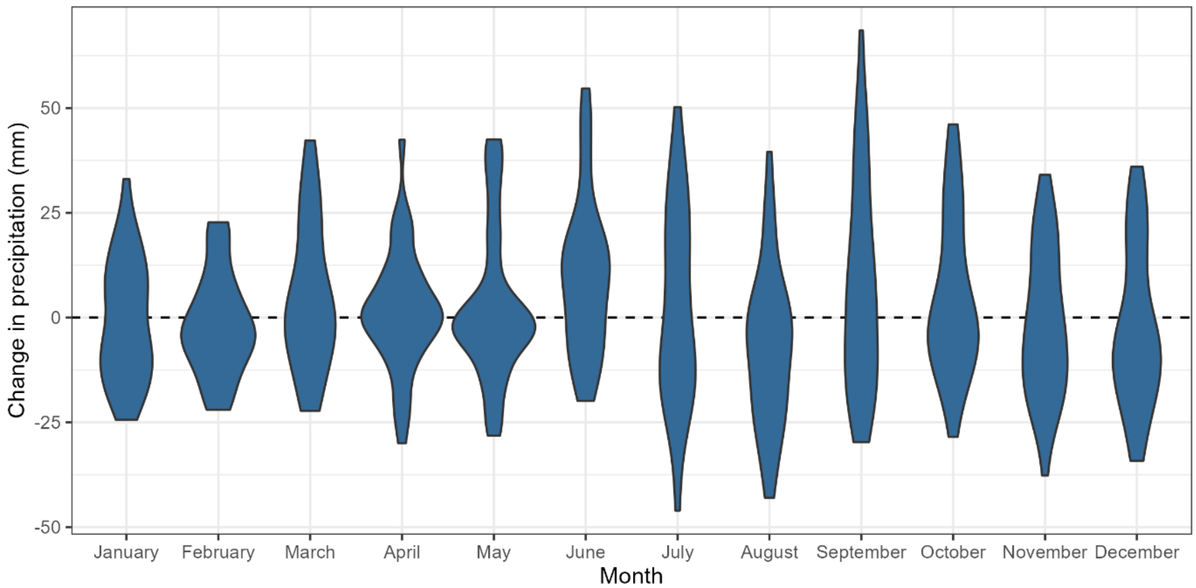

Figure 5.*Violin plot of observed change in monthly precipitation. The mean monthly precipitation during 1950–80 was used as the baseline. Changes in monthly precipitation are calculated as millimeter change from monthly baseline. Monthly change was calculated for each year between 1980-2020. The width of the violin represents the density of data points at that change value for each month; therefore, the wider the violin the more times that change value was observed across the 40 years. Data from Osadchyi and others (2022).*

Table 2. *Observed change in annual precipitation summarized by region following Kyiv International Institute of Sociology (KIIS) regions. The mean annual precipitation during 1950–80 was used as the baseline. Changes in precipitation are calculated as millimeter change from baseline with percent change from baseline in parentheses using 10-year mean annual values (for example, 1990 change calculated by using the mean annual precipitation during 1980–90, 2000 change calculated by using the mean annual precipitation during 1990–2000, and so forth). Data from Osadchyi and others (2022).*

Region	Baseline (mm) (1950-80)	1990 change (mm)	2000 change (mm)	2010 change (mm)	2020 change (mm)
Central	45.62	3.06 (+6.71%)	1.95 (+4.27%)	2.26 (+4.95%)	0.04 (+0.09%)
East	43.06	1.15 (+2.67%)	1.70 (+3.95%)	2.69 (+6.25%)	0.78 (+1.81%)
South	38.18	0.49 (+1.28%)	0.97 (+2.54%)	1.27 (+3.33%)	1.54 (+4.03%)
West	57.71	0.82 (+1.42%)	1.42 (+2.46%)	3.68 (+6.38%)	0.38 (+0.66%)
Ukraine	42.55	0.85 (+2.00%)	0.30 (+0.71%)	2.52 (+5.92%)	0.72 (+1.69%)

Future Projections

Temperature and precipitation are expected to continue changing in the future across Ukraine based on a multi-model ensemble from the European Coordinated Regional Downscaling Experiment (Euro-CORDEX) projecting changes for 2030, 2050, and 2090 under multiple Representative Concentration Pathways (RCP) scenarios (World Bank, 2021). RCP are standardized emission scenarios used to increase consistency across climate model projections and include scenarios such as RCP4.5, which assumes slowing emission trends to reach a 2.4°C warming limit by 2100, and RCP8.5, which assumes increased emission and aligns with a 4.3°C global warming limit by 2100.

Similar to forecasted temperature increases in present member states of the EU, the model ensemble presented in World Bank (2021) indicates Ukraine will also likely experience warmer winters and hotter summers, with the mean temperature undergoing the greatest increases under higher emission scenarios and continuing to increase later into the century. Forecasted mean increases in annual temperature in Ukraine range from 0.9±1.4 °C in 2030 to 2.1 ±1.8 °C in 2090 under RCP 4.5, and from 1.1±1.5 °C in 2030 to 4.3 ±12.1 °C in 2090 under RCP 8.5. Summer-like weather in Ukraine is expected to begin earlier in the year under both scenarios and total frost-free days may increase to an additional 40+ days under RCP 8.5. Southern and eastern regions of Ukraine will likely experience increased risks of heatwaves (Mishra and others, 2023).

The model ensemble predicts a slight increase in total precipitation and continued temporal shifts, with precipitation increasing in colder months and decreasing in warmer months. Higher emission scenarios predict greater increases in annual precipitation. Mean increases in precipitation range from 6 percent in both 2030 and 2090 under RCP 4.5, and from 4 percent in 2030 to 8 percent in 2090 under RCP 8.5. Northern regions of Ukraine are projected to experience the largest increase in precipitation, with smaller increases in southern regions. Also, by using results from a multi-model ensemble under RCP 8.5, Beck and others (2018) demonstrated possible shifts in climate zones using the Köppen-Geiger climate classifications and projected for the end of the century (Figure 6). Results show an expansion of arid zones in Ukraine from the south to the north and to the east. Much of the northwest is likely to shift from cold to temperate zones with increased summer temperatures. These future changes will have substantial implications for agriculture suitability moving forward.

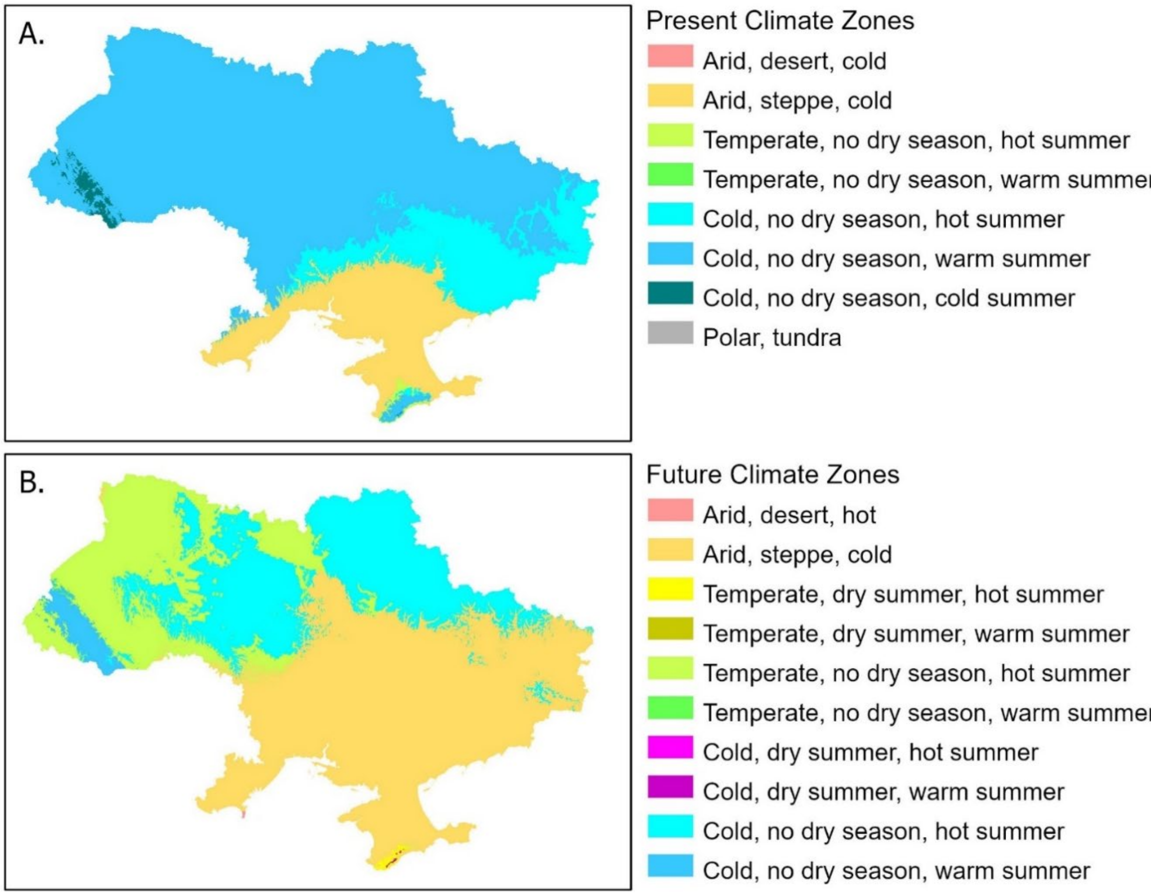

Figure 6. *Projected climate zone shifts in Ukraine. A. Current climate zones across Ukraine (1980-2016) and B. Future climate zones across Ukraine from an ensemble of 32 climate model projections under RCP8.5 scenarios projected for 2071-2100. Data from Beck and others (2018). Projection used: WGS 1984 UTM Zone 37N.*

Implications of Climate Change for Agriculture in Ukraine

Changes in climate characteristics, such as temperature and precipitation, can influence the overall suitability of an area for agriculture and the success of crop production. In Ukraine, projected climate changes are expected to have variable effects on agriculture by region and crop type, with potentially greater adverse effects in the Steppe region in the south and southeast (Boychenko and others, 2016; Skrypnyk and others, 2021). Warming temperatures in the north will create new opportunities for the expansion of winter crops, such as winter wheat, from the Steppe to Forest-Steppe zones (Skrypnyk and others, 2021). However, land conversion for agriculture has been shown to increase CO_2 emission and to adversely affect local landscapes and ecosystems (refer to “Increasing Efficiency” section in Chapter 2). In southern Ukraine, yields may decrease as a result of increased aridity and drought events (Skrypnyk and others, 2021). Additionally, increased heatwaves in southeastern region of Ukraine, where most winter wheat if grown, can cause irreversible crop damage (Mishra and others, 2023).

Overall, projected changes are likely to increase grain production in Ukraine due to increased time windows with favorable growing conditions and longer frost-free periods (Tarariko and others, 2017). Rising temperatures are expected to increase growing season lengths of winter crops and shorten those of spring crops (Boychenko and others, 2016). In the absence of extreme events, such as flooding, drought, or windstorms, yields for crops including winter wheat, barley, rice and soybean are expected to increase, while corn and sunflower are expected to be more variable and will depend on adaptation measures implemented (Skrypnyk and others, 2021). According to the World Bank (2021), a key factor in determining future yields will be access to sufficient water resources. Rising temperatures can increase evapotranspiration and reduce soil moisture, ultimately increasing water requirements for crops. In areas experiencing an imbalance in temperature and precipitation increases, a larger dependence on irrigation will be required to maintain production success.

Other variations may also influence successful crop production and challenge agricultural planning. For instance, predicted changes in temperature and precipitation are also likely to influence temporal aspects of agricultural practices. Plant-life stages may be disrupted by unusually warm and dry conditions. Changes in the seasonality of precipitation will likely influence planting calendars, with drier conditions in late summer leading to postponed planting dates for winter crops, such as winter wheat, barley, or rapeseed. Other climate factors which will influence agricultural production include snow cover and extreme events such as flooding, drought, or windstorms. Flood risk is expected to increase in the Carpathians region and extreme drought may lead to desertification in the southern districts of the Steppe region (Boychenko and others, 2016). Winter snow cover is key to protecting winter crops from extreme temperatures or high winds and reducing risks of frost damage. A reduction in snowfall or a shift from snow to rain in winter precipitation may reduce plant protection and expose plants to harsher winter elements. Temporary warming of temperatures can also lead to increased soil moisture from melting snow, which then refreezes when temperatures drop again, harming root systems and potentially killing plants (Boychenko and others, 2016).

Understanding how climate conditions have changed and are likely to continue changing can help increase preparedness among agricultural producers. Recent reports have outlined potential adaptation measures in response to Ukraine’s changing climate, including adjusting planting calendars for spring and winter crops, increasing access to irrigation, incorporating better moisture retention practices, and increasing use of strategic crop varieties, such as drought-resistant varieties in the Steppe region (Boychenko and others, 2016; World Bank, 2021). This report further investigates the use of strategic crop varieties, specifically for winter wheat production (refer to Chapter 5, “Winter Wheat Breeding”).

Ukraine’s Agricultural Sector

Ukraine is one of the world’s top agricultural producers and exporters and plays a critical role in supplying oilseeds and grains to the global market. In the year leading up to Russia’s invasion, Ukraine’s percentages of global exports included 9 percent of wheat, 12 percent of corn, 17 percent of barley, 20 percent of rapeseed, and 46 percent of global sunflower oil exports (USDA, 2022). Its agriculture sector makes up an estimated 20 percent of the country’s GDP and an estimated 40 percent of total export revenue (Nivievskyi and others, 2022). Ukraine primarily grows wheat, sunflower, corn, barley, soybeans, potatoes, and rapeseed. However, wheat, spring barley, and corn are the country's principal grain crops. Within the wheat crop sector, winter wheat is the dominant crop accounting for about 97 percent of Ukraine’s total wheat production (USDA 2022). Given the importance of winter wheat production in Ukraine’s agricultural sector, the case study analysis in this report focuses on winter wheat (refer to Chapter 5, “Winter Wheat Breeding”).

Winter wheat is planted from early September to mid-November and harvested between July and September. Production is concentrated in the southeastern region of Ukraine (USDA, 2022). In fall of 2021, 6.1 million hectares of winter wheat were planted, or slightly more than 10% of the total area of Ukraine. This figure fell to 4.1 million hectares in 2022 following Russia’s invasion. The decline in planted area of winter wheat has created concerns of a global shortage of wheat and wheat-food products (FAO, 2023).

Governance and Policy

The Ministry of Agrarian Policy and Food of Ukraine (MINAGRO) is responsible for developing and implementing policies concerning crop cultivation, land management and soil health, state water infrastructure, fisheries, rural development, and agriculture-supporting industry. MINAGRO also manages policy regarding national geospatial data. In addition, there are other ministries with influence over the Ukrainian agriculture sector, including the Ministry of Environmental Protection and Natural Resources of Ukraine (MENRU), the Ministry of Economic Development and Trade, and the Ministry of Internal Affairs. Table 3 provides an overview of all institutions on a ministerial- and state-level responsible for agriculture policy, environmental resources management, and climate adaptation strategies in Ukraine.

Table 3. *An overview of all institutions on a ministerial and state level responsible for agriculture policy, water management, and climate adaptation strategies in Ukraine.*

Institution	Primary Functions (Non-agricultural functions in parentheses)	Year Established	References
Ministry of Agrarian Policy and Food (MINAGRO)	Primary government entity responsible for shaping agricultural policies, including crop cultivation, land management and soil health, state water infrastructure, fisheries, rural development, and industry supporting agriculture. Also manages policy regarding national geospatial data.	2000; The precursor General Secretariat of Land Affairs was established 1917. MINAGRO was merged with the Ministry for Economic Development and Trade in August 2019, then re-established as a separate entity in December 2020.	Plotnikov and Senyshyn, 2022. Prodanyuk, 2020. Nivievskyi and others, 2022. MINAGRO, 2021.
Ministry of Environmental Protection and Natural Resources (MENRU)	Water resource management, land reclamation, and fisheries management, forestry (environmental/climate policy, waste management, subsoil policy reform)	1991	Yara and others, 2018. Nazarov and others, 2001.
Ministry of Economic Development and Trade	The State Statistics Service of Ukraine within the Ministry of Economic Development and Trade is responsible for collecting and maintaining environmental data as well as economic data for the agricultural sector. Agricultural data is aggregated from surveys collected from all agricultural cooperatives/enterprises.	1991	Verkhovna Rada of Ukraine, 1991.

Ministry of Internal Affairs	The Ukrainian Hydrometeorological Center (UHMC) is housed under the State Emergency Service of Ukraine, under the Ministry of Internal Affairs. The UHMC is responsible for state weather forecasting, but it also conducts environmental monitoring, including water quality data. UHMC also collects and stores historical climate data and assesses growing conditions, yields, and expected seasonal weather conditions.	UHMC established 1921	UHMC, 2023. Osadchyi and others, 2021.
State Committee for Water Management	Central executive body tasked with development and implementation of water resource management.	1991	Cabinet of Ministers of Ukraine, 1991. Ministry of Economic Development and Trade, [undated].
Law on Seeds and Planting	Law setting system of state support and supervision of crop seed production, trade, and planting. State certificates are required to import and export seeds. Responsible for supervising the crop seed industry and compliance of international law on import and export of plant materials set by the World Trade Organization (WTO) and the International Plant Protection Convention (IPPC).	2002	Plotnikov and Senyshyn, 2022
Water basin administrations	Integrated water resource management within each of the nine recognized basins in Ukraine	In development	Yara and others, 2018. Leidel and others, 2011. Nabyvanets and others, 2017.

The transition from a planned economy to a market economy in Ukraine in the 1990s led to major disruptions that reduced agricultural production, and therefore led to a sharp decline in fertilizer use (Swinnen, 2004). Prior to 2000, agricultural land was governed by state and collective farms before it was mostly reallocated to private entities (Nivievskyi and others, 2022). By 2013, it was estimated that 46.9 percent of agricultural land belonged to commercial agricultural enterprises, 38.4 percent belonged to private individual landowners, 2.3 percent belonged to state agricultural enterprises, and 12.4 percent belonged to other entities (FAO, 2015). On March 31, 2020, the Ukrainian Parliament lifted a ban on the sale of agricultural land which had been in place for almost 20 years. On July 1, 2021, private individuals were able to own up to 100 hectares of agricultural land. As of December 3, 2021, sales to individuals resulted in private individuals acquiring 143,000 hectares. Further privatization of agricultural land is planned to start in 2024, when additional agricultural land will become available for purchase by Ukrainian citizens and entities (Plotnikov and Senyshyn, 2022).

Agricultural Land Use

In 2021, there were an estimated 42 million hectares of agricultural land in Ukraine, of which 32 million hectares, approximately 80 percent, were designated as arable. This is an area equivalent to nearly one-third of all arable land within the neighboring EU countries (Trading Economics, 2023). Of the remaining agricultural land, roughly 2.06 percent was classified as areas with "permanent crops," such as fruit trees and shrubs (ornamental trees and berry crops) or vineyards (Eurostat, 2023), whereas 18.2 percent were classified as "permanent meadows and pastures." The amount of agricultural land in Ukraine has remained steady since the early 1990s with only a slight decrease from 72.4 percent of agricultural land making up the total land area in 1992 to 71.3 percent in 2021 (FAO Statistics Division [FAOSTAT], 2024b). However, because of the ongoing Russia-Ukraine war, it is unclear what percentage of arable land will continue to be available to producers in Ukraine as well as whether enough producers will remain in Ukraine to produce food (Brumfiel, 2023; Martyshev and others, 2023).

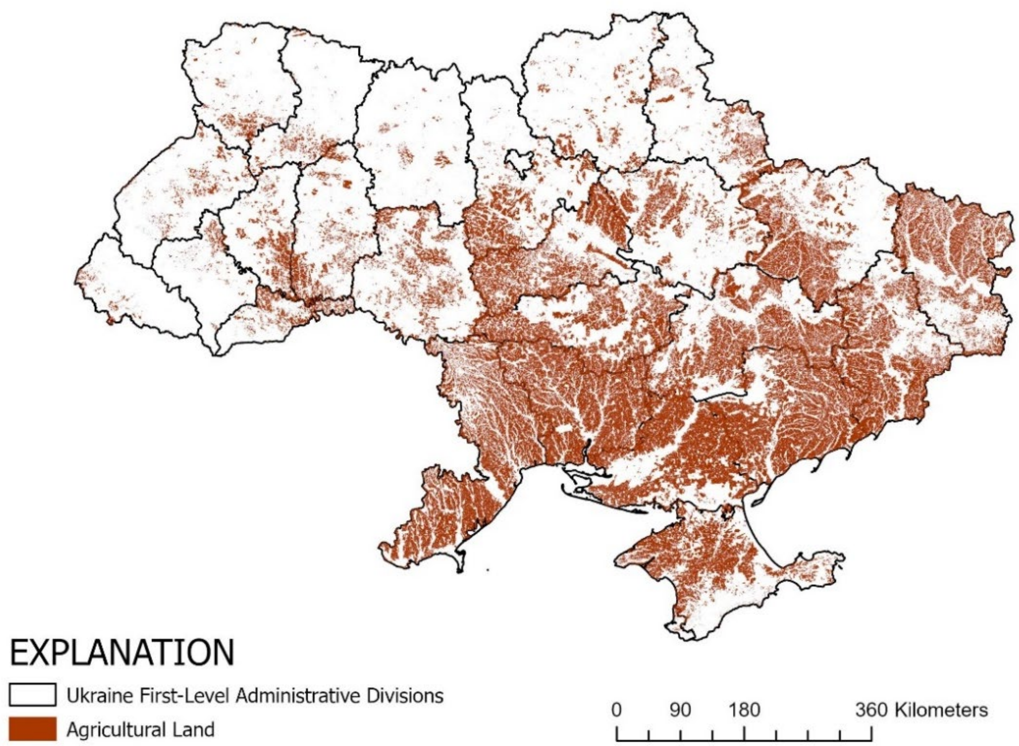

Figure 7. *Distribution of agricultural land in Ukraine. Land use classification data from World Bank Data Catalog (2022). Ukraine First-Level Administrative Divisions data from Hijmans (2015). Projection used: WGS 1984 UTM Zone 37N.*

Agricultural Fertilizer Use

According to Ritchie (2021), Ukraine used 76.51kg of fertilizer per hectare in 2021 – the total consisting of 52.4kg of Nitrogen (N), 13.35kg of nutrient phosphate (P_2O_5), and 10.76kg of nutrient potash, or potassium oxide (K_2O). When compared to recorded fertilizer use within the same period, Ukraine used substantially less fertilizer than the EU mean (120.39kg per hectare) and the global mean (118.62kg per hectare), and Ukraine's nitrogen use efficiency (NUE) was extremely high. NUE is a ratio calculated between the input and output of nitrogen and is calculated as percentage of use of total N (or N uptake) by crops. For instance, a NUE of 40 percent would mean that a crop used 40 percent of the total N input (typically in the form of fertilizer) while the remaining 60 percent was not taken up or used by the crop, therefore becoming an environmental pollutant. While a low NUE means the crop is taking up very little of the fertilizer applied to the field, a very high NUE (greater than 100 percent) means there is an undersupply of N for the quantity of crops being grown in an area. Under these growing conditions, crops instead take N from the soil—a process called "nitrogen mining" —which depletes the soil over time (Ritchie, 2021). In 2014, the NUE for Ukraine was 120.05 percent, a total much higher than most bordering countries such as Belarus (43.39 percent), Poland (45.27 percent), Slovakia (70.15 percent), Hungary (92.95 percent) and Moldova (98.5 percent), but similar to other bordering countries, namely Romania (107.17 percent) and Russia (125.2 percent) (Lassaletta and others, 2014). Although Ukraine's fertilizer use is less than recorded mean values from the EU and the world, its annual mean fertilizer use prior to the Russia-Ukraine war had been steadily increasing since the 1990s (FAOSTAT, 2024a). In conversation with a deputy minister of MINAGRO, it was reported that the quality of sowing decreased since the start of the Russia-Ukraine war given the sharp increase in price of fertilizer (which became three to five times more expensive) and the decreased quality and quantity of seeds available as a result of the ongoing conflict (Markiyan Dmytrasevych, a former deputy minister of MINAGRO, oral commun., 2023).

Agricultural Water Use

Agricultural water use was estimated as 4.4 billion cubic meters per year in 2010, or 30 percent of the country's total water use of 14.8 billion cubic meters (FAO, 2015). The stored reservoir capacity of Ukraine is an estimated 55.5 billion cubic meters, which includes 43.7 billion cubic meters in the Dnipro River basin (Grebin and others, 2014). These reservoirs serve roles of flood management, hydropower generation, and irrigation. In 2013, 2.269 million hectares, approximately 6 percent of cultivated land, had the capability for irrigation, which means the infrastructure was in place, and there was access to water that could be diverted through canals from Ukraine's rivers, primarily in the southern and eastern parts of the country (FAO, 2015). After factoring in groundwater and surface water inflows from neighboring countries, the total for renewable water resources for Ukraine is estimated to be 175 billion cubic meters per year. Ukraine's canals mostly serve southern and eastern parts of the country, from Kharkiv to Kherson to eastern Crimea, distributing water from the Dnipro River to other watersheds. Specifically, canals carry water from the Dnipro through Kharkiv to the Siverskyi Donets River from the Siverskyi Donets south to the coastal watersheds that drain into the Sea of Azov, and from the Dnipro to Crimea. Canals also divert water from the Dnipro to tributaries within the Dnipro basin (FAO, 2015).

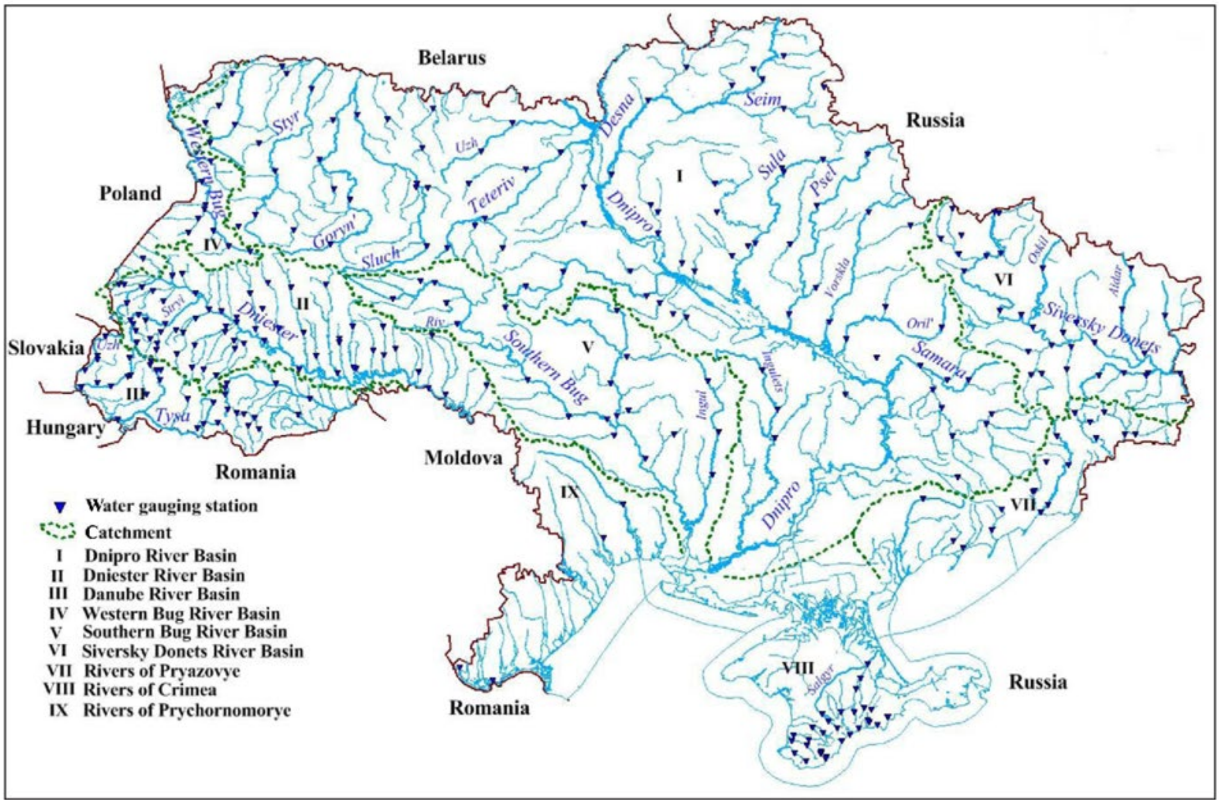

Figure 8. *Map of water gauging stations and the main catchments of rivers in Ukraine (2010). I – Dnipro; II – Dniester; III – Danube; IV – Western Bug, tributary of the Vistula; V – Southern Bug; VI – Siversky Donets, tributary of the Don; VII – Rivers of the Azov Sea coast; VIII – Rivers of Crimea; IX – Rivers of the Black Sea coast. Figure from Gorbachova, 2015. Reprinted from The intra-annual streamflow distribution of Ukrainian rivers in different phases of long-term cyclical fluctuations by Gorbachova, 2015, with permission from the Lithuanian Academy of Sciences.*

4. European Union's Strategy on Climate Change, Agriculture, and the Environment

In 1993, the EU was established as a multi-national political and administrative entity responsible for overseeing the economic and political integration of mostly Western European countries (Gabel, 2023; McBride, 2022). The modern EU was built, and ultimately evolved from, earlier post-World War II efforts at peaceful integration and collaboration amongst European countries that had previously been in conflict (EU, [undated]). Since its formation, the EU has grown from 15 member states covering most of western Europe in 1995 to 27 member states spanning across the European continent including eastern European countries such as Bulgaria and Romania and other former Soviet-occupied countries, such as Latvia, Lithuania, and Estonia (European Commission, [undated] e).

The EU consists of seven major political and administrative bodies responsible for executive, legislative, judicial and financial functions. Although the European Council is the first of the executive bodies and is responsible for setting policy agendas, the European Commission (the second of the executive bodies) is principally responsible for proposing laws, managing the EU budget, implementing decisions made, issuing new regulations, and representing the EU globally amongst non-EU entities (McBride, 2022). This means that while the European Council steers the general direction of the EU on social and political issues, the European Commission develops action items and designates what funds are allocated to certain causes. Therefore, in this report, policy documents reviewed are those published by the European Commission in furtherance of EU strategic goals on climate change, agriculture, and the environment. Moreover, potential research funding opportunities outlined by the European Commission are highlighted in this report to emphasize the importance of certain factors influencing food security, climate mitigation, and climate adaptation, and to illustrate the EU's commitment toward progress in climate-smart agricultural practices.

To better understand the EU's strategy on climate change, agriculture, and the environment, this report reviews the strategy and policy documents below with the purpose of identifying the assessment criteria used by the EU to review agricultural strategy, policy and practices of its member states. Additionally, the principal elements (problem identification, statements of strategy or position, goals and objectives, and brief explanations) of the above strategies, policies, and key research areas have been summarized in Tables 4, 5, 6, and 7.

- *Common Agricultural Policy (CAP)*: A policy applicable to the agricultural sectors of all EU member states, focusing on three major principles (for example, unified market for the free flow of agricultural products, EU product preference, and common financing of agricultural programs and initiatives [USDA Economic Research Service, 2023a]) with emphasis on food security, stable rural economies, and sustainable agricultural practices (European Commission, [undated] c). Refer to "Common Agricultural Policy" section and Table 4 in this chapter for an explanation of strategic objectives of the EU CAP.
- *Farm to Fork Strategy*: A strategic document which guides member states in developing CAP strategic plans which are aligned with the European Green Deal and Green Deal targets for 2030, including the development of sustainable and resilient food systems, a healthy populace, and a healthy environment (European Commission, 2020). Refer to "Farm to Fork Strategy" section and Table 5 in this chapter for an explanation of strategic goals of the Farm to Fork Strategy.
- *EU Biodiversity Strategy for 2030*: A long-term plan to increase societal resilience to various threats, including the adverse effects of climate change and food insecurity, and recover Europe's biodiversity (European Commission, Directorate-General for Environment, 2021). Refer to "Biodiversity Strategy for 2030" and Table 6 in this chapter for an explanation of four strategic objectives of the EU Biodiversity Strategy for 2030.

- *Key research areas*: Seven key research areas (refer to Table 7) outlined by the European Commission's Directorate-General for Research and Innovation that are most relevant when considering the intersections of agriculture, climate change, and the environment (refer to Chapter 2 of this report, "Climate-Smart Agriculture as a Framework").

Common Agricultural Policy

A common agricultural policy has existed since before the start of the modern EU in 1993. In 1958, when the Treaty of Rome was established, founding member states sought to rectify "systemic imbalances" in the agricultural sectors between member states due to differences in climate and landscapes across European countries. These differences caused disparities in supply and demand and led to instability in prices of agricultural products and farmer incomes. Because of concerns about "permanent market instability" amongst founding member states who would be trading agricultural goods with one another, member states agreed to enact supranational regulations and policy to guide and govern their agricultural sectors (Milicevic, 2023). The core objectives of the Common Agricultural Policy (CAP) are:

- Increasing agricultural productivity through technological progress and ensuring efficiency in production factors
- Establishing and ensuring a fair standard of living for farmers (farmer income and farm viability)
- Stabilizing agricultural markets
- Safeguarding supply availability
- Ensuring reasonable prices for agricultural goods

In addition to the CAP's core objectives, CAP strategic plans (comprehensive agricultural plans developed by members states) are also required to address strategic goals and objectives set for the CAP every four years by the European Council. The current iteration of these strategic goals and objectives, which are in effect from the year 2023 until 2027, include ten key objectives that address rural economies, environmental stewardship, innovative agricultural practices, sustainable food systems, and climate change (European Commission, [undated] f). This report highlights five out of ten key objectives (refer to Table 4) as EU assessment criteria for CAP Strategic Plans directly concerned with the intersections between climate change, agriculture, and the environment as outlined in the CSA framework (refer to Chapter 2: "Climate-Smart Agriculture as a Framework").

Table 4. *Explanation of five 2023-27 strategic objectives of the EU Common Agricultural Policy (CAP). Data from European Commission, Directorate-General for Agriculture and Rural Development (undated) a.*

Strategy/Policy	Period of Effect/Date Established	Issues/Concerns	Goals/Objectives	Explanation
Common Agricultural Policy (CAP)	2023-2027	Food, environment, rural landscapes and economies	Protect food quality and human health	Improve EU agricultural production for more adequate response to societal demands on food and health, including high-quality, safe and nutritious food produced in a sustainable manner.

			Contribute to climate change mitigation	Reduce greenhouse gas emissions and enhance carbon sequestration while promoting sustainable energy.
			Manage natural resources efficiently	Increase efficiency in development and management of natural resources, including by reducing chemical dependency.
			Preserve landscapes and biodiversity	Stop and reverse biodiversity loss, enhance ecosystem services and preserve habitats and landscapes.
			Foster knowledge and innovation	Modernize agriculture and rural areas through sharing knowledge, innovation and digitalization, and by supporting farmers through improved access to research, innovation, knowledge exchange and training.

Along with CAP core objectives and the 2023-2027 strategic goals and objectives highlighted in Table 4, agricultural strategy, policy, and practices of member states are also evaluated against two additional strategic initiatives: the Farm to Fork Strategy and the EU Biodiversity Strategy for 2030 (Tables 5 and 6).

Farm to Fork Strategy

The Farm to Fork Strategy is a strategic document which provides guidance to member states on how to develop national agricultural policies and encourage or incentivize subnational and local agricultural practices which further or align with UN's Sustainable Development Goals, and the European Green Deal (specifically in meeting the Green Deal targets for 2030). The strategic position expressed in the Farm to Fork Strategy document recognizes food produced by member states as already setting the global standard for "safe, plentiful, nutritious" and high-quality food, but that European food should also become the "global standard for sustainability" in agriculture and food systems planning and implementation (European Commission, 2020). Relevant assessment criteria for CAP Strategic Plans based on this strategy are captured in Table 5.

Table 5. *Explanation of two strategic goals of the EU Farm to Fork Strategy. Data from European Commission (2020).*

Strategy/Policy	Period of Effect/Date Established	Issues/Concerns	Goals/Objectives	Explanation
Farm to Fork Strategy (European Commission, 2020)	Est. 2020	Challenges of sustainable food systems	Strengthen EU food system resilience and ensure food security	Improve plant health. "Climate change brings new threats to plant health. The sustainability challenge calls for measures to protect plants better from emerging pests and diseases, and for innovation" (European Commission, 2020 p. 10).
		Climate change: non-uniformity and non-linear progress to reducing greenhouse gas (GHG) emissions across member states	Reduce environmental and climate footprint	Reverse biodiversity loss. Reduce dependency on pesticides and antimicrobials. "The use of chemical pesticides in agriculture contributes to soil, water and air pollution, biodiversity loss and can harm non-target plants, insects, birds, mammals and amphibians" (European Commission, 2020 p. 9).
		Environmental degradation: Air, soil, water pollution and GHG emissions from non-production stages in food cycle (e.g., manufacturing, processing, retailing, packaging, transporting, and so forth)		Reduce excess fertilization. Preserve and recover aquatic biodiversity. "The excess of nutrients (especially nitrogen and phosphorus) is another major source of air, soil and water pollution and climate impacts. It has reduced biodiversity in rivers, lakes, wetlands and seas" (European Commission, 2020 p. 9).

Biodiversity Strategy for 2030

The EU Biodiversity Strategy for 2030 is a comprehensive plan developed to set "Europe's biodiversity on the path to recovery by 2030" (European Commission, Directorate-General for Environment, 2021). The strategy guides member states in the development of national policies and actions which align with the 2030 Agenda for Sustainable Development set by the UN (United Nations General Assembly, 2015), and the Paris Agreement on Climate Change (UN, 2015). The document links biodiversity loss and climate change and identifies inefficient use of natural resources as a driver of both. Regarding the intersection between climate change, agriculture, and the environment, the strategic position is to "build societal resiliency to future threats including climate change and food insecurity" (European Commission, Directorate-General for Environment, 2021). Relevant assessment criteria for CAP Strategic Plans based on this strategy are captured in Table 6.

CAP Strategic Plans are also assessed by whether and to what extent they have implemented country-specific recommendations previously issued by the EU to each member state. Given that Ukraine is not yet a member state of the EU, country-specific recommendations are out of the scope of this report but could be relevant for planning if already issued.

Table 6. *Explanation of four strategic objectives of the EU Biodiversity Strategy for 2030. Data from European Commission, Directorate-General for Environment (2021).*

[%, percent]

Strategy/Policy	Period of Effect/Date Established	Issues/Concerns	Goals/Objectives	Explanation
EU Biodiversity Strategy for 2030 (European Commission, Directorate-General for Environment, 2021)	2020-2030; Est. 2020	The protection and conservation of natural resources and ecosystems	Reduce pesticide use	Reduce the use of chemical pesticides by 50% and reduce the use of more hazardous pesticides by 50%.
			Increase fertilizer use efficiency	Reduce the loss of nutrients from fertilizers by 50%, resulting in the reduction of fertilizer use by at least 20%.
			Increase area of agroecosystems	Ensure at least 10% of agricultural area is under high-biodiversity landscape features.
			Increase organic farming	Place at least 25% of agricultural land within EU under organic farming management, and appreciably increase the uptake of agro-ecological practices.

European Union's Key Research Areas

Seven key research areas as defined by the European Commission's Directorate-General for Research and Innovation are highlighted in Table 7 not only because of their compatibility with the CSA framework, but also to serve as further evidence of the EU's commitment to supporting the adoption of climate-smart agricultural practices by EU member states. These seven key research areas are supported by three primary funding programs within the European Commission: the European Agricultural Fund for Rural Development (which is one of the principal funding programs of CAP), Horizon Europe (European Commission, 2023), and the LIFE Programme (European Commission, 2021). These funding programs could be potential sources of external support for Ukraine's adoption of new programs or the improvement of existing programs that further food security, climate adaptation, and contribute to climate mitigation.

Table 7. *Summary of seven key EU research areas in Agriculture, forestry, and rural areas (European Commission, [undated] a-g).*

Key Research Areas	Issues/Concerns	Goals/Objectives	References
Genetic Resources and Breeding	Healthy diets; Changing and variable climate; Loss of genetic diversity (limited number of plant and animal species)	Halt further loss of genetic diversity; Broaden genetic based of cultivated crops; Create varieties that meet demands related to quality, resilience and sustainability	(European Commission, [undated] a)
Plant Health	Pests, disease, and other biotic (living) threats	Develop of a wide range of tools for prevention, monitoring, control and management of pests and diseases along with risk management strategies, including seeking alternatives to contentious pesticides	(European Commission, [undated] b)
Public Goods from Agriculture and Forestry	Lack of depth of knowledge around public goods provided by agriculture and forestry, including biodiversity, water regulation, erosion control, resilience to floods, and climate change mitigation	Improve the understanding of complex interactions between primary production systems and ecosystems services	(European Commission, [undated] c)

Rural and Farming Dynamics and Policies	Aging farmers; demographic and/or social decline of rural communities; transitioning rural economies	Identify evidence and generate knowledge that aid in designing modern policies to help rural communities and business overcome challenges associated with meeting demands for generational renewal, food security, ecosystem services	(European Commission, [undated] d)
Soils	Soil degradation and erosion; desertification; the role of soil as climate mitigation practice (carbon and nitrogen sinks)	Design methods to increase soil carbon content, enhance soil biodiversity, and reduce soil erosion (all crucial for food security ["Soil-Food Web"]); Increase knowledge in long-term process of soil formation, on soil fertility, and on improving productive and ecosystem functions of soil	(European Commission, [undated] e)
Sustainable, Circular and Innovative Value Chains	Inefficient resource use; food insecurity; rural economic growth and development; carbon dioxide emissions from food and energy production	Better understand the links between food systems and their efficiency, resiliency and sustainability; "green chemicals, green growth and circular economy"; Understand food chain dynamics and interactions with non-food chains	(European Commission, [undated] f)
Water, Nutrients and Waste	Natural resources depletion; environmental degradation; externalities from agricultural sectors which contribute to climate change	Develop solutions that will strike a proper balance between productivity and environmental goals in agriculture and forestry	(European Commission, [undated] g)

5. Winter Wheat Breeding

Plant breeding is the development of new varieties of plants with the goal of attaining varieties with desirable traits, such as increased crop yield, more flavor, or an increased nutritional value (Sharman, 2022). Traditional breeding of crops, by manually cross-pollinating varieties with desirable phenotypic traits, has been practiced since the beginning of agriculture and plant domestication (Pérez-de-Castro and others 2012; Sharman, 2022). Phenotypic traits are observable traits, such as color, size, and the presence or absence of disease (National Human Genome Research Institute, 2023). Today, the availability of genomic tools and resources make genomic-based crop breeding practicable (Pérez-de-Castro and others, 2012).

Plant genomics is the study of plant genes and the study of the interaction of those genes with the environment. Plant genomics allows researchers to “identify genes and genomic regions responsible for plant growth, development, and stress response” (You, 2023). Knowledge generated from genomic research has benefited plant breeders by providing them with “an understanding of the molecular basis of complex traits” (Pérez-de-Castro and others, 2012). Moreover, fine genetic mapping, or association mapping, methods have led to the identification of genetic markers linked to genes responsible or associated with desirable traits (Pérez-de-Castro and others, 2012). Marker-assisted breeding is a method which employs identified genetic markers to select plants based on the presence of certain genes, rather than phenotypic traits (Sharman, 2022).

Genomic mapping and selection, and marker-assisted breeding have substantial potential to aid in development of crops that can meet strategic and substantive goals set for climate adaptation, climate mitigation, and food security. As stated by Fess and others (2011, p. 1745), “with proper and efficient breeding technologies that address low-input conditions, varieties that are geared toward limited or stressed agroecosystems could alleviate the production pressures” associated with increased demand, limited resources, and variable climate conditions. Potential benefits of using marker-assisted breeding methods over traditional phenotypic selection methods include large time reductions in developing new varieties, an increase in overall rate of genetic gain per breeding cycle, and the possibility of improving traits that cannot be measured using phenotypic screening (Brennan and others, 2005). Some desirable traits which could be attained for wheat crops through genomic-based breeding methods include increased crop yield (Fess and others, 2011; Hatfield and Beres, 2019), increased disease resistance (Fess and others, 2011; National Research Council (US) Committee on Biosciences, 1985), increased drought tolerance and water efficiency (Qiao and others, 2022; Yu and others, 2020), increased heat tolerance (Ni and others, 2018), increased pest resistance (Fess and others, 2011), pre-harvest sprouting, improved frost tolerance (Brennan and others, 2005), and improved end-use qualities, such as grain characteristics, and milling, dough and baking properties (Subedi and others, 2023).

The value of using marker-assisted breeding methods over traditional phenotypic selection methods in wheat breeding programs depends on a number of factors, including the objective(s) of the breeding program, the relevance of a particular trait in key target regions, how closely linked a particular genetic marker is to the desired trait, and the cost of or capacity to employ a phenotypic screening for the desired trait (Brennan and others, 2005). Costs of wheat breeding programs are variable and depend on the costs of a number of components within a particular program (refer to Appendix B for a list of potentially applicable components). Some attempts have been made to estimate costs for components of wheat breeding programs (Brennan and others, 2005; Brennan and Martin, 2006) and tools have been developed to aid decisionmakers in better understanding capital and operating costs, such as the University of Queensland’s Breeding Costing Tool (OZ Sorghum, 2020).

Kansas State University Wheat Breeding Program

A case study is a form of qualitative research and refers to the collection and presentation of detailed information about a particular instance, group, or individual, with a focus on in-depth description (Becker and others, 2005). The unit of analysis of this case study is one winter wheat breeding program: the Kansas State University (KSU) Wheat Breeding Program. The rationale for choosing the KSU Wheat Breeding Program as a case study is three-fold: (1) the relatively similar climate and agricultural landscape between Kansas and Ukraine (World Data Center for Geoinformatics and Sustainable Development, [undated]); (2) the crop of interest for this report (winter wheat); and (3) Kansas's role as the top producer of winter wheat in the United States, which is comparable to Ukraine's role as a major global exporter of winter wheat (USDA National Agricultural Statistics Service [USDA NASS], 2023 b). The purpose for this case study is to describe the basic components that make up the winter wheat breeding program at KSU as well as to describe the program's objectives and outputs and to what extent those objectives and outputs satisfy the guiding principles and three pillars (climate adaptation, climate mitigation, and productivity) of CSA and address concerns, requirements and expectations that have been created for EU member states regarding climate change, food security, and environmental stewardship.

In exploring and describing this case study (refer to the "Description of the Case Study" section in this chapter), the following questions are answered:

- What is the KSU Wheat Breeding Program?
- Who are the entities involved in the program? What are their respective roles?
- What is the scope of the program? What are its objectives and intended benefits?
- What is the process by which new varieties are developed and selected? By what metrics does the program determine a successful variety?
- What is the success of KSU-developed winter wheat varieties in the Kansas market?

In analyzing the case study (refer to "Analysis of the Case Study" section in this chapter), the following questions are answered:

- Does the KSU Wheat Breeding Program serve the objectives of the CSA framework (refer to Chapter 2, "Climate-Smart Agriculture as a Framework")?
    - How does the program address the three CSA pillars (climate adaptation, climate mitigation, and productivity)?
    - How does the program address the two guiding principles of CSA (increasing efficiency and increasing resiliency)?
- Does the KSU Wheat Breeding Program serve goals and objectives of EU strategy and policy on climate, agriculture, and the environment?
    - How does the program address the assessment criteria set for CAP Strategic Plans (refer to "The European Union's Strategy on Climate Change, Agriculture, and the Environment" section in Chapter 4)?

Review of the KSU Wheat Breeding Program was conducted via analysis of government and university web pages, blog posts, and interviews available online about the program, and by thematic mapping of major concepts and components integral to the program.

Description of Case Study

The KSU Wheat Breeding Program (hereinafter "the program") is a plant breeding program focused on developing new hard red and white winter wheat varieties (Western Kansas Research Extension Centers, 2024). The program started in the early 1900s with no projected end date and was established to serve the changing needs of wheat producers and markets in Kansas, and in other neighboring wheat producing states, such as Oklahoma, Colorado, Nebraska, and Texas (Kansas Wheat Alliance, 2019; Kansas Wheat [undated]). The program uses 10 experimental field sites (nine in Kansas and one in Texas) for preliminary and advanced screening of varieties in development and, since its inception, has released more than 40 winter wheat varieties (Kansas Wheat, [undated]). The program includes a network of governmental and non-governmental collaborators, funders, and partners which assist with genomic mapping, marker-assisted breeding, preservation of genetic materials, conducting pest and disease research, funding research, quality assurance, quality control, and distributing varieties to the market (Table 8).

Table 8. *Explanation of entities involved in the Kansas State University (KSU) Wheat Breeding Program as well as their roles and focus areas.*

Actor	Affiliation	Functional Group	Role	Focus Area
Wheat Genetics Resource Center	KSU	Public	Research	Genetic data and genomic mapping; Knowledge in genetics and biotechnology; Marker-assisted breeding (Kansas Wheat, [undated])
			Breeding	Facilities: state-of-the-art laboratories, greenhouses, and field-plot facilities; Gene bank (2,500 wheat species accessions) (KSU, [undated] b); focus on development of varieties adapted to central and eastern Kansas (Western Kansas Research Extension Centers, 2024)
Wheat Quality Laboratory	KSU	Public	Research	Wheat and flour quality assessments (KSU, [undated] c)
Western Kansas Research Extension Centers	KSU	Public	Breeding	Focus on development of varieties adapted to western Kansas (Western Kansas Research Extension Centers, 2024)
Department of Plant Pathology	KSU	Public	Research	Plant diseases for wheat varieties (KSU, [undated] a)
Department of Entomology	KSU	Public	Research	Pests that endanger wheat varieties (KSU, [undated] a)
Kansas Wheat Commission		Private	Funding	Provides funding to the KSU program for the development of winter wheat varieties (KSU, [undated] b)

Kansas Wheat Alliance		Private	Funding	Provides funding to the KSU program for the development of winter wheat varieties (Kansas Wheat Alliance, [undated]).
			Marketing and distribution	Broker for the licensing and marketing of value-added wheat technology produced by the KSU Wheat Breeding program and other wheat breeding programs (Kansas Wheat Alliance, [undated])
Central Small Grain Genotyping Laboratory	USDA Agricultural Research Service (ARS)	Public	Research	Genomic selection ; marker-assisted breeding (U.S. Department of Agriculture [USDA] Central Small Grain Genotyping Lab, [undated])
The Hard Winter Wheat Quality Laboratory	USDA ARS	Public	Research	Wheat and flour quality assessments (USDA Center for Grain and Animal Health Research, 2016)
Kansas Crop Improvement Association		Private	Funding	Provides funding to the KSU program for the development of winter wheat varieties (Kansas Wheat, [undated]).

The program's mission is to "develop and release new public hard red and white winter wheat varieties marketed by the Kansas Wheat Alliance" (KSU, [undated] d), a not-for-profit member organization founded with the express purpose of assisting in the delivery of new wheat varieties with "farmer-preferred" characteristics to wheat farmers (Kansas Wheat Alliance, [undated]). In the execution of its mission, the program has six categories of goals and intended benefits by which it currently seeks to improve winter wheat varieties (KSU, [undated] d):

1. *Productivity*: developing varieties with high yield and tolerance to pre-harvest sprouting due to early rainfall
2. *Disease resistance*: developing varieties with resistance to disease caused by fungus (leaf rust [*Puccinia triticina*], stripe rust [*Puccinia striiformis f.sp. tritici*], and fusarium head scab [*Fusarium graminearum*]) and by viruses (wheat streak mosaic virus, barley yellow dwarf virus)
3. *Drought tolerance*: developing varieties with ability to grow under limited water availability and increasing water efficiency
4. *Heat tolerance*: developing varieties with increased heat-stress tolerance
5. *Pest resistance*: developing varieties with resistance to insects (Stem sawfly [*Cephus cinctus*], Hessian fly [*Mayetiola destructor*])
6. *Food and product quality*: developing varieties with high marketability (wheat and flour quality) for pan bread and noodle making

The development of a new winter wheat variety by the program is a process that takes roughly 12 years to complete from the "initial cross [of genetic traits] to the release" of a particular variety (KSU, [undated] a). In the first year, more than 1,000 new experimental lines are crossed in greenhouses in bulk populations. From the second year through the fourth year, the primary criterion for success of the new lines is their relative resistance to wheat diseases. In the second year, the new experimental lines are planted in locations outside of the greenhouses and then exposed to certain wheat diseases. In this year, approximately 60 percent of lines (or 600 lines) exhibiting disease resistance will be selected to continue onto the next year's planting. By year four, only 300 of the original experimental lines will be selected to remain in the program based on disease resistance alone. In year five, the experimental lines are planted in different locations and continue to be evaluated for disease resistance as well as other criteria, including drought tolerance and some indicators of productivity, including field performance and "shatter" tolerance (KSU, [undated] a), or the loss of grain due to seed shattering (Bokore and others, 2022).

In year six, small samples (50-100 grams) of wheat are taken from lines and wheat and flour quality assessments are conducted on the samples, including a mixing test which tests the quantity of water and time spent mixing required to make a dough with desirable traits such as smoothness, pliability, and elastic structure. Approximately half of the remaining lines are eliminated at this stage because of poor dough mixing qualities. From years 7 to 12, sample sizes increase to 1,200 grams for each line and more robust quality assessments are conducted. The experimental lines, at this stage referred to as "advanced lines," will continue to be evaluated for and some will be eliminated on the basis of their general disease and pest resistance, overall plant characteristics, and end-use quality for bread and noodle making – both food product markets on which the program focuses. The advanced lines that perform well for 2–3 years (typically about 15 lines from the original 1,000 experimental lines) are sent to external winter wheat quality laboratories to be tested for their milling and baking characteristics. Advanced lines that are considered for release as a new winter wheat variety undergo extensive milling and baking quality assessments and are compared to popular winter wheat varieties already in the market (KSU, [undated] a). Quality targets are set for both hard red and hard white winter wheat (HWW Quality Target Committee, 2006; HWW Quality Targets Committee, 2007). Any advanced line selected for market distribution must have the same or better quality than varieties already in the market (KSU, [undated] a).

Winter wheat varieties developed by the program have been successful in the market. The USDA NASS and the Kansas Department of Agriculture's Kansas Agricultural Statistic Service have generated annual summaries of winter wheat varieties planted by wheat farmers in the state of Kansas since 2003. In these annual summaries, winter wheat varieties are ranked from first to tenth most popular variety in the state dependent on the number of acres planted per variety in a given year. In a 20-year period, from 2003 to 2023, winter wheat varieties developed or maintained by the program at KSU have ranked within the top ten of varieties, and most have sustained their presence within the top ten for multiple years (Figure 9). Notably, two winter wheat varieties developed by the program ("Jagger" and "Everest") have each been in the top ten for 12 years over two decades. In the same period, a KSU-developed variety has placed first 12 times. On average, the program has had nearly three (or 2.8) varieties place within the top ten each year. In 2023, the program had four varieties place within the top ten: "Everest" at 9th place, "Zenda" at 8th place, "Joe" at 7th place, and "Bob Dole" at 2nd place (Kansas Agricultural Statistics Service, 2003–07; Kansas Department of Agriculture Division of Statistics, 2008–09; USDA NASS, 2010–23 a).

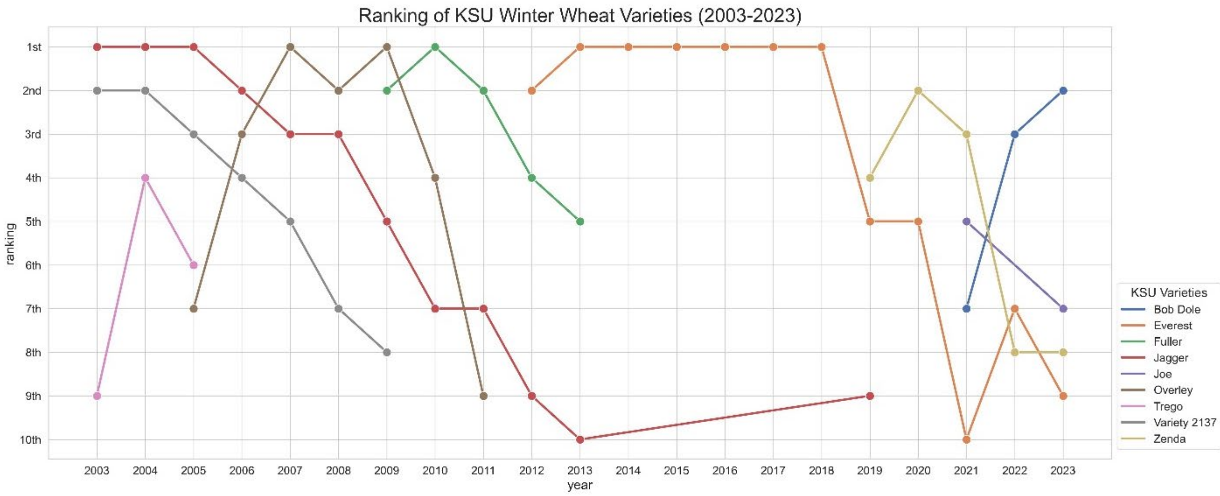

Figure 9. *Performance of winter wheat varieties developed or maintained by Kansas State University (KSU) winter wheat breeding program according to wheat acres planted in Kansas from 2003 to 2023. Data from Kansas Agricultural Statistics Service (2003–07), Kansas Department of Agriculture Division of Statistics (2008–09), and USDA NASS (2010–23 a).*

Analysis of Case Study

Cohesiveness with the Climate-Smart Agriculture Framework

The case study successfully demonstrates the potential for winter wheat breeding programs to meet the objectives outlined in each of the three pillars (climate adaptation, climate mitigation, and productivity) of the CSA framework. By providing farmers with access to new winter wheat varieties with increased drought and heat tolerance, winter wheat farmers are able to adapt and build resilience to the projected adverse effects of climate change, including increase in mean temperatures, variable precipitation, and prolonged drought. The case study also demonstrates some success in meeting the climate change mitigation objective by reducing potential GHG emissions through developing varieties with increased crop yield and drought tolerance, therefore potentially decreasing the reliance on expanding agricultural land use and decreasing agricultural water use. Publicly available information on the program does not directly address if the program is selecting for varieties that more efficiently uptake nutrients, such as N. However, the report team confirmed that the eastern section of the program is currently experimenting with selecting varieties that produce more protein than expected given their higher yield levels – a potential indicator of a variety's ability to uptake N more efficiently and perform better with lower N inputs when compared to other varieties (Dr. Allan Fritz, KSU, written commun., 2024). Lastly, the case study is successful in addressing the third pillar of the CSA framework, "productivity," which seeks to increase productivity. The case study shows the ability for breeding programs to develop winter wheat varieties that not only are more productive but that also have higher quality in wheat and flour characteristics, therefore increasing the marketability of wheat varieties grown by farmers.

Regarding the first guiding principle of CSA (increasing efficiency), the case study shows some success in developing winter wheat varieties which can potentially mitigate the future need for expansion of agricultural land use and increased agricultural water use through increased crop yield and productivity and increased drought tolerance. However, increasing efficiency of nutrient uptake in wheat varieties for flour is challenging, and potential gains in nutrient uptake may reduce crop yield or overall flour quality (Dr. Allan Fritz, KSU, written commun., 2024). Nevertheless, selecting genomic traits and breeding for improved nutrient uptake is possible (Fess and others, 2011; Ritchie, 2021; Walter and others, 2017; Dr. Allan Fritz, KSU, written commun., 2024), and could be incorporated into any breeding program as a specified target.

Regarding the second guiding principle of CSA (increasing resiliency), the case study demonstrates the potential for winter wheat breeding programs to reduce exposure and sensitivity to risks in agricultural production (refer to "Increasing Resiliency" section in Chapter 2) through the following interventions:

- Increasing crop yield and productivity
- Decreasing input requirement for crops (land and water)
- Improving nutrient uptake (N)
- Increasing drought tolerance
- Increasing heat tolerance
- Increasing pest resistance
- Increasing disease resistance
- Meeting policy standards for some but not all sustainability targets in agriculture

Cohesiveness with the European Union's Strategy on Climate, Agriculture, and the Environment

When reviewing the three principal strategies and policies (CAP, Farm to Fork Strategy, and the EU Biodiversity Strategy) concerning agricultural planning in the EU, three major overarching goals can be identified:

1. Food security and food quality
2. Reduction of environmental and climate footprint by reducing use of resources and increasing efficiency
3. Preservation of landscapes and biodiversity

As exhibited by the case study, winter wheat breeding programs can contribute to food security and food quality goals by increasing productivity and nutritional value of wheat and improving end-use qualities of flour. Decreasing the susceptibility of wheat varieties to biotic and abiotic stressors contributes to food security and the reduction of environmental and climate footprints by decreasing pesticide use and water use (Fess and others, 2011). Increasing productivity of wheat crops could also potentially reduce the number of hectares needed to produce sufficient grain supply to meet food security goals while also preserving forested lands and the ecosystems dependent on them. Furthermore, reduced pesticide and water use could benefit ecosystems vulnerable to high-input agricultural systems. However, improving the efficiency of nutrient uptake in wheat varieties, particularly uptake of N, may reduce crop yield or overall flour quality (Dr. Allan Fritz, KSU, written commun., 2024). Therefore, tradeoffs between improving efficiency in nutrient uptake, in particular uptake of N, and increasing yield or nutritional value of wheat varieties, or improving flour end-use properties must be considered.

Regarding the key research areas outlined in Table 7 in Chapter 4, the case study demonstrates that a winter wheat breeding program could directly contribute to the stated goals and objectives of five of the seven key research areas (for example, Genetic Resources and Breeding, Plant Health, Soils, Public Goods from Agriculture and Forestry, and Water, Nutrients and Waste) through the following interventions in the winter wheat sector:

- Increasing knowledge of biotechnology and genomics
- Increasing crop yield and productivity
- Increasing the food quality and nutritional value of varieties
- Increasing crop varieties
- Increasing heat tolerance
- Increasing drought tolerance
- Increasing pest resistance
- Increasing disease resistance
- Decreasing input requirements for crops (land and water)
- Improving nutrient uptake (N)

Although the case study shows that winter wheat breeding programs can increase food quality and the nutritional value of wheat varieties, it does not explicitly demonstrate potential to increase job or career opportunities in rural areas (stated objectives of the two remaining key research areas previously highlighted: Rural and Farming Dynamics, and Sustainable, Circular and Innovative Value Chains). Although the benefit of increased job or career opportunities may not be explicit, the potential for a winter wheat breeding program to provide increased job and career opportunities in rural areas is implicit given the need for personnel to make the program's operations possible. Therefore, although not explicitly a goal of the program at KSU, increased job opportunities and the creation of new career pathways could be intentionally planned for as articulated outcomes of any crop breeding program if such outcomes align with development goals.

6. Discussion

Given mounting pressures on global agricultural production from climate change, decreased availability of natural resources, including water, and market and political instability due to the ongoing Russia-Ukraine war, Ukraine faces the substantial challenge of forming a national agricultural policy that will meet EU requirements and serve global and domestic food demand under complex circumstances.

Analysis of climate data in this report (refer to “Climate of Ukraine” section in Chapter 3) suggests that the mean annual temperature in Ukraine has increased since the 1980s, and future climate projections indicate that the pattern of increasing temperatures will continue (World Bank, 2021). With the greatest increases in temperature occurring in the winter months (January through March), winter wheat production will need to adapt to keep productivity stable. The climate analysis also demonstrates that there will be more adverse effects from climate change experienced in the Steppe region, including elevated risks of heat waves, where most agricultural land is currently situated in Ukraine (Skrypnyk and others, 2021; Mishra and others, 2023). Heat stress from increasing temperatures and heat waves is of particular concern for cool season crops such as winter wheat (Mishra and others, 2023). Therefore, these findings support the concept that wheat varieties would benefit from genetic improvement of traits responsible for increased heat tolerance (Ni and others, 2018).

The result from climate projection models discussed in the “Implications of Climate Change for Agriculture in Ukraine” section in Chapter 3 also indicate that winter wheat yields are expected to be negatively affected by increased aridity, drought events, and heatwaves. Arid zones are projected to expand from south to north and to the east, compromising most agricultural regions in Ukraine. Whereas the winter wheat season may become longer as a result of climate change, initial planting dates may be postponed because of drier conditions in the late summer and wheat crops may require more water owing to increased evapotranspiration rates and reduced soil moisture. Considering that most agricultural land is in the southern and eastern regions of Ukraine where most winter wheat is grown, and that moving or expanding agricultural production to northern or western regions of Ukraine is costly and in some cases detrimental to forests and dependent ecosystems, these findings support the hypothesis that wheat varieties would benefit from genetic selection of traits which could increase drought tolerance and improve water efficiency (Qiao and others, 2022; Yu and others, 2020).

This report has found that Ukraine’s nitrogen use efficiency (NUE) score (120.05 percent in 2014) is exceptionally high, especially when compared to most neighboring countries. As discussed in the “Agricultural Fertilizer Use” section in Chapter 3, NUE scores of more than 100 percent are indicative of nutrient-depleted soils. At the same time, Ukrainian farmers have been unable to access affordable fertilizers since the start of the war, which has negatively affected sowing quality. This finding supports the idea that resilience in agricultural systems requires low-input crop varieties (Fess and others, 2011). However, selecting for winter wheat varieties with improved nutrient uptake, in particular improved uptake of N, could reduce yield or overall flour quality (refer to “Analysis of Case Study” section in Chapter 5).

This report has also found that winter wheat breeding programs are a potential mechanism for addressing the need for climate adaptation and mitigation, as well as ensuring food security. As reviewed in the “Kansas State University Wheat Breeding Program” section in Chapter 5, the case study analysis supports the notion that winter wheat breeding programs can successfully identify and select for desirable traits in winter wheat varieties, and that those varieties can be successful in the market. As the authors of this report learned from MINAGRO, Ukraine is currently experiencing decreased access to quality seeds, which has adversely affected sowing quality. As demonstrated by the case study, winter wheat breeding programs can store genetic material of quality varieties and make them readily accessible to farmers within the region, therefore decreasing the reliance on attaining seed varieties from external sources.

Lastly, as outlined in the "Analysis of Case Study" section in Chapter 5, winter wheat breeding programs can address the strategic and substantive goals and objectives of the CSA framework and of the EU's agricultural standards. Addressing these goals and objectives are not only crucial for Ukraine's admittance into the EU but can also facilitate Ukraine obtaining external support and funding for new or existing programs for genetic research, genomic selection, and marker-assisted breeding.

Limitations and Future Research

The scope of this report is limited to information which could be obtained online in public-facing government and university webpages, and other publicly available sources, and one virtual interview with Markiyan Dmytrasevych, a former deputy minister of MINAGRO. Regarding agricultural strategic and policy goals of Ukraine, this report could have benefitted from long-term engagement with MINAGRO. However, long-term engagement with MINAGRO personnel is not yet possible because of the ongoing war.

Further research is required to identify winter wheat breeding programs which focus on reducing reliance on fertilizer and the development of low-input winter wheat varieties as this is a particularly challenging trait to select for winter wheat varieties developed for flour. Additional research could also assess existing wheat breeding programs in Ukraine and how they could be improved and tailored to satisfy climate-smart agriculture goals and EU CAP standards. Furthermore, a cost-benefit analysis could also be useful for determining if investing in domestic winter wheat breeding programs is both feasible and suitable for Ukraine.

7. Conclusion

New and exacerbated stressors are projected to emerge from the adverse effects of climate change, increased global population, and environmental degradation. Ukraine's role as a global exporter of food and agricultural products is crucial for stabilizing future global food supply and prices. At present, Ukraine is doubly challenged to address climate and environmental pressures, as it has to contend with social and political pressures due to the ongoing war with Russia and ensuing political and economic instability. Furthermore, Ukraine's aspirations to join the European Union (EU) as a new member state requires policy- and decision-makers to restructure existing policies and draft new policies that conform to standards held by the EU.

This report used the climate-smart agriculture (CSA) framework developed by the Food and Agriculture Organization of the United Nations (FAO) as an approach to identify and understand important factors at the intersection of climate, agriculture, and the environment. This report has examined the potential climate change effects in Ukraine and the implications of those effects for Ukrainian agriculture. Using the CSA framework, this report has also identified and reviewed the assessment criteria used by the EU to evaluate common agricultural policy (CAP) strategic plans generated by EU member states. And lastly, this report has highlighted and examined the potential for one climate-smart agricultural practice (winter wheat breeding) in Ukraine's largest crop sector (winter wheat) to address climate, agricultural and environmental goals.

Ultimately, this report finds that winter wheat breeding programs could be a meaningful approach for climate mitigation and adaptation in Ukraine's agricultural sector and could help to stabilize crop yields in areas where winter wheat crops may be subject to drier and hotter conditions, thereby contributing to global food security. Furthermore, winter wheat breeding programs would satisfy numerous EU goals around climate change, agriculture, and the environment. The information provided by this report and its findings are intended to aid Ukrainian policy- and decision makers and others in technical and development assistance roles in the development of agricultural strategy, policy and planning.

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Appendix A

Appendix A. List of oblasts and municipalities with oblast status within each of the Kyiv International Institute of Sociology (KIIS) regions

Kyiv International Institute of Sociology (KIIS) Region	*Name of oblast or municipality*
Central	Cherkasy
	Chernihiv
	Kyiv
	Kyiv City
	Kirovohrad
	Poltava
	Sumy
	Vinnytsia
	Zhytomyr
East	Donetsk
	Kharkiv
	Luhansk
South	Autonomous Republic of Crimea
	Dnipropetrovsk
	Kherson
	Mykolaiv
	Odesa
	Sevastopol City
	Zaporizhzhia
West	Chernivtsi
	Ivano-Frankivsk
	Khmelnytskyi
	Lviv
	Rivne
	Ternopil
	Zakarpattia
	Volyn

Appendix B

Appendix B. A list of components that can be used to estimate potential costs of wheat breeding programs (Brennan and others, 2005; Brennan and Martin, 2006).

General components of wheat breeding programs (Brennan and Martin, 2006)	• Assessment and scoring • Capital investments (infrastructure, equipment, and so forth) • Data management • Disease inoculation • Harvest and post-harvest activities • Land leasing • Operation and maintenance of machinery and equipment • Seed preparation and sowing • Site and irrigation management • Travel to and between sites
Components of marker-assisted breeding (Brennan and others, 2005)	• Intellectual property rights related to marker (if not developed by breeding program) • Research and development for marker (if developed by breeding program) • Tissue collection and storage • Method of extraction of DNA/protein for analysis • Extent to which extracted DNA is used for different markers • Analytical method used • Rate of throughput of analytic system • Degree to which the analysis is combined with that for other markers ("multiplexing") • Ease of scoring the alleles after the analysis • Labor required for the different operations • Laboratory equipment required • Utilization of the equipment required (or the overall throughput of the laboratory)