chapter 7

contents

Page

1. Introduction 212

2. Historical trends of grain production and trade 213
   2.1 Decline in agriculture in 1991-2001 213
   2.2 Recovery trends in 2002-2013 215

3. Short-term weather variability and land dynamics 219
4. Impacts of climate change on grain production 222

5. Outlooks for grain production and export 229

6. Conclusions 235

References 237

Citation

Lioubimtseva, E., N. Dronin and A. Kirilenko. 2015. Grain production trends in the Russian Federation, Ukraine and Kazakhstan in the context of climate change and international trade, In: *Climate change and food systems: global assessments and implications for food security and trade*, Aziz Elbehri (editor). Food Agriculture Organization of the United Nations (FAO), Rome, 2015.

chapter 7

Grain production trends in the Russian Federation, Ukraine and Kazakhstan in the context of climate change and international trade

Elena Lioubimtseva[1], Nicolai Dronin[2] and Andrei Kirilenko[3]

main chapter messages

- Russian Federation, Ukraine, and Kazakhstan (RUK) together are very likely to surpass the European Union and the United States within the next few years in total grain exports. However, official government goals of boosting grain and meat production by 2020s are unlikely to be fully reached by the three countries.

- High grain exports from RUK have been primarily driven by reduced domestic demand than by increased productivity. The latter remains below the historical trend and is still much lower than officially projected. Future use of abandoned arable lands for cropping remains uncertain and unlikely, given that abandoned lands in 1990's are marginal with very low potential productivity.

- Climate change scenarios suggest that the grain production potential in RUK may increase due to a combination of winter temperature increase, extension of the growing season, and yield-enhancing CO2 fertilization; however the most productive semi-arid zone could suffer a dramatic increase in drought frequency.

- Uncertainty about future grain production outlook in RUK region in relation to climate change require more refined modelling on crop yield impacts, land-use and land cover trends and their future impacts on GHG emissions. Also critical are future socio-economic changes including development pathways of infrastructure, financial systems, land market development and alignments between WTO requirements and agricultural subsidies.

[1] Geography and Planning Department, Grand Valley State University, Michigan, USA
[2] School of Geography, Moscow State University, the Russian Federation
[3] Department of Earth System Science and Policy, University of North Dakota, USA

1. Introduction

Climate change and variability increase the frequency and amplitude of regional crop shortfalls and create an impact on agriculture and food systems all over the world (Adams *et al.,* 1998; Parry *et al.*, 2004, Easterling *et al.*, 2007). Geographic patterns of food production are directly affected by climatic variables such as temperature and precipitation and the frequency and severity of extreme events (Tebaldi *et al.*, 2006; Rosenzweig and Tubiello, 2007). Climate change may also change the types, frequencies and intensities of various crop and livestock pests, the availability and timing of irrigation water supplies, and the severity of soil erosion (Adams *et al.*, 1998), while the rising carbon dioxide (CO_2) concentration might influence crops' photosynthetic activity and water-use efficiency (Antle *et al.,* 2004).

By the middle of the twenty-first century, world population is expected to reach 9.6 billion (United Nations 2013). This growth is projected to occur primarily in developing countries, where dependency on cereal imports is already high and is likely to increase. International trade will play an important role in fulfilling this increase in food demand. Trade flows and prices may become increasingly volatile and unpredictable as a result of changing geographic patterns of agro-ecological potential in different regions. In the context of an increasingly interconnected global economy and the increasing interdependence of food trading partners, climate change – along with other global changes (such as rapid land use and land cover changes and increasing consumption of water and energy resources) – is likely to contribute to increasing food prices and overall instability of the global food market. Understanding the magnitude of expected changes is crucial to developing adaptation and mitigation measures as well as more productive and resilient food systems to meet the challenge of food security at national, regional and global levels. The tradeoff between mitigation for climate change through increase of carbon sink to natural vegetation and meeting the increasing food demand adds additional challenges.

The grain-growing belt of Central Eurasia, shared by the Russian Federation, Ukraine and Kazakhstan, extends almost 20 000 km, from the Carpathian Mountains to the Amur River valley in the Russian Far East, and offers significant underutilized grain production potential. These three countries of the former Union of Soviet Socialist Republics (USSR) have recently reemerged as leading grain exporters; their share in the global grain exports rose from 1 percent in 1991 to 18 percent in 2013 (Liefert *et al*., 2013; FAOSTAT 2013). Understanding impacts of climate change on the future productivity of this region is essential for predicting its potential as a major grain supplier in the future. The recent growth in grain exports from the Russian Federation, Ukraine and Kazakhstan has been driven by a combination of multiple factors, including structural changes in their agricultural sectors, economic recovery of the region after the deep decline of the 1990s, and relatively favourable weather conditions (Liefert *et al*., 2013; Lioubimtseva *et al*., 2013; Dronin and Kirilenko, 2013). Several studies based on coupling climate and crop models indicate that the agro-ecological potential of the grain-producing zone of Central Eurasia may increase due to warmer temperatures, longer growing seasons, decrease of frosts and positive impact of higher atmospheric concentrations of CO_2 on crops (Pegov, 2000; Fischer *et al*., 2005), while other modelling experiments project the decline of agricultural potential due to increasing frequency of droughts (Alcamo *et al*., 2007; Dronin and Kirilenko, 2008). Economic scenarios driven by climate and crop models are extremely uncertain as they fail to capture multiple environmental, social, economic, and institutional factors (Lioubimtseva and Henebry, 2012).

This paper is a combination of an extensive bibliographic review and our own computations of potential changes in grain production in the Russian Federation, Ukraine and Kazakhstan considering impacts of climate change, international trade, and agricultural policy changes.

We examine historical trends since the collapse of the USSR and future outlooks for grain production and export potential by the Russian Federation, Ukraine and Kazakhstan in the context of physical and economic effects of climate change on the Central Eurasian grain belt.

Section 2 examines structural changes in the agriculture sectors of the Russian Federation, Ukraine and Kazakhstan that have led to changing their role from net importers to major net exporters of grain. There is a general consensus that dramatic economic and policy changes over the past few decades have had a significantly higher impact on grain production than climate variability and change (Liefert *et al*., 2013; Lioubimtseva *et al*., 2013), although socio-economic and biophysical changes may overlap, partly masking each other's effects (Dronin and Kirilenko, 2013). This section discusses the turning points in the changing trends of this region's arable area, productivity, and exports of the major cereal crops.

While agricultural statistics provide critical information about land-use dynamics and yields, remote sensing offers a complementary perspective on land changes. Section 3 provides a brief discussion of the recent short-term weather variations and land cover changes in the grain-growing regions of the Russian Federation, Ukraine and Kazakhstan, derived from remote sensing data.

Section 4 provides a detailed review of historical climate trends and scenarios of climate change and grain productivity based on a review of previous experiments and our own simulations of agro-ecological changes and their impact on future yields. Section 5 outlines and discusses our three bio-economic scenarios of the future grain production and export potential of the Russian Federation, Ukraine and Kazakhstan: "Federal Program", "Historical Trend", and "Historical Trend Plus Climate", and discusses likelihoods of each of them. The concluding section identifies the major knowledge gaps and provides some recommendations for future research.

2. Historical trends of grain production and trade

2.1 Decline of agriculture in 1991-2001

The steppe and forest-steppe belt of Ukraine, the Russian Federation and Kazakhstan was "the bread basket" of the USSR. During the last 30 years of its existence, the USSR increased its cereal production from 119 million tonnes in 1961 to 155 million tonnes in 1991, with a maximum production of more than 170 million tonnes in 1980 (Lioubimtseva, 2010). In the 1950s the growth of grain production was driven by the expansion of arable lands (the "Virgin Lands Campaign"), but during the following years the area of cereal cultivation contracted slightly and the growth was the result of increasing productivity. Despite significant efforts to increase yields through the "agriculture intensification" programme, by the end of its existence, the USSR's yields were significantly lower compared with other major cereal producers and lower than they are now (Table 1). In addition, in its effort to satisfy growing standards of food consumption, the USSR launched a shift to a livestock sector at the beginning of 1970s that caused a growing grain imbalance in the country.

Although grain production grew between 1970 and 1990, the role of USSR grain exports declined significantly during that time because of increasing domestic consumption. The USSR wheat exports reached a maximum of 8.5 million tonnes per year in 1971 but declined steadily during the 1980s to less than 0.5 million tonnes in 1991. Increasing cereal production could not keep up with increasing domestic needs (both for livestock feed and human consumption) and wheat imports rose from 0.4 million tonnes in 1969 to 20 million tonnes in 1991 (FAOSTAT 2013).

The collapse of the USSR and the Council for Mutual Economic Assistance (COMECON) in 1991 began a period of drastic transition from state-controlled to market-driven economies

table 1

The top wheat producers in 1991 and in 2012

	Wheat yields t/ha		Wheat production, metric tonnes	
	1991	2011	1991	2011
China	4.2	4.8	95 953 781	117 410 000
USSR	1.5		71 991 008	
Russia		2.3		56 239 990
Ukraine		3.4		22 323 600
Kazakhstan		1.7		22 732 000
USA	4.6	2.9	53 890 000	54 413 310
Canada	2.6	3.0	31 945 600	25 261 400
Australia	1.6	2.0	10 557 400	27 410 076
Brazil	1.6	2.7	2 916 823	5 690 043

Source: (FAOSTAT 2013)

across Eastern Europe and Central Asia that has resulted in fundamental transformation of their agricultural systems and land use. These transitional economies went through a stage of catastrophic decline in 1991 to 2000. The "Free Market" reforms of the 1990s made a heavy impact on the economy of the former USSR. Deterioration of the agriculture sector contributed to an overall economic decline. For instance, from 1991 to 2001, gross domestic product (GDP) in the Russian Federation, Ukraine and Kazakhstan declined by 65-67 percent (UNData 2013), average life expectancy declined from 69 to 65 years, and male life expectancy in rural areas of the Russian Federation declined from 61 to 53 years (Prishchepov *et al*., 2013). This economic and social crisis was particularly pronounced in rural regions, where state support of agriculture ended and rural development ceased almost entirely (Prishchepov *et al*., 2013). The major changing trends in the 1990s were the disintegration of the centrally planned institutions and existing agricultural policies, uncertainties about the legal status of land, sharp declines of agricultural subsidies and other forms of governmental support (Lioubimtseva and Henebry, 2012). Producer support estimates from the Organisation for Economic Cooperation and Development (OECD) for the Russian Federation, Ukraine and Kazakhstan indicate substantial positive support for farmers up to 1991, which then fell almost to zero in the following few years (OECD-FAO 2008). As the subsidies declined, the high cost of imported herbicides, fungicides and insecticides caused farmers to cut back on their use (Lerman *et al*., 2004). Fertilizer use fell by 85 percent in the Russian Federation and Ukraine and by almost 90 percent in Kazakhstan between 1990 and 2000 and total grain production fell by more than 50 percent during the same period of time (FAOSTAT 2013). Between 1990 and 2000, investments in the Russian Federation's agricultural sector declined from USD 39 billion to USD 2 billion (Prishchepov *et al*., 2013) and the area of land under cereals was reduced from 65 million to 50 million hectares (Liefert *et al*., 2009a). According to the Food and Agriculture Organization of the United Nations (FAO), the use of arable lands in the Russian Federation, Ukraine and Kazakhstan together dropped from 200 million hectares in 1991 to 177 million hectares in 2003 (FAOSTAT 2013), which constituted a withdrawal of 23 million hectares or 12 percent of the arable lands in 1991 (Lioubimtseva and

Henebry, 2012), although even these numbers may be underestimated. Statistics in the Russian Federation for cultivated areas (ROSSTAT, 2013) and remote sensing data suggest that abandoned cropland area in the Russian Federation alone constitutes up to 40 million hectares, significantly more than reported by FAO land resource statistics (Shierhorn *et al*., 2010; Prishchepov *et al*., 2013). Given that there was almost no change in rural population of the country (UniSIS 2013), labour productivity in agriculture dropped by 30 percent in the Russian Federation. It is notable that in other countries of Eastern Europe, such as Czech Republic and Slovakia, even though the total production decreased, the labour productivity in agriculture has been increasing; in Hungary, for instance, the agricultural production has doubled (Rozelle and Swinnen, 2000).

The loss of state subsidies also increased feed and production costs and reduced profitability for livestock enterprises. As prices for meat products increased, consumer demand declined, thus establishing a downward spiral that continued throughout the decade (Lioubimtseva and Henebry, 2012). Livestock inventories and demand for forage both continued to decline. Between 1992 and 2006, the Russian Federation lost almost half of its meat production: the number of cattle dropped from almost 20 million to 10.3 million; the number of pigs fell from more than 36.3 million to 18.7 million; and the number of sheep dropped from 20 million to 7 million (FAOSTAT 2013). In Kazakhstan, 33.9 million sheep were in stock in 1992, but by 1999 that number had dropped 75 percent, to 8.6 million (Lioubimtseva and Henebry, 2009). In addition, shrinking livestock inventories in all three countries caused the demand for feedgrain to plummet, which led to a 76 percent drop in barley area (Lioubimtseva, 2010). The increasing inability of large agricultural enterprises to maintain livestock operations, largely because of inefficient management and the inability to secure adequate supplies of feed, resulted in increased dependence on smaller household farms to satisfy demands for meat (Welton, 2011). Furthermore, the involvement of investor groups in agricultural production has had an impact on livestock numbers. Many farmers who entered agreements with investment firms killed off their herds because livestock was not quickly profitable and not as attractive to investors. For example, in Kazakhstan, due to the loss of incentives to keep the herds, two-thirds of the sheep population was lost between 1995 and 1999 (Lioubimtseva and Henebry, 2012). The drop in livestock inventories led in turn to a drop in demand for feedgrain and pastures across the region. Although the free fall in livestock inventories has slowed since 2000, large industrial farms have been shifting away from livestock and towards crop production (Ioffe *et al*., 2012) and livestock inventories continued to decrease, particularly in the areas with extensive herding, such as Central Asia, Kazakhstan, and semi-arid and arid zones of the Russian Federation (Lioubimtseva and Henebry, 2009, 2012). Between 1991 and 2001, meat production in the Russian Federation, Ukraine and Kazakhstan declined by 50 percent (OECD 2002).

The economy-wide decline and the collapse of the agriculture sector have caused fundamental changes in the trade structure. Following the declines in demand and in purchasing power, wheat imports in the Russian Federation fell from 18.9 million tonnes in 1992 to only 0.3 million tonnes in 2002, a decrease of over 98 percent (FAOSTAT 2013).

2.2 Recovery trends in 2002-2013

By the end of the 1990s, the majority of Russian and Western experts did not see much evidence of success from ongoing market reforms in Russian agriculture, suggesting instead that the stagnating agriculture sector would be dominated by former collective farms, which would be undergoing transformation into large cooperative units (Zogoleva, 1997; Osborne and Trueblood, 2002; Miloserdov, 2006). This "Anti-Free Market" scenario was expected to limit labour productivity in agriculture (Prosterman *et al*., 1999). Despite this negative outlook, fast growth of agriculture in the 2000s has made the Russian Federation the leading grain exporter. The free fall in the agricultural production of the Russian Federation, Ukraine and Kazakhstan had slowed down by 2000 and signs of recovery have been observed in all three countries since 2002, clearly coinciding with economy-wide recovery of the entire region. Some experts believe that the tipping point for Russian agriculture occurred in the year 2000 (von Cramon-Taubadel, 2002). With the exception of several years with unfavourable weather (such as an anomalously rainy 2003 and severe droughts in 2010 and 2012), cereal production has rebounded in all three countries. Since 2000, the Russian Federation has had several outstanding harvests and, on average, grain yields are also showing signs of improvement. However, the yields still remain below the 1991 levels and are much lower than potential yields for this region; in 2010, wheat yields were only 2.6 tonnes/hectare (t/ha) in Ukraine, 1.9 t/ha in the Russian Federation, and 0.7 t/ha in Kazakhstan, much lower numbers compared with 7.0 t/ha in France, 4.7 t/ha in China, and 3.1 t/ha in the United States (Lioubimtseva *et al*., 2013). Although weather remains a very important determinant for grain yield, improvements in crop management practices fueled by the growing state subsidies have also contributed to the recent increase and stabilization of wheat and barley yields (Uzun *et al*., 2012; Liefert, 2013).

During the Soviet period, growth was essentially driven by extensive conversion of marginal lands to agriculture, but in the more open economy of the 2000s, marginal arable lands grew unprofitable and were gradually abandoned even under high grain demand (Liefert *et al.*, 2009b). Unlike in the 1970s and 1980s, the increase of agricultural production in the 2000s was not based on land expansion. On the contrary, the area under cereals continued to shrink, from 50 million hectares in 1996-2000 to 45 million hectares in 2001-2008 (FAOSTAT 2013). In 2008, the area under cereals in the Russian Federation increased marginally (by 5 percent), driven by the record high world grain prices of USD 400-450 per metric tonne. The Russian Federation declared agriculture to be a national priority area in 2005 and increased federal support for agricultural development from USD 2.6 billion in 2006 to USD 5.2 billion in 2008 (EBRD-FAO 2008). Despite the increase in level of overall support given to agricultural producers, federal support as a share of total farm receipts remained relatively low (15 percent in the Russian Federation and 12 percent in the Russian Federation and Ukraine, compared with 55 percent in Japan, 33 percent in the EU and 16 percent in the United States) (Lioubimtseva and Henebry, 2012). Due to recovery of some agricultural subsidies and at least partial success of reforms, fertilizer and machinery use have increased during the past few years. The use of mineral fertilizer has tripled since 1999 in Kazakhstan and doubled in the Russian Federation and Ukraine, but current application rates represent only a fraction of the amounts applied in the late 1980s (Lioubimtseva and Henebry, 2012). A return to the 1980s application rates is unlikely – and unnecessary, as they were frequently excessive. Between 1996-2000 and 2001-2008, the yields grew from 1.3 t/ha to 1.83 t/ha (FAOSTAT 2013).

The share of harvested land under various major crops has changed in a different way (Figure 1). Wheat has been the primary cereal crop in terms of area harvested and shows a slight increase in harvested area after half a century of decline that followed the Virgin Lands expansion campaign (Table 2). Barley has been a significant secondary crop, but declines in area harvested started in the mid-1970s and accelerated through the mid-1990s. Rye, which is largely restricted to the Russian Federation, has declined substantially since 1991, and shows no evidence of recovery. Maize continues to be a minor crop regionally, but the harvested area has been increasing steadily since the mid-1990s, particularly in Ukraine (Lioubimtseva *et al*., 2013).

In the Russian Federation, the first result of the privatization reform of 1992 was the emergence of 280 000 private farmer households by 1995. However, these first private farms held only five percent of arable lands, while

figure 1

Trends of harvested land under various major cereal crops

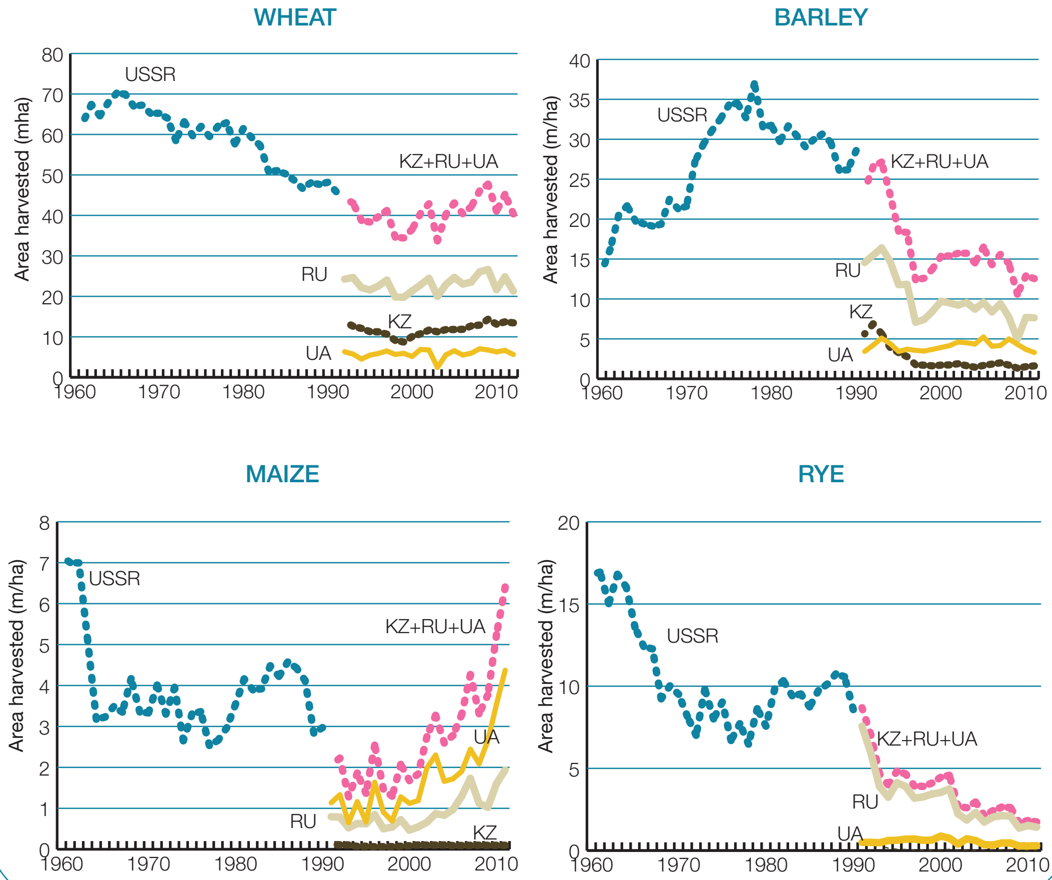


table 2

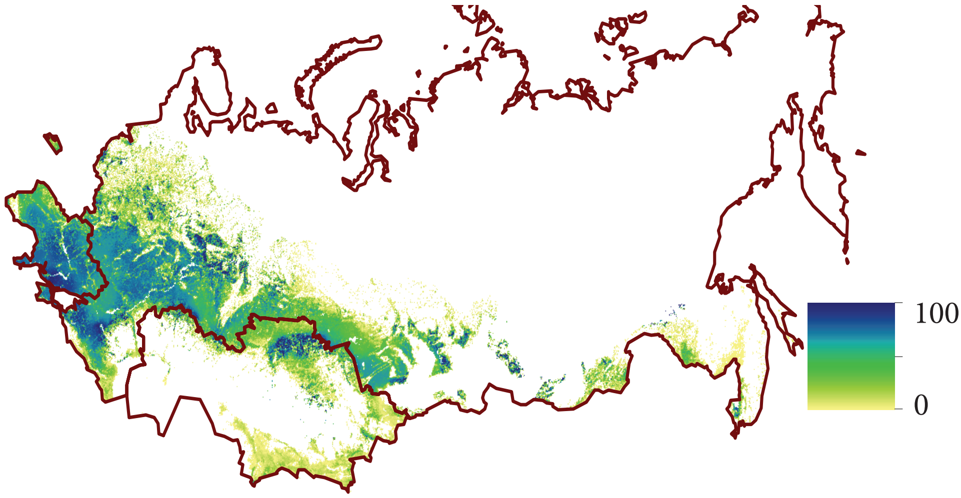
The area under wheat and mean wheat yield for Kazakhstan, Russia and Ukraine (FAOSTAT, 2014)

Time period	Area harvested (th. km²)			Yield (t/ha)		
	Kazakhstan	Russian Federation	Ukraine	Kazakhstan	Russian Federation	Ukraine
1991–1995	124	232	55	0.82	1.64	3.19
1996–2000	100	215	58	0.85	1.59	2.41
2001–2005	115	230	56	1.02	1.95	2.72
2006–2010	130	242	63	1.07	2.15	2.86

FAOSTAT, 2014. http://faostat.fao.org, last accessed 13 April 2014

figure 2

Percentage of land under crops in year 2000 in Kazakhstan, Russia and Ukraine (Ramankutty *et al*., 2008)



collective farms – slightly reorganized kolkhozy and sovkhozy – still prevailed (Csaki and Lerman, 1997; Prosterman *et al*., 1999). These collective farms owned 108 million hectares, which were formally privatized by managers of the collective farms. About 40 percent of these lands belonged to elderly people. According to the survey of farm managers conducted by the Rural Development Institute, no change or very little change had occurred in the way of governance of the farms compared with the Soviet period (Prosterman *et al*., 1999). While ineffective cooperative units inherited from reformed kolkhozes and sovkhozes still produce a significant share of grain in the country (Brock *et al*., 2008), many experts believe that the increased yields since 2000 resulted from the growth of large, vertically integrated agro-industrial holdings (Serova 2007; Uzun *et al*., 2012). This growth started at the end of the 1990s, when some banks, oil companies, and similar large businesses started investing in agriculture, primarily in the steppe and forest-steppe zones of the Russian Federation (Smelansky, 2003), where large-scale intensive agriculture is possible (Figure 2). The new businesses brought a significant increase in investments, new technologies and contemporary management to a number of collective farms in the most productive regions of the country (Serova, 2007). According to the Institute of Agricultural Market Studies (IKAR), in 2002 the agro-industrial holdings were already producing 10 percent of grain, 25 percent of meat, and 70 percent of sunflower oil in the Russian Federation (http://www.vedomosti.ru Ivanova, May 26, 2003). A thorough discussion of agro-industrial production has been published by Uzun *et al*. (2012).

In 2005, the Russian Federation's government designated agriculture a primary industry for receiving federal support and during the following two years federal support for agriculture increased by 52 percent (adjusted for inflation) (Liefert *et al.*, 2009a,b). In 2009, the Russian Federation's government created the United Grain Company, which has become the main federal agent for the grain market, with the goals of supporting grain producers, increasing competitiveness of grain exports and improving grain production infrastructure.

Another noteworthy recent trend in the agricultural land use of this region has been a significant increase in oilseeds production (sunflower, rapeseed, soybean, safflower and cotton), mainly at the expense of cereals and forage. For example, between 2001 and 2012, sunflower seed production increased from 2.7 to 8 million tonnes in the Russian Federation and from 2.3 to 8.3 million tonnes in Ukraine, rapeseed production grew from 0.1 to 1 million tonnes in the Russian Federation and from 0.1 to 1.3 million tonnes in Ukraine, and soybean production rose from 0.3 to 1.8 million tonnes in the Russian Federation and from 0.06 to 2.4 tonnes in Ukraine (FAOSTAT 2013). These shifts indicate a response to global market signals and are linked to the higher profitability of oilseed crops. It is likely that this trend will continue into the future and it may have a negative impact on the potential for grain production.

The livestock industry has become another priority area for federal support. Throughout the 1990s, livestock numbers were reduced dramatically, leading to a 55 percent reduction in milk and meat production (OECD 2002). This actually had a positive effect on food security; a lower demand for feedgrain has resulted in more grain production available for domestic food use, even though the yields continued to be depressed (annual grain production in 2001-2008 was 83 million tonnes, compared with 103 million tonnes between 1987 and 1990). In 2007, the Federal Program of Agricultural Development and Regulation of Markets for Agricultural Produce, Raw Materials, and Food for 2008-2012 was accepted. The goal of the Program was to increase production of meat and poultry by 32.9 percent (in live weight; all numbers are for 2012 compared with 2006). The target numbers for 2012 were 11.4 million tonnes for meat and poultry and 37 million tonnes for milk production. The main vehicles of the Program were federal subsidies and protection for producers from cheap meat imports.

As a result, meat production in the Russian Federation has grown remarkably (Welton, 2011) so that the Program's goals were exceeded (Table 2), although not in all sectors. The higher growth rates for pork and poultry production are explained by both their higher level of development in the USSR and their faster return on investment compared with beef, due to their shorter production cycle (Welton, 2011). This impressive growth was accompanied by an equally impressive increase in labour productivity, by 80 percent for poultry and 50 percent for pork production (Table 3). It is noteworthy that federal support for these sectors of agriculture is very high, even in comparison with the most developed countries (Table 4). On the other hand, the impressive federal support for animal husbandry between 2008 and 2012 had almost no effect on beef and milk production (Table 4). After the collapse of the USSR, dairy cattle remained the main source of beef (Gosudarstvennaya programma.., 2012). Domestic beef production has not been profitable for most farms; in 2011 the average profitability of the sector was only -24 percent, compared with 22.6 percent for pork and 10.2 percent for poultry production (O hode y resultatah realizacii.., 2012). According to experts in the Russian Federation, profitability should be at least 25 percent to make growth of these sectors stable (Rau, 2009).

The fast growth of animal husbandry in the second half of the 2000s had little impact on the positive balance of grain supply in the Russian Federation. The impressive grain exports combined with low internal meat and dairy production resembled the agricultural sector of the late period of the Tsarist Russia in the nineteenth century, as during both periods the positive balance of grain supply was largely based on poor development of livestock production and low internal demand, rather than on high yields.

3. Short-term weather variability and land dynamics

Although economic and institutional changes have probably been the dominant factors influencing recent grain production trends in post-Soviet

table 3

Livestock production (tonnes): Federal Program goals vs. actual data

	Commodity	2008	2009	2010	2011	2012
Goal	Poultry and meat (live weight)	8 950	9 520	10 100	10 750	11 400
	Milk production	33 000	34 000	35 000	36 000	37 000
Actual	Poultry and meat (live weight)	9 331	9 972	10 553	10 965	11 621
	Milk production	32 362	32 570	31 847	31 646	31 831

Source: Federal Program ...., 2007; ROSSTAT, 2013

table 4

Meat, eggs and dairy production in 2008-2012 to 1990 (percentage)

Commodity	2008	2009	2010	2011	2012
Cattle	36.9	36.2	35	35.3	35
Pigs	42.2	45	44.9	45	49.2
Birds	61.3	65.7	68.1	71.7	75
Beef	40.9	40.2	39.9	37.5	38
Milk	58.1	58.5	57.2	56.8	57.3
Pork	58.7	62.3	67	69.8	72.2
Poultry	123	142	158	178	199
Eggs	80.2	83.1	85.5	86.6	88.5

Source: Federal Program ...., 2007; ROSSTAT 2013

table 5

Federal subsidies for poultry production, USD per metric tonne of final product

Countries	1995	2000	2005	2010
Russia	430	350	473	1126
EU	No Data	240	398	426
Canada	222	7	29	301
USA	10	1	0	1

Source: Borodin *et al*., 2013

transitional economies, agricultural production is also highly sensitive to inter-annual climate variability, as expressed in growing season weather. Multiple studies have debated the relative roles of agricultural policy changes, weather variability and climate change in the performance of agriculture in Central Eurasia during various historical periods (Ioffe *et al*., 2012; Lioubimtseva and Henebry, 2012; Wright *et al.*, 2012; Liefert *et al*., 2013). Detailed analysis of climate variability and policy changes in the Russian Federation in the twentieth century can be found in Dronin and Bellinger (2005). Furthermore, Dronin and Kirilenko (2013) examined the relative roles of climate and state agricultural policies affecting production of cereals using statistical yield modelling and found a tight correlation between actual and weather-explained yields. Their study suggested that weather changes had a significant effect on yields in the Russian Federation between 1958 and 2010, with the residual yield variability explained by large-scale changes in agricultural policies at the state level. The continental climate of the Central Eurasian grain belt results in volatile weather conditions for grain production, especially in terms of rainfall. The productivity of grain crops (winter wheat in the European parts of the Russian Federation and Ukraine, spring wheat and barley in Kazakhstan and in the Russian Federation east of the Volga River) depends strongly on spring and summer precipitation, which is particularly important during the critical phases of wheat growth, such as bushing and earring. The second major climatic constraint is temperature; for example, dry cold winters often kill winter wheat crops, but high summer temperatures, above 33 °C, damage crops and reduce production of spring wheat and barley.

Grain yields for the Russian Federation, Ukraine and Kazakhstan were very low every year between 1994 and 2000 – with the exception of a good yield in 1997 – mostly as the result of unfavourable weather. However, grain production was high every year between 2001 and 2013, except for the plunges in 2003, 2010 and 2012 (FAOSTAT 2013; Liefert *et al*., 2013). Again, the main driver for high yields was favourable weather, with only a few exceptions. The summer of 2010 featured an extraordinary heat wave, with the region experiencing the warmest July since at least 1880 and numerous locations breaking all-time maximum temperature records (Dole *et al,.* 2011).

The heat wave and extreme drought of summer 2010 affected all major grain-producing areas of the former USSR (Lioubimtseva *et al*., 2013). The government declared a state of emergency in 27 agricultural regions and a total of 43 regions were affected, with over 24 million hectares of crops destroyed (Welton, 2011). This area accounted for 17 percent of the total crop area and included almost 25 000 farms. The 2010 heat wave cut grain yield in the Russian Federation by a third, the potato harvest by 25 percent and vegetables by 6 percent (FAOSTAT 2013). More than 25 percent of all crops were destroyed and many small dairy farmers were forced to slaughter their cattle as fodder prices increased rapidly in response to the heat wave. There are four main grain- producing regions in the Russian Federation: Central, South, Volga and Siberia. Of these, the Volga region – which is the largest producer – was the most severely hit by the drought, seeing its annual harvest drop by more than 70 percent, while the Central region's production dropped by 54 percent. Overall, the harvest was down about one-third compared with the previous year (Welton, 2011). Although the 2012 summer temperatures in this region were not as high as in 2010, persistent droughts have continued during the past three years throughout the entire grain-producing belt of Central Eurasia.

Both weather variability and institutional changes have had observable impacts on land surface phenology of the region, captured by a time series of satellite imagery. Land surface phenology studies the timing and magnitude of seasonal patterns in the vegetated land surface as observed at spatial resolutions that are very coarse relative to individual plants. In the absence of obscuring clouds, the vegetated land surface is readily viewed from space because of the strong contrast in green plants between the near infrared and red portions of the electromagnetic spectrum. Green plants are very bright in the near infrared, scattering upwards of a third of incident radiation, but very dark in the red, absorbing more than 90 percent of incoming light. The Normalized Difference Vegetation Index (NDVI) exploits this spectral contrast[4].

[4] NDVI is calculated as follows: NDVI = (NIR-RED)/(NIR+RED), where RED and NIR stand for the spectral reflectance measurements acquired in the red and near-infrared regions, respectively (Tucker *et al*., 1991). Vigorously growing healthy vegetation has low red light reflectance and high near-infrared reflectance, and hence, high NDVI values. Increasing positive NDVI values indicate increasing amounts of green vegetation. NDVI values near zero and decreasing negative values indicate non-vegetated features such as barren surfaces (rock and soil), snow, ice and clouds.

Time series of NDVI data provide additional information about land surface phenology changes that can be caused either by land use changes or climatic variability and change, as well as growing season weather. Several studies based on analyses of NDVI and other vegetation indices derived from satellite imagery found an evidence of gradual increase of the length of growing season and overall increase of green vegetation cover across Eurasia (Bogaert *et al,.* 2001; deBeurs and Henebry, 2004; Lioubimtseva, 2007; Kariyeva and van Leewuven, 2011; Wright *et al.,* 2012). Satellite imagery indicates that, while North America shows a fragmented pattern of NDVI change, Eurasia exhibited a persistent increase in growing season NDVI over a broad contiguous swath of land (Zhou *et al*., 2001; Bogaert *et al*., 2001). This greening trend has been attributed partially to institutional and land-use changes (DeBeurs and Henebry, 2004; Prishchepov *et al*., 2013) and partially to climate change and variability (DeBeurs and Henebry, 2008; Propastin and Kappas, 2008). Propastin and Kappas (2008), for instance, show that from March to May, greening increased in 65 percent of cropland pixels, and decreased in only 2 percent of the pixels; 73.5 percent of variation is explained by the change in spring temperature.

The signs of agricultural decline in the 1990s were sufficiently strong across the Russian Federation, Ukraine and Central Asia to be captured by NDVI and other vegetation indices derived from coarse resolution remote sensing data, such as AVHRR (Advanced Very High Resolution Radiometer) as well as more detailed satellite imagery, e.g. Moderate Resolution Imaging Spectroradiometer (MODIS) and Landsat (de Beurs and Henebry, 2004; Kariyeva and van Leeuwen, 2011; Prishchepov *et al*., 2013). A recent study of the agricultural conditions and NDVI trends in the grain belt between 2001 and 2010 by Wright *et al.* (2012) has revealed strong divergence between areas within and outside of the *Chernozem* zone. The agricultural sector has been disintegrating since at least 1991 in the marginal areas outside of the highly fertile *Chernozem* zone, where productivity was always low. In contrast, agriculture in the *Chernozem* area is vigorous and NDVI series show no evidence of agricultural decline (de Beurs *et al*., 2012; Ioffe *et al*., 2012). Combining analyses of NDVI trends and land-cover changes, Wright *et al*. (2012) found a pattern of increasing greenness associated with agricultural abandonment (i.e. cropland to grassland) in the southern range of the Eurasian grain belt coinciding with statistically significant negative NDVI trends and likely driven by regional drought. In the northern range of the grain belt they found an opposite tendency towards agricultural intensification; in this case, represented by land-cover change from cropland mosaic to pure cropland, and also associated with statistically significant negative NDVI trends.

4. Impacts of climate change on grain production

A credible projection of grain production should include a physically based or statistical yield model, taking into account not only the changes in demand or technologies, but also variability of agricultural climates in the country and frequency of extreme weather conditions such as droughts, soils and other external parameters. Multiple authors have estimated the impact on yields of changes in one or a few of these parameters. Agricultural production is highly sensitive to inter-annual climate variability as expressed in growing season weather. Climate change is likely to have multiple effects on potential productivity and yields, such as: effects of elevated CO_2 on plant growth, water-use efficiency and yields; effects of increased temperature; extension of the growing season; effects of increase of precipitation in some areas and decrease in others; effects of increased frequency and intensity of extreme events; and increased risk of weed invasion, insect pests and diseases.

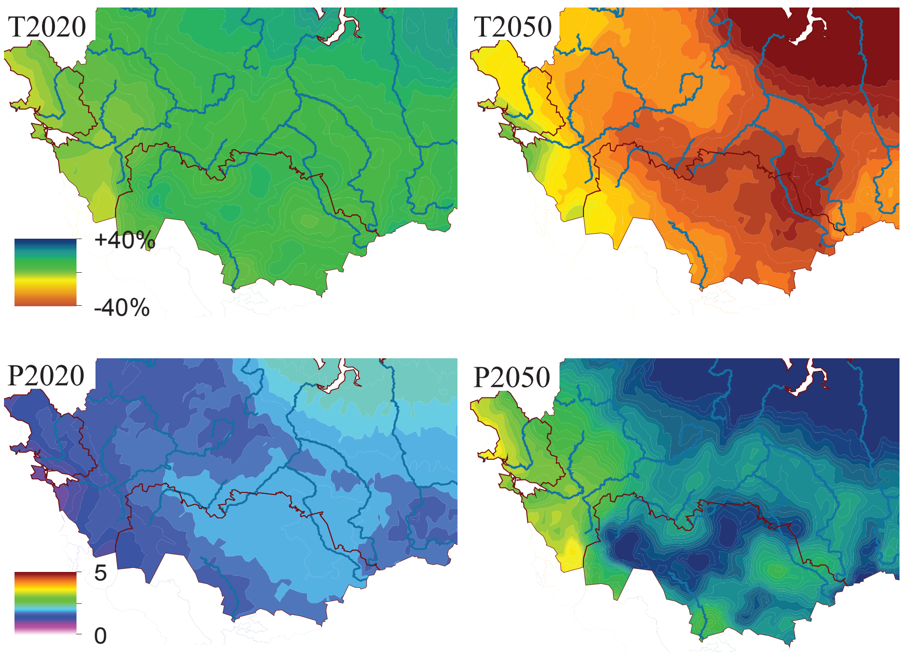
Global Climate Models (GCMs) are the most advanced tools currently available for simulating the response of the global climate system to increasing greenhouse gas concentrations. The climate modelling scenarios suggest that, compared with the late Soviet Union period of the 1980s, the temperature in the grain-producing areas of the Russian Federation, Ukraine and Kazakhstan will increase by 1.5-1.8 ºC by the 2020s and by 2.2-3.9 ºC by the 2050s, with the greatest increase in winter (Mitchell *et al*., 2002; Lioubimtseva and Henebry, 2009; 2012; Dronin and Kirilenko, 2013). Despite significant differences in the range of changes among the scenarios produced by different models, most studies tend to agree that summer precipitation is likely to decline all over the region and winter precipitation is projected to increase in parts of Western Russia and Siberia (Dronin and Kirilenko, 2008; Lioubimtseva and Henebry, 2012).

In order to evaluate impacts of climate change on the grain belt of Central Eurasia, we have computed the twentieth century temperature and precipitation trends for Kazakhstan, the Russian Federation and Ukraine by fitting a linear regression model to the 1901-2000 mean temperature and precipitation of these three countries. The historical climate data for the countries were retrieved from University of Eastern Anglia's Tyndall Centre for Climate Change Research (TYN) country average (CY) database 1.1 (Mitchell *et al*., 2003). Temperature trends are similar for the Russian Federation and Ukraine (0.08 ˚C/decade), with a higher trend in Kazakhstan (0.14 ˚C/decade). These changes were accompanied by precipitation increases of 0.7, 4.6 and 3.5 mm/decade in Kazakhstan, the Russian Federation and Ukraine, respectively. Over the last three decades of the twentieth century, these changes accelerated, with the temperature trend increasing to 0.37 ˚C/decade in Kazakhstan, 0.32 ˚C/decade in the Russian Federation and 0.23 ˚C/decade in Ukraine, with higher changes in winter (1.30, 0.81 and 0.73 ˚C/decade, respectively) and considerably lower warming in summer (0.33, 0.25 and 0.35 ˚C/decade, respectively). During the last three decades of the twentieth century, the increasing precipitation trend continued in Kazakhstan (2.1 mm/decade) and the Russian Federation (2.8 mm/decade), but was reversed in Ukraine (-3.7 mm/decade). While in Kazakhstan, summer precipitation has increased, in Ukraine and the Russian Federation it has declined.

Observed trends exhibit a high level of spatial heterogeneity, especially in the Russian Federation. While on average the temperatures have become 1.29 ˚C warmer over the past 100 years (1907-2006 – compared with 0.74˚ C global warming over the same period) (National communication, the Russian Federation, 2010), the warming trend was higher in Eastern Siberia and in the north of the European part of the country, with lesser warming in the intensive agriculture zone located in the south of the European part of the Russian Federation (NOAA GISS Surface Temperature Analysis, http://data.giss.nasa.gov/gistemp/). Similarly, the highest changes in precipitation were observed in the eastern part of the country in the spring season. There is considerable uncertainty in the data on precipitation trends, especially over the entire twentieth century, due to low density of the observational network (National communication, the Russian Federation 2010). In the agricultural region of northern Kazakhstan, the warming trend is higher compared with the entire country, especially in winter, and is accompanied by increasing winter and decreasing summer precipitation (National communication, Kazakhstan, 2009). Higher temperatures lead to a greater effective temperature sum (ETS, measured as a sum of growing-degree days with base temperature of 10 ˚C), a longer vegetative period, and to shifts in phenology. In extra-tropical regions, multiple studies demonstrated a lengthening of the growing season by approximately 10-20 days in the last few decades, mostly as the result of an earlier spring (Linderholm, 2006). In Europe, the growing season has extended by 3.5 days/˚C over the last 30 years of the twentieth century (Menzel *et al,.* 2006). In the principal agricultural areas of the Russian Federation, the length of the period with temperatures above 10 ˚C (associated with the growing period) was increasing by 2.3-2.7 days per decade in central *Chernozem*, northern

figure 3

Climate change impacts on temperature (T) and precipitation (P) change compared to the base period for 2020s and 2050s. The data present the mean of four CMIP-3 GCM integrations under IPCC SRES A1FI scenario



Caucasus, and western Siberian regions, and by 0.2-0.7 days per decade in the Ural and *Povolzhie* regions (Sirotenko *et al*., 2007). The highest increase in ETS, over 120 ˚C per decade, was observed in Ukraine, with 57-77 ˚C per decade growth in central *Chernozem*, northern Caucasus, and western Siberian regions, and lower growth or even decrease in the Ural and *Povolzhie* regions (Sirotenko *et al.,* 2007).

We estimated projected future changes of climate over the territory of Kazakhstan, the Russian Federation and Ukraine in the 2020s and 2050s as deviations from the base values at the end of the Soviet period (1980s); the base period was selected for compatibility with earlier projections of climate change impacts on agriculture in the Russian Federation (Alcamo *et al.,* 2007). The following parameters were computed as mean values from the ensemble of four GCMs (CGCM2, CSIROmk2, ECHam4 and DOE PCM): the change in annual and warm period temperature and precipitation; potential evapotranspiration; and growing degree days at base temperature of 10 ˚C (GDD10). We computed the values of each parameter for the entire territory of interest, divided into 0.5˚ geographical latitude and longitude cells with a regular grid (Figure 3). The values for each country were then combined as a weighted mean with weights equal to percentage of agricultural lands in each cell (Table 6).

In the 2020s, the temperature increase in all three countries – with lower increase in Ukraine (Figure 3) – would be followed by a correspondent increase in potential evapotranspiration, by 15-18 percent. The increase in precipitation, by 3-6 percent in the Russian Federation and Kazakhstan and by 0-2.3 percent in Ukraine, can partially compensate for an increased water deficit; however, the increase in precipitation is projected mostly for the cold part of the year, with

table 6

Change of climate parameters for four IPCC SRES scenarios for the 2020s and 2050s, in comparison with the late USSR period (1980s). An ensemble mean for four GCMs (CGCM2, CSIROmk2, ECHam4, and DOE PCM) is shown

TIME	Country	Scenario	T ann.	P ann.	T warm	P warm	PET	GDD10
2020s	Kazakhstan	A1	1.6	4.7	1.8	2.2	17	244
		A2	1.7	5.0	1.8	1.0	15	244
		B1	1.7	4.8	1.8	1.3	16	250
		B2	1.9	5.6	1.9	0.6	17	277
	Russia	A1	1.5	3.0	1.5	0.6	17	218
		A2	1.6	3.4	1.5	0.3	16	215
		B1	1.5	3.5	1.6	0.6	18	225
		B2	1.8	4.2	1.7	0.7	18	247
	Ukraine	A1	1.3	1.0	1.3	-1.3	17	236
		A2	1.3	0.3	1.3	-1.6	15	237
		B1	1.3	2.3	1.4	-0.1	16	238
		B2	1.6	1.8	1.5	-0.7	17	271
2050s	Kazakhstan	A1	3.9	11.1	4.2	5.4	42	617
		A2	3.5	10.4	3.6	2.2	33	528
		B1	2.7	8.0	2.9	2.3	28	424
		B2	3.2	9.4	3.3	1.1	31	484
	Russia	A1	3.5	7.1	3.6	1.5	45	549
		A2	3.2	7.0	3.1	0.7	34	462
		B1	2.5	5.8	2.6	1.0	31	383
		B2	3.0	7.1	2.9	1.2	32	434
	Ukraine	A1	3.1	2.4	3.1	-3.0	42	584
		A2	2.7	0.6	2.7	-3.3	33	501
		B1	2.2	3.7	2.2	-0.2	28	403
		B2	2.6	3.0	2.6	-1.3	30	468

Note: The climate parameters are as follows: change in annual temperature (˚C) [T ann.], precipitation (percentage) [P ann.], change in warm period (April through September) temperature [T warm] and precipitation [P warm], change in annual potential evapotranspiration (percentage) [PET], and and change in ETS base 10 ˚C (˚C) [GDD10

a considerably smaller warm period increase in the Russian Federation and Kazakhstan and even some decrease in Ukraine. The ETS is projected to grow by approximately 250 ˚C, roughly following these observations.

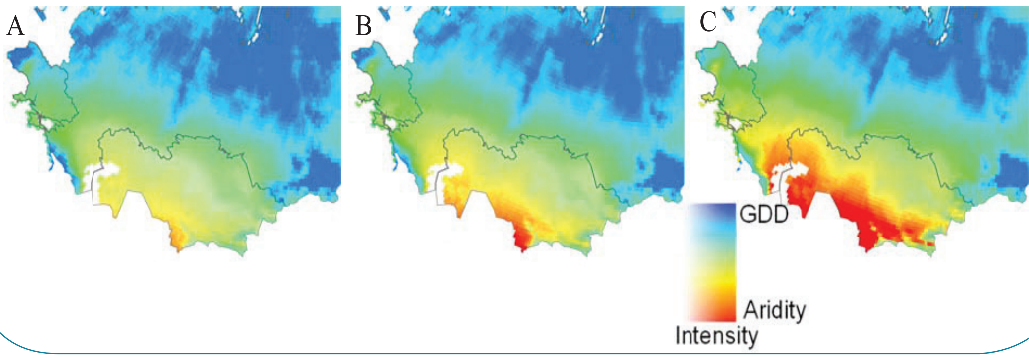
Food security studies frequently employ Dynamic Global Vegetation models (DGVMs) and crop simulation models driven by climate change projections, combined with economic models (Pegov, 2000; Golubev and Dronin, 2004; Fischer *et al*., 2005; Schmidhuber and Tubiello, 2007; Alcamo *et al*., 2007; Dronin and Kirilenko, 2008; 2013). A DGVM is a computer programme that simulates shifts in potential vegetation and the associated biogeochemical and hydrological cycles as a response to shifts in climate. Such models use time series of climate data and, given constraints of latitude, topography and soil characteristics, simulate monthly or daily dynamics of ecosystem processes. Crop models are crop-specific computer programmes that allow a user to estimate crop growth and yield as a function of weather conditions and management scenarios. Several studies based on analysis of agro-ecological scenarios indicate that the Russian Federation, Ukraine and Kazakhstan might be among the greatest beneficiaries of expansion of suitable croplands due to increasing winter temperatures, a longer frost-free season, CO_2 fertilization effect and projected increases in water-use efficiency by agricultural crops – as well as possible, though uncertain, increases in winter precipitation projected by some Atmosphere-Ocean General Circulation Models (AOGCMs) (Fischer *et al*., 2005). For example, the International Institute for Applied Systems Analysis (IIASA)/ Basic Linked System (BSL) models driven by the Hadley Centre climate prediction model 3 (HadCM3) climate change scenarios suggest that, as a result of regional climate changes by 2080, the total area with agro-ecological constraints could decrease, and the potential for rainfed cultivation of major food crops could increase in the Russian Federation (primarily due to temperature increase and the CO_2 fertilization effect on C3 plants) (Fischer *et al*., 2002). A study by Pegov *et al*., (2000) suggests that grain production in the Russian Federation may double, due to a northward shift of agricultural zones. Other modelling studies, however, indicate that the predicted shift of agro-ecological zones is unlikely to result in increasing agricultural productivity. Alcamo *et al*. (2007) and Dronin and Kirilenko (2008) have shown that, although large portions of the Russian Federation might increase their agricultural potential under warming scenarios, agriculture in the most productive Chernozem zone in the Russian Federation and Ukraine, between the Black and the Caspian Sea, could suffer a dramatic increase in drought frequency. This region is the main commercial producer of wheat and any declines in productivity would be detrimental to exports (Lioubimtseva and Henebry, 2012). The Global Assessment of Security (GLASS) model computes a considerable decrease of cereal yields in the most productive parts of the Russian Federation (Golubev and Dronin, 2004). Even though cereals will grow in the more humid central and northern regions, the average yield in the Russian Federation will decrease considerably because of a severe increase in droughts in the most productive regions. At its extreme, in Stavropolsky Krai, the key agricultural region of the northern Caucasus, potential cereal production would decrease by 27 percent in the 2020s and by 56 percent in the 2070s. In contrast, the yield of cereals in the central region will not change much, whereas yields in the northern regions will increase significantly. However, this latter increase would contribute little to the total grain production of the country.

A longer and warmer growing period generally would allow northward expansion of intensive agriculture. Globally, agriculture in the Russian Federation could gain the greatest benefit from a warmer climate if the increase in ETS is considered separately from other factors. Warmer temperatures shift the area of the country that is bioclimatically suitable for agriculture as much as 600 km northward (by the 2080s, under high-emission scenarios) with an increase in production of up to 1.5-2 times (Pegov *et al*., 2000). It will also allow introduction of new or more productive crops. For example, accepting the ETS=850 °C isoline roughly limiting the cultivation area of corn for grain (Carter *et al.*, 1991), which includes almost the entire territory of Kazakhstan and Ukraine and crosses the Russian Federation just south of Moscow, the 250 °C change in ETS by the 2020s (compared with 1980s climate – see Table 6) expands the potential corn cultivation area up to 400 km north in the Russian Federation. Considering more realistic scenarios, with limitations on both temperature and precipitation, the area potentially suitable for agriculture may increase by 64 percent (Fischer *et al*., 2005).

On the other hand, the best agricultural lands in the Russian Federation, Ukraine and Kazakhstan (Figure 4A) coincide with the zone of limited water availability and are more limited

figure 4

Climate change impacts on the factors limiting agriculture: growing degree days base 10 ˚C (GDD) and Thornthwaite's aridity index (Aridity), for the current (1970-2000) climate (A) and projections for the 2020s (B) and 2050s (C). The projections combine mean GDD and aridity computed for five CMIP-3 GCM projections under the IPCC SRES A1FI scenario



by precipitation levels (322 mm for agricultural lands in Kazakhstan, 507 mm for the Russian Federation and 547 mm for Ukraine) than by temperatures (Figure 4A). Droughts regularly occur in this region (Table 6). Over the last three decades, the frequency of drought in the main agricultural regions of the Russian Federation has increased (Gruza *et al*., 1999; Spinoni *et al*., 2013). On these lands, a longer and warmer growing season may affect soil moisture, decreasing yields and leading to higher incidence of drought (Alcamo *et al*., 2007; Figure 4B, 4C). Limited land availability and soil fertility outside of *Chernozem* areas (Stolbovoi and McCallum, 2002) make it highly unlikely that the shift of agriculture to the boreal forest zone will ever compensate for crop losses caused by increasing aridity in the current zone of intensive agriculture. Decreasing availability of soil moisture is especially important for the main grain-growing regions of the Russian Federation and Ukraine, which in the past have been subjected to droughts every third year on average (Khomyakov *et al*., 2005). Without expansion of agricultural lands, increased temperatures combined with minor changes in precipitation, which are projected by the majority of GCMs for the steppe regions of the Russian Federation, Ukraine and Kazakhstan (Figure 4) will lead to a 6-9 percent reduction in grain production on average (Alcamo *et al*., 2007).

These simulations do not take into account any effects on yields from higher aerial CO_2 concentrations. "Carbon fertilization" directly affects yields by increasing photosynthetic production (Smith *et al*., 2000). Higher CO_2 concentrations may also indirectly affect yields in water-deficit conditions by decreasing plants' water requirements. Both direct and indirect effects are significantly more pronounced for C3 plants, such as wheat. The earlier laboratory studies demonstrated a very high carbon fertilization effect, with 19 to 31 percent increased wheat yield under a 550 ppm CO_2 concentration (Long *et al*., 2006). On average, across several species and under unstressed conditions, recent data analyses find that, compared with current atmospheric CO_2 concentrations, crop yields would increase at 550 ppm CO_2, in the range of 10-20 percent for C3 crops and 0-10 percent for C4 crops (IPCC 2007). However, the results obtained for the Russian Federation with physically explicit models based on these data – e.g., by Sirotenko *et al*. (1997) – are likely to overestimate the related increase in global yields (Ainsworth, 2008). The Free Air-Enrichment Experiments (FACE) suggest that outside the highly artificial conditions of a test enclosure the carbon fertilization effect is significantly lower, with a mean yield increase of 12 percent for wheat (Long *et al*., 2006) and no response for C4 plants, such as corn. The fertilization effect is more pronounced under water stress (18 percent) than under good watering conditions (8 percent) (Ainsworth, 2008). Note, however, that the results of FACE experiments are highly variable over the test plots, with no data available for the region of interest. Temperature and precipitation changes in future decades are likely to modify, and possibly limit, direct CO_2 fertilization effects on crops and other plants. For instance, high temperature during flowering may lower CO_2 effects by reducing grain number, size and quality (Caldwell *et al*., 2005). Increased temperatures may also reduce CO_2 effects indirectly, by increasing water demand. Rainfed wheat grown at 450 ppm CO_2 demonstrated yield increases with temperature increases of up to 0.8 °C, but declines with temperature increases beyond 1.5 °C; additional irrigation was needed to counterbalance these negative effects (Xiao *et al*., 2005).The ongoing discussion of the role of carbon fertilization effect in future yields (see e.g. Ainsworth, 2008) contains very different estimates of CO_2 fertilization impact on future food security.

Complicating the estimates of yield enhancement under increased CO_2 concentration, the progressive nitrogen limitation (PNL) effect may decrease production on a longer time scale (Luo *et al.,* 2004) without additional nitrogen input or a reduction of nitrogen loss. Furthermore, yield enhancement would be counteracted by the negative effect from increased ozone concentrations in the troposphere (Long *et al*., 2005). These and other effects of modifications in climate and chemical composition of the atmosphere increase the uncertainty of future yield estimations.

The physically based models discussed above attempt to project future yields by simulating major physical processes affecting photosynthesis, hydrology, availability of nutrients and other parameters affecting crop production at a local (e.g., DSSAT – Jones *et al*., 2003), regional (e.g., APEX – Gassman *et al*., 2010) or global (e.g., GAEZ – Fischer *et al*., 2002) level. For the region of interest, Alcamo *et al*. (2007) used a modified GAEZ model (Fischer *et al*., 2002) to find the response of multiple crops to GCM-projected 2020s, 2050s and 2080s changes in temperature and precipitation and to estimate the impacts of climate change on water and food security. They found a general decline in the potential climate-related yield for the majority of analysed model integrations, with a correspondent decrease in food and water security. Furthermore, Dronin and Kirilenko (2010) combined these results with a simple model of food trade between regions and analysed the capacity for adaptation to increasing yield variability. While their analysis took into account the possibility of replacing some cultivars with others better suited for changing climate, they did not consider any change in yields due to progress in technology and management.

The statistical models attempt to use the historical yields in different years (time series), areas (cross-sections) or across both time and space (panels) to build a regression model, with temperature, precipitation and other parameters of climate used as predictor variables. While the physically based models are much more complex and require estimation of multiple parameters during the process of calibration, much simpler statistical models may demonstrate similar accuracy (Lobell and Burke, 2010). The additional benefit, which could also be a weakness of statistical models, is that local non-climatic conditions such as soils, management practices and technological advancement are intrinsically included in the model. For example, Dronin and Kirilenko (2013) used a statistical model to analyse the historical yields in The Russian Federation from 1958 to 2010, attempting to explain the difference between the reported yield and the sum of climatic (explained by the weather) yield and multiyear trend as a result of agrotechnological progress. The variations of harvest adjusted for weather and management improvements were considered in connection with the policies during key periods of agriculture in the Russian

Federation: the "Virgin Lands" campaign (end of 1950s); Kosygin-Liberman initiatives (late 1960s); Brezhnev's stagnation era (late 1970s-early 1980s); Gorbachev's "*Perestrojka*" (1985-1991); and land privatization and price liberalization (1990s). They found a long-term trend of ~1.15 percent yield increase annually, which they attributed to long-term technological change.

To estimate future climate-related yield changes in the region of interest, we used a dynamic yield model by Alcamo *et al*. (2007) and a statistical model by Dronin and Kirilenko (2013). Both models were limited in coverage to the Russian Federation territory; for this reason, we estimated corresponding changes in Ukraine and Kazakhstan by computing the changes in yields in the adjacent agricultural zones of the Russian Federation. For Kazakhstan, this zone included Chelyabinskaya, Kurganskaya, Omskaya, and Tumenskaya *Oblasts*, and for Ukraine, Belgorodskaya, Kurskskaya, Lipetskskaya, Rostovskaya, and Voronezhskaya *Oblasts* and Stavropolsky *Kray*. For the territory of the Russian Federation, the dynamic and statistical models both show similar patterns in yield change, generally with a small reduction or an increase in yield for the Russian Federation and Ukraine and larger reductions for Kazakhstan (Table 7). Since the statistical model may poorly represent the yield outside the range of the historical climatic envelope, in the next section we base our assessments on the results of the dynamic model (Alcamo *et al*., 2007), while assuming the historical long-term technology-related trends in yields found by Dronin and Kirilenko (2013).

5. Outlooks for grain production and export

The outlooks for grain production and export are typically based on analyses of the recent agricultural trends, agricultural and economic policies, and assumptions about improvements of technology, infrastructure, and management techniques. They do not usually take into account climate change scenarios. The Federal Program of Agricultural Development and Regulation of Markets for Agricultural Produce, Raw Materials, and Food for 2013-2020 (Gosudarstvennaya programma razvitiya…, 2012) set new targets for the agriculture sector of the Russian Federation focusing on: (1) increased export potential; and

table 7

Estimated wheat yield change from 1980s to 2020s (percentage) attributable to temperature and precipitation shift alone, as simulated by dynamic (D, see Alcamo *et al*., 2007) and statistical (S, see Dronin and Kirilenko, 2013) yield models. Notice that for this time period the pattern of climate change is similar for A1FI and A2 scenarios

Scenario	Model	Kazakhstan	Russia	Ukraine
A1FI	S	78.9	91.6	97.3
	D	-	-	-
A2	S	75.9	90.1	97.1
	D	96.8	94.0	78.5
B1	S	80.4	90.8	98.0
	D	-	-	-
B2	S	-	-	-
	D	73.8	90.3	86.4

Sources: ERBD, 2008 ; IKAR, 2009 ; Liefert et al., 2013 ; Rau, 2012 ; FAOSTAT, 2013 ; Babkin, 2013, Schierhorn et al., 2012

table 8
Summary of published wheat production trends and outlooks

	Cereal production, million tonnes, selected years						Outlooks for cereal production, million tonnes				
	1998	2002	2005	2008	2010	2012	IKAR for 2016	IKAR for 2019	USDA for 2021	EBRD maximum potential scenario	Road Map 2020
Russia	46	84	77	106	59	69	98	125	100	126	295.6
Ukraine	25	46	37	53	39	46	44	Na	59	75	na
Kazakhstan	6	16	14	15	12	15	22	Na	na	29	na
Total	77	146	128	174	110	130	164			230	na

(2) increased food security based on reliance on internal meat and dairy production. In the view of the authors, the numerical targets set under this program[5] are overly optimistic based on unrealistic productivity gains assumptions (2.5 percent annual growth rate for grains). In 2008, despite record high prices for grain on the world market (up by USD 400-450/tonne), the area under cereals increased by only 5 percent in the Russian Federation. During the Soviet period, much marginal land had been ploughed but it was then abandoned in the 1990s and its cultivation is still unprofitable regardless of high prices for grain (Liefert *et al*., 2009a). The national report summarizing realization of the prior Federal Program as of 2011 shows that the area under cereals decreased slightly in the Russian Federation in 2008-2011 (O hode y resultatah … 2012).

In fact, the high growth rates are based on expert estimates of potential yields, which are projected to exceed the current yields by hundreds of percentage points. For example, the European Bank for Reconstruction and Development (EBRD) estimated the maximum potential grain production in the Russian Federation at 126 million tonnes (EBRD-FAO, 2008). These estimates are based on the assumption that since the agroclimatic conditions in the Russian Federation are similar to those in Canada, the Russian Federation can increase its average yields from 1.86 t/ha (2008-2012) to the current level of yields in Canada (3.54 t/ha). Similarly, the Russian Institute for the Agrarian Market Studies has projected that in 2019, grain production in the Russian Federation will reach 125 million tonnes and grain export will be about 45-50 million tonnes (Schierhorn, *et al*., 2012). According to a projection by the Russian Federation's Ministry of Agriculture, by 2020, grain production could reach 120-130 million tonnes, which would allow export of 30 to 40 million tonnes of grain (Schierhorn *et al*., 2012). Perhaps the least convincing among these outlooks is the "Road Map of Agricultural Development in the Russian Federation by 2020" published by Babkin (2013), which projects a 214 percent increase in grain production from 2011 to 2020, up to 295.6 million tonnes, which would require a 13.5 percent annual growth in grain production.

We have developed more realistic growth projections, taking into account changes in management practices and technology, as well as the changes of climate in the main agricultural regions of the Central Eurasian grain belt.

One simple, albeit frequently used, approach to estimating future yields employs a linear

5 Average annual grain production under the Program is set to increase to 115 million tonnes, with overall export potential estimated at 30 million tonnes. Meat and poultry production to go up to 14.07 million tonnes in live weight, and milk production up to 38.2 million tonnes which translates into increased consumption from 69.1 to 73.2 kg/per capita for dairy and from 247 to 259 kg/per capita for meat, and an increase in exports of pork and poultry, up to 200 000 and 400 000 tonnes, respectively.

regression model with climate parameters (usually temperature and precipitation) as predictors, assuming other parameters to be constant (e.g. Lobell *et al*., 2009). The next step would be to analyse time series, attempting to explain the observed long-term yield trends with the change in technology and management practices and short-term variations with climate.

Historically, the long-term rate of grain yield increase has demonstrated surprisingly little variability. To the best of our knowledge, Obukhov (1927) was the first to publish a statistical analysis of the historical trends of yields in the Russian Federation. Obukhov computed the linear trend for six different crops based on the 1883-1914 yield statistics, estimating a 1.1 percent annual yield increase (8 kg/ha) with the "yield norm" (potential yield not accounting for weather variability) of 0.57 t/ha in 1883 and 0.82 t/ha in 1914. Another study of the historical change in yield (Wheatcroft, 1977) analysed the 1885-1940 yield data and found a lower annual trend of 0.87 percent (7 kg/ha), presumably due to significant agriculture fallback during the periods of World War I, Civil War, and experiments in economics in the 1920s. Dronin and Kirilenko (2013) applied the same approach to analyse the 1958-2010 grain crops and found a 1.15 percent annual increase trend (1.6 kg/ha). Similarly, despite drastic changes in economics, the 1980-2010 yields demonstrate a 1.15 percent increase on average.

While the twentieth century's long-term trend in yield can be explained by technological changes, a future scenario of grain balance should also take climate change into account. We have already described the potential future reduction in yield, mainly due to restricted water availability. Combined with a realistic rate of yield increase attributable to technological changes, however, higher yields can be projected. For example, a 6 percent decrease in potential grain yield in the Russian Federation in the 2020s due to climate change (Alcamo *et al,*. 2007), combined with a 1.15 percent agrotechnological yield increase trend (Dronin and Kirilenko 2013) would result in a 35 percent yield increase over the 1980s-2020s period.

For the purpose of this study we have accepted the historical yield trend as a conservative estimate of future yield growth in the Russian Federation and suggest the following three scenarios of future yield growth due to changes in technology and management:

I. Federal Program projection: 2.5 percent annual yield growth.
II. Historical Trend ("business as usual"): 1.15 percent annual yield growth.
III. Historical Trend Plus Climate: 1.15 percent annual yield growth plus climate change.

Table 9 shows the current (2008-2010) and future (2020) grain balance for the Russian Federation according to these three scenarios. The Federal Program projections show a significant increase in the amount of extra grain after meeting the requirements of human consumption, livestock and industry, indicating a surplus which can be exported. However, even projections under the conservative Historical Trend scenario indicate that a significant amount of grain can be exported.

While the cereal production in the Russian Federation, Ukraine and Kazakhstan is projected to increase, domestic demands are likely to grow at a much slower rate (see Tables 9-11). Populations of all three countries are projected to decline and the regional per capita incomes are expected to continue growing, with consumer diets shifting away from cereals. With appropriate policies, this combination of rising prices and demand on the international market and moderate domestic demand is likely to benefit export opportunities for the Russian Federation, Ukraine and Kazakhstan.

On the other hand, when the impact of climate change is taken into account, meeting the Federal Program goals of increasing meat production is possible only if grain exports are reduced more than 50 percent. However, we suggest that even the 2008-2012 rates of meat production are not sustainable. First, the most successful sector, poultry production, has already approached the level of demand (3.8 million tonnes – cf. 3.2 million tonnes produced in 2010). The increase in poultry

table 9

Current (2008-2010) and future (2020) grain balance (million tonnes) for Russian Federation, according to the Federal Program (I), Historical Trend (II) and Historical Trend Plus Climate scenarios (III)

Item	2008-2010	2020 scenarios		
		I	II	III
Beginning stocks	13.8	13.9	10.8	10.8
Production	88.4	115	99.0	90 -93
Import	1.6	0.4	0.4	0.4
Total production	103.8	129.2	113.2	102.2-105.2
Food and industry	24.7	26.0	26.0	26.0
Seeds	11.8	12.0	12.0	12.0
Feed	35.6	42.0	42.0	42.0
Total consumption	72.1	80.0	80.0	80.0
Production-consumption	31.7	49.2	33.2	22.2-25.2
Export	16.0	30.0	14.0	2.9-5.9
Intervention fund	7.2	8.5	8.5	8.5
Ending stocks	8.5	10.8	10.8	10.8

Notes: The 2020 grain production (115 million tonnes), export (30 million tonnes), intervention fund (8.5 million tonnes) and grain imports (0.3 percent from the grain production and stocks) are based on the Federal Program of Agricultural Development and Regulation of Markets for Agricultural Produce, Raw Materials, and Food for 2013-2020 (Gosudarstvennaya programma razvitiya… 2012). The current grain production in the table (88.4 million tonnes) is based on the 2008-2010 mean, which is slightly higher than the current grain production (85.2 million tonnes) in the Federal Program. The estimates of food, feed, seeds and industry requirements are found in several Russian sources (see, for example, Altukhov, 2013). The size of ending stocks for Russia is recommended to be 10.8-10.9 million tonnes with 50 percent reliability and 13.4-13.7 million tonnes with 60 percent reliability (Altukhov, 2013).

production is thus possible only for export, but this option is limited due to competition from the United States and other countries, where cheaper corn is used for feed compared with more expensive wheat used in the Russian Federation (Welton, 2011). Domestic protection measures will be effective only in the case of poultry, while pork and beef production will meet higher competition with imports since the Russian Federation joined the World Trade Organization (WTO) in 2012 (Kiselev, 2013). Currently, the agricultural protectionist policies are based on veterinary standards, but after they are lifted, some experts in the Russian Federation warn that an unprecedented volume of pork imports will immediately enter the Russian market.[6] While the Federal Program aims to increase both beef and milk production, this is a very challenging task due to limited availability of fodder and increasing competition with imports of meat from Brazil, Argentina and Uruguay, which are currently the main beef exporters to the Russian Federation. With a limit on trade-distorting support and without the ability to raise customs duties above bound levels, the Russian Federation is likely to depend on beef imports for a long period to come (Kiselev and Romashkin, 2012).

Accession to the WTO will therefore not allow the Russian Federation to implement its policy of substituting relatively low-cost beef imports with domestic beef production. This will have a positive influence on grain exports. Grain export and livestock breeding are competitors, and success

[6] http://chickeninfo.ru/perspectivnoe_zhivotnovodstvo/ptitsevodstvo-segodnya/hvatit-li-rossiyanam-myasa--obzor-rinka-myasa-v-2013-godu

in grain exports does not automatically lead to an increase in meat production. If there is a choice between exporting grain or allocating it for the livestock sector (i.e. poultry), the former option has the advantage because of the attractiveness of earning hard currency.[7] We suggest that the demand for feedgrain will increase at a slower rate, compared with the Federal Program's goals, leaving more grain for export. A recent report on agriculture in the Russian Federation by Salputra *et al*. (2013) used an econometric model to suggest similar projections for 2020-2025. These included: a decrease in beef production with a corresponding increase in imports to meet growing demand; an increased import of pork to address the gap between the fast growth of demand and slow growth of production; and a fast growth of poultry production, exceeding the internal demand. While the authors concluded that the Russian Federation will retain its position as a grain exporter, they also predicted a conservative increase in grain yields combined with some contraction in the area under cereals in favour of more profitable sunflower production (Salputra *et al*., 2013). The Federal Program's predicted demand for feedgrain is based on the assumption of further improvement of productivity of the livestock sector. The Program suggests that, if approximately 3.6 tonnes of grain was needed in 2008-2011 for production of 1 tonne of meat (live weight), then in the 2020s only 3 tonnes of grain would be required to produce 1 tonne of meat. (Altukhov, 2013).

During the past 20 years, Ukraine and Kazakhstan have both demonstrated very similar changing trends in agricultural production and exports, comparable to those occurring in the Russian Federation. Therefore, we assume that the scenarios formulated for the Russian Federation may also be valid for Ukraine and Kazakhstan. The initial 1990s policies of price liberalization and privatization were followed by a chronic deep crisis in agriculture. In the early 2000s, a huge increase in government support and the emergence of large, vertically integrated agro-industrial holdings led to a rapid agriculture recovery, but evidence indicates that in recent years, grain surplus was achieved mainly as a result of favourable weather and low internal demand for feedgrain. Thus, both Ukraine and Kazakhstan seek their fortunes by boosting grain export; however, this is limited by the current state of infrastructure. Nevertheless, both countries have ambitious goals of becoming major world grain exporters, while reaching self-sufficiency in meat production (Programma po razvitiju agropromyshlennogo...2012).

The targets for 2020s grain production in both countries are based on the maximum potential productivity for a given climate. For example, the EBRD-FAO (2008) estimates that grain yields in Ukraine could increase from 2.6 t/ha to 7.0 t/ha (thus attaining the level of yields in France), while the Ukrainian officials call for achieving 90 percent of West European yield levels by 2020.[8] Similarly, according to the EBRD maximum potential scenario, Kazakhstan's yields can increase to the level of Australia's, from 1.16 t/ha to 1.9 t/ha. Note that EBRD-FAO projections were intended only to demonstrate full agro-ecological potential of the region, without taking into consideration other factors. In addition, none of these outlooks takes into account the impacts of climate change.

For Ukraine, annual production of 72 million tonnes of grain would require 4.6 percent annual growth; however, the historical trend has been 1.35 percent. Similarly, the EBRD projections for Kazakhstan would require a 4.5 percent annual grain yield growth, but the yield trends in the arid steppes of Eurasia have not exceeded

7 For example, in 2012, the Russian Federation enjoyed good harvest of cereals (71 million tonnes) but an article in a Russian newspaper "*Nezavisimaya*" ("Independent") from 7 November 2012 stated that the chairman of the flour milling union of the Russian Federation had warned about a possible deficit of grain in spring of 2013 because of excessive export of grain in autumn of 2012.

8 According to Nikolay Prisyazhnuk, the Minister of Agricultural Policy and Food: "Reaching the level of 90 percent of the yield of developed countries, while keeping the existing area, will provide an additional 30 million tonnes of production." http://www.proagro.com.ua/news/ukr/4081864.html

table 10

Current (2008-2010) and future (2020) grain balance (million tonnes) for Ukraine, according to the Federal Program (I), Historical Trend (II) and Historical Trend Plus Climate scenarios (III)

Item	2009-2011	2020 scenarios		
		I	II	III
Beginning stocks	4.5	5.6	5.6	5.6
Production	46.0	72.0	52.6	41.3-45.2
Import	0.1	0.1	0.1	0.1
Total production	50.6	77.7	58.3	46.9-50.9
Food	6.4	6.0	6.0	6.0
Seeds	4.0	4.0	4.0	4.0
Feed	15.1	18.0	18.0	18.0
Total consumption	25.5	28.0	28.0	28.0
Production/consumption	25.1	49.7	30.3	18.9-22.9
Export	18.8	41.0	21,6	10.2-14.2
Intervention fund	-	3.1	3.1	3.1
Ending stocks	6.3	5.6	5.6	5.6

Notes: The 2020 grain production (72.0 million tonnes) and export (41.0 million tonnes or more) are frequently cited by Ukrainian media with a reference to the Ministry of Agricultural Development and Food. On the consumption side, foodgrain demand is declining from 46 to 43 million tonnes due to projected decline of Ukrainian population. Grain for seeds estimates are based on 0.27 t/ha average seed requirements for Russia (Altukhov, 2013). It is likely that the sown area under cereals will not change significantly in Ukraine. In any case, Ukrainian officials have called on farmers to keep the sown area under grain.* We expect some growth in feed demand because of an existing trend for increase of meat production. Since no official projection for 2020 feed demand is available, we calculate feed requirements from total internal consumption demand for grain (28 million tonnes), food (6 million tonnes) and seeds (4 million tonnes). The internal consumption of grain at 28 million tonnes is believed to guarantee food security of Ukraine (Rynok zenovyh 2013). Estimate of grain reserve reaching 5.6 million tonnes is based on FAO's recommendation to reserve at least 20 percent of annual grain consumption (Rau, 2012).

* http://news.mail.ru/inworld/ukraina/ua_center/109/economics/15594169/

0.48 percent during the past 60 years. Due to the lack of grain production statistics at the regional (subnational) level for Ukraine and Kazakhstan prior to 1991, we have calculated historical trends for these countries using analogous data from the adjacent parts of the Russian Federation. For Ukraine we used data for the Central Black Earth region and North Caucasus. For Kazakhstan, the closest analogy is the southern fringe of Western Siberia. The scenarios of future grain balances of Ukraine and Kazakhstan are summarized in Tables 9 and 10. The official 2020 goals (scenario I) are unlikely to be achievable, as they assume a much higher than historical rate of annual yield growth. Meanwhile, a conservative scenario (scenario II) still indicates a sizable grain surplus, which is comparable to current volumes of grain export, while meeting internal feed demand compatible with the goals for increased meat production. However, meeting the goals for expanded grain export is possible only through reductions in meat production.

Combined with climate change (scenario III), the conservative scenario (scenario II) discussed above becomes less plausible. Reduction to below the current grain yield level will lead to intensified competition between grain exports and meat production. By the 2020s, the world cereal trade is projected to increase 17 percent, to 328 million tonnes (OECD/FAO 2011). The official targets for grain production and exports show the RUK region (the Russian Federation, Ukraine and Kazakhstan) supplying close to 30 percent of all grain exports (Table 11), justifying the idea of developing the RUK Grain Pool, first announced in 2009 and still being considered by the parties. However, the conservative scenario II would reduce the RUK share of exports to 12 percent, which is close to the current state, and taking climate change into account would further diminish it to merely 6 percent. Slow growth (in the Russian Federation) or stagnation (in Ukraine and Kazakhstan) of grain production combined with high variability of yields in future climate would reduce the prospects of the RUK Grain Pool countries to influence the world grain market.

6. Conclusions

The Russian Federation, Ukraine and Kazakhstan have become leading producers and exporters of grain, particularly wheat. Projections by several national and international agencies (Table 8) suggest that within the next few years these three countries together are very likely to surpass the European Union and the United States in terms of total grain exports and wheat exports. However, estimates of different agencies differ greatly from each other. For example, the United States Department of Agriculture (USDA) projects that, by 2021, total grain and wheat exports from the Russian Federation and Ukraine will rise by 93 percent and 76 percent, respectively, relative to average annual volumes during 2006-2010, and that this region would supply 22 percent of the world's total grain exports and 29 percent of wheat exports (Liefert *et al.*, 2013). In contrast, the outlook by the Food and Agricultural Policy Research Institute - Iowa State University (FAPRI-ISU) (2010) projects much slower growth of grain production and exports for this region.

These outlooks and scenarios are generally based on extension of the recent export and production trends, as well as several assumptions made by various authors, such as favourable weather conditions, benefits of climate change, improvement of agricultural policies, continuous improvement of management techniques and infrastructure and the possibility of recultivating previously abandoned arable lands. Given the many uncertainties about these factors, such assumption-based projections need to be treated with caution.

The recent growth of exports from these three countries has been driven primarily by three factors: a) favourable temperature and precipitation regimes in 2002-2009, compared with the previous ten years (Liefert *et al*., 2009b; 2013); b) grain surplus caused by the relatively low domestic demand for grain; and c) significant increase of investments in agriculture and increase of agricultural subsidies, resulting in the growth in productivity in grain and livestock production in the second part of the period (2010-2012).

Comparison of production and export trends, however, also clearly indicates that high grain exports from the Russian Federation, Ukraine and Kazakhstan have been driven primarily by low domestic demand rather than significant increase in productivity. Future recultivation of the abandoned arable lands remains uncertain and unlikely, given that most of the marginal land abandoned in the 1990s had very low potential productivity.

A sequence of years with favourable weather conditions (2002-2009) was followed by severe droughts in 2010-2012. Total grain production by the Russian Federation, Ukraine and Kazakhstan dropped from the record high 174 million tonnes in 2008 to the meager 110 million tonnes in 2010 and 130 million tonnes in 2012, due to the persistent drought. Such short-term weather-related fluctuations do not provide any valid base for production scenarios and need to be viewed in a much longer-term context of climatic variability and trends.

Agro-ecological projections driven by climate change scenarios suggest that the grain production potential in the Russian Federation, Ukraine and Kazakhstan may increase due to a combination of winter temperature increase, extension of the growing season, and CO_2 fertilization effect on agricultural crops; however,

table 11

Current (2008–2010) and future (2020) grain balance (million tonnes) for Kazakhstan, according to the Federal Program (I), Historical Trend (II) and Historical Trend Plus Climate scenarios (III)

Item	2006-2009	2020 scenarios		
		I	II	III
Beginning stocks	11.3	13.0	13.0	13.0
Production	18.3	28.0	19.0*	14.1 -18.4
Import	0.1	0.1	0.1	0.1
Total production	29.7	41.1	35.1	27.2-31.4
Food and industry	4.4 +0,4	5.7	5.7	5.7
Seeds	2.7	2.6	2.6	2.6
Feed	3.5	6.0	6.0	6.0
Losses	0.6	0.6	0.6	0.6
Total consumption	11.6	14.9	14.9	14.9
Production-consumption	18.1	26.2	20.2	13.9-16.5
Export	4.9	13.2	7.2	0.9-3.5
Ending stocks	12.9	13.0	13.0	13.0

Notes: In contrast to Ukraine and Russia, Kazakhstan has not published its 2020 grain production goals. Since Scenario I is based on the EBRD-FAO (2008) maximum potential production of grain using the climate analogue method, we calculated yield increase based on mean yields in Australia, from 1.16 t/ha to 1.9 t/ha by 2016. On the consumption side, we estimated that the demand for foodgrain will increase by 20 percent following population growth from 15.6 million in 2008 to 18.7 million in 2020. The 2013-2020 Kazakhstan Agricultural Program calls for a reduction in area under cereals in favour of forage and technical crops. However, this crop replacement has had a slow start, with no more than 2-3 percent reduction in area under cereals last year (Moldashev, 2013).The Program also projects an increase in internal demand for each category of meat (beef, lamb, horsemeat, and broiler chicken), targeting self-sufficiency in meat consumption and an increase in beef exports of 150 thousand tonnes by 2020. Total meat production is projected to increase by 71 percent, from 0.7 million tonnes in 2009 to 1.2 million tonnes in 2020, with corresponding increase in feedgrain demand (Programma po razvitiju.. 2012).

table 12

Current (2008–2010) and future (2020) grain export (million tonnes) in Russia, Ukraine and Kazakhstan, according to the official goals (I), Historical Trend (II) and Historical Trend Plus Climate scenarios (III). Note that model projections for (III) are given for SRES A2 and B2; compare with Tables 9, 10, and 11, where a range is given for model projections

Country	2008-2010	2020 scenarios			
		I	II	III	
				SRES/B2	SRES/A2
Russia	16.0	30.0	10.9	2.9	5.9
Ukraine	18.8	41.0	21.6	14.2	10.2
Kazakhstan	4.9	13.2	7.2	0.9	3.5
Total export	39.7	84.2	39.7	18.0	19.6

the most productive semi-arid zone could suffer a dramatic increase in drought frequency. In view of these projections, further research is needed to evaluate vulnerability of grain production to future climate change and to determine suitable adaptation measures. If projected climatic changes are slow enough that adaptations to the new climatic conditions can go along with the normal cycle of equipment replacement, the costs of adaptations might be relatively low. These responses include selection of new cultivars, introduction of new crops, early planting, changes in crop mixture and crop rotation, change in land and water management practices, new pest and disease control techniques, etc. However, if climate change is accelerated, as projected by GCMs for this century, reactive adaptations may carry much higher costs and planned adaptations may be required (Dronin and Kirilenko, 2011).

The following sources of uncertainty need to be further examined in order to produce more reliable grain production outlooks:

- Level of uncertainty associated with climate change scenarios.
- Lack of regional data on CO_2 fertilization effect on crops and their water-use efficiency.
- Errors associated with land statistics and uncertainties associated with land cover trends derived from satellite imagery.
- Impacts of proposed recultivation of previously abandoned marginal lands on future greenhouse gas emissions, considering that recultivation would decrease current levels of carbon sequestration.
- Uncertainties associated with future political, social and economic changes in the RUK countries and their future agricultural policies.
- Uncertainties about the future development pathways of infrastructure, financial systems, land market development and future alignment between WTO requirements and agricultural subsidies.

Development of effective and sustainable food-production strategies in the Russian Federation, Ukraine and Kazakhstan requires further basic, applied and translational research in several areas:

- More accurate modelling of climate change and its impacts on water resources and agro-ecological systems at the regional scale.
- FACE and laboratory experiments to improve understanding of CO_2 fertilization on agricultural crops.
- Modelling of probability and frequency of extreme events, such as droughts, heat waves, wildfires, frosts and floods;
- Modelling human vulnerability and adaptations to climate change.
- Research on how adaptation measures can be incorporated into ongoing activities such as land-use planning, water resource management, drought and heat wave early warning and diversification of agriculture.

Our analysis shows that the ambitious goals of boosting grain and meat production by the 2020s, recently articulated by the governments of the three countries, are unlikely to be accomplished. However, the overall outlook is optimistic. The conservative “business as usual” scenario and the model GCM-based projections all indicate that the Russian Federation, Ukraine and Kazakhstan will be able to increase their meat production while maintaining grain production surplus similar to the current level.

References

Adams, R., B. Hurd, S. Lenhart, & N. Leary, 1998. Effects of global climate change on agriculture: an interpretative review. *Climate Research* 11: 19 30.

Alcamo, J., N. Dronin, M. Endejan, G. Golubev & A. Kirilenko. 2007. A new assessment of climate change impacts on food production shortfalls and water availability in Russia. *Global Environmental Change* 1 (3 4): 429–444.

Altukhov, A. 2013. Ustojchivost' zernovogo khozyajstva i rynka zerna – osnova ikh razvitiya. *Kheloprodukty*, 2013, № 9. pp. 4-10. In Russian: Алтухов А.И. 2013. Устойчивость зернового хозяйства и рынка зерна – основа их развития. *Хлебопродукты*, № 9. С. 4-10.

Antle, J., S. Capalbo, E. Elliott & K. Paustian. 2004. Adaptation, spatial heterogeneity, and the vulnerability of agricultural systems to climate change and CO_2 fertilization: an integrated assessment approach. *Climatic Change* 64(3): 289-315.

Babkin, K. 2013. Dorozhnaya karta razvitiya sel'skogo khozyajstva Rossii do 2020 goda (Road map of development of agriculture in Russia to 2020). Moskovskij ekonomicheskij forum, 20-21 marta 2013.

Borodin, K., M. Prokopiev & A. Strokov. 2013. In Russian: Бородин К.Г., Прокопьев М.Г., Строков А.С. Оценка перспектив развития отечественного рынка мяса птицы в условиях присоединения России к ВТО. Проблемы прогнозирования, 2013, № 2. С.68-75.

Bogaert, J., L. Zhou, C. Tucker, R. Myneni & R. Ceulemans. 2002. Evidence for a persistent and extensive greening trend in Eurasia inferred from satellite vegetation index data. *Journal of Geophysical Research* 107, (D11), 10.1029/2001JD001075, 2002.

Brock, G., M. Grazhdaninova, Z. Lerman & V. Uzun. 2008. Technical efficiency in Russian agriculture. In: Lerman, Z. and Lanham, M.D., eds. *Russia's agriculture in transition*. Lexington Books. pp. 353–372.

Caldwell, C., S. Britz & R. Mirecki. 2005. Effect of temperature, elevated carbon dioxide, and drought during seed development on the isoflavone content of dwarf soybean [Glycine max (L.) Merrill] grown in controlled environments. *Journal of Agricultural and Food Chemistry* 53: 1125-1129.

Carter, T., M. Parry, & J. Porter. 1991. Climatic change and future agroclimatic potential in Europe. *International Journal of Climatology* 11(3): 251–269.

Csaki, C. & Z. Lerman. 1997. Land reform and farm restructuring in East Central Europe and CIS in the 1990s: Expectations and achievements after the first five years. *European Review of Agricultural Economics* 24(3-4): 428-452.

de Beurs, K. & G. Henebry. 2004. Land surface phenology, climatic variation, and institutional change: Analyzing agricultural land cover change in Kazakhstan. *Remote Sensing of Environment* 89(4): 497-509.

de Beurs, K. & G. Henebry. 2008. Northern Annular Mode effects on the land surface phenologies of Northern Eurasia. *Journal of Climate* 21: 4257-4279.

Dole, R., M. Hoerling, J. Perlwitz, J. Eischeid, P. Pegion, T. Zhang, X-W. Quan, T. Xu & D. Murray. 2011. Was there a basis for anticipating the 2010 Russian heat wave? *Geophysical Research Letters* 38: 10.1029/2010GL046582.

Dronin, N. & E. Bellinger. 2005. Climate dependence and food problems in Russia (1900-1990). The interaction of climate and agricultural policy and their effect on food problems. CEU Press, Budapest-New York, 366 p.

Dronin, N. & A. Kirilenko. 2008. Climate change and food stress in Russia: what if the market transforms as it did during the past century? *Climatic Change* 86: 123-150.

____________________. 2010. Climate change, food stress, and security in Russia. *Regional Environmental Change* 11(1): 167-178.

____________________. 2013. Weathering the Soviet Countryside: The Impact of Climate and Agricultural Policies on Russian Grain Yields, 1958

2010. *The Soviet and Post-Soviet Review* 40(1): 115 143.

Easterling, W., P. Aggarwal, P. Batima, K. Brander, L. Erda, S. Howden, A. Kirilenko, J. Morton, J-F. Soussana, J. Schmidhuber & F. Tubiello. 2007: Food, fiber and forest products. In Parry, M.L., Canziani, O.F., Palutikof, J.P., van der Linden, P.J. & Hanson, C.E., eds., *Climate Change 2007: Impacts, Adaptation and Vulnerability*. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK, 273-313.

EBRD-FAO, 2008. Grain production and export potential in CIS countries. Fighting food inflation through sustainable investment. European Bank for Reconstruction and Development/ Food and Agriculture Organization, London, 8 p.

FAOSTAT, 2013. Food and Agriculture Organization Statistics. http://www.fao.faostat.org, last access December 2013.

Fisher G., M. Shah & H. van Velthuizen. 2002. *Climate Change and Agricultural Vulnerability*. International Institute for Applied Systems Analysis, Vienna, 152 p.

Fischer G., M. Shah, F. Tubiello & H. van Velhuizen. 2005. Socio-economic and climate change impact on agriculture: an integrated assessment, 1990-2080. *Philosophical Transactions of Royal Society* B 360: 2067-2083.

Jones, J., G. Hoogenboom, C. Porter, K. Boote, W. Batchelor, L. Hunt, P. Wilkens, U. Singh, A. Gijsman & J. Ritchie. 2003. DSSAT Cropping System Model. *European Journal of Agronomy* 18: 235-265.

Gassman, P., J. Williams, X. Wang, A. Saleh, E. Osei, L. Hauck, R. Izaurralde & J. Flowers. 2010. Policy Environmental EXtender (APEX) Model: An Emerging Tool for Landscape and Watershed Environmental Analyses. *Transactions of the ASABE* 53(3): 711 740.

Golubev, G. & N. Dronin. 2004. Geography of droughts and food problems in Russia (1900 2000). Report of the international project on global environmental change and its threat to food and water security in Russia. Center for Environmental Systems Research, Kassel.

Gosudarstvennaya programma razvitiya.., 2012, in Russian: Государственная программа развития сельского хозяйства и регулирования рынков сельскохозяйственной продукции, сырья и продовольствия на 2013 – 2020 годы. М.: Мин-во сельского хозяйства Российской Федерации, 2012. 204 с. (The Federal Program of Agricultural Development and Regulation of Markets for Agricultural Produce, Raw Materials, and Food for 2013-2020), Moscow, 2012.

Gruza, G., E. Rankova, M. Bardin, *et al*. 1999. In Russian: Груза Г.В., Ранкова Е.Я., Бардин М.Ю., Рочева Е.В., Платова Т.В. Самохина О.Ф., Соколов Ю.Ю. Рачкулик О. Изменения климата 1998. Обзор состояния и тенденции изменения климата России. Институт глобального климата и экологии. М., 1999.

Linderholm, H. 2006. Growing season changes in the last century. *Agricultural and Forest Meteorology* 137(1 2): 1-14.

IKAR 2013: Institute for Agricultural Market Studies, Russia. http://www.ikar.ru/eng/, last access December 2013.

Ioffe, G., T. Nefedova & K. de Beurs. 2012. Land abandonment in Russia: the case of two oblasts. *Eurasian Geogr Econ* 53(4): 527–549. doi:10.2747/1539-7216.53.4.527.

Kariyeva, J. 2010. Land Surface Phenological Responses to Land Use and Climate Variation in a Changing Central Asia. Dissertation, University of Arizona, Tucson, AZ.

Kariyeva, J. & W. van Leewuven. 2011. Environmental Drivers of NDVI-Based Vegetation Phenology in Central Asia. *Remote Sensing* 3(2): 203-246; doi:10.3390/rs3020203.

Kiselev, S. & R. Romashkin. 2012. Possible Effects of Russia's WTO Accession on Agricultural Trade and Production; ICTSD Programme on Agricultural Trade and Sustainable Development; Issue Paper No. 40; International Centre for Trade and Sustainable Development, Geneva, Switzerland, www.ictsd.org.

Kiselev, S. 2013. In Russian: Киселев С. Влияние вступления в ВТО на сельское хозяйство и продовольственный сектор в России. ФАО Региональное бюро по Европе Центральной Азии. 2013 Июль.

Khomyakov, P., V. Kuznetsov & V. Konyshev. 2001. In Russian: Хомяков П.М., Кузнецов В.И, Конышев В.Н. Влияние глобальных изменений климата на функционирование экономики и здоровье населения России. М.: Ленадат, 2001, 424 с.

Liefert, W., O. Liefert, & M. Shane. 2009a. Russia's Growing Agricultural Imports: Causes and Outlook. Outlook Report No WRS-09-04, Washington, DC, Economic Research Service, USDA. http://www.ers.usda.gov/Publications/WRS0904/.

Liefert, W., O. Liefert, & E. Serova. 2009b. Russia's transition to major player in world agricultural markets. *Choices* 24(2): 1.

Liefert, O., W. Liefert & E. Luebehusen. 2013. Rising Grain Exports by the Former Soviet Union Region. Causes and Outlook. A Report from the Economic Research Service, USDA, February 2013, WHS-13A-01, February 2013, www.ers.usda.gov.

Lioubimtseva, E., 2007. Possible changes in the carbon budget of arid and semi-arid Central Asia inferred from land-use/landcover analyses during 1981-2001. In Lal, R., Suleimenov, M., Stewart, B.A., Hansen, D.O. & Doraiswami, P., eds. *Climate Change and Terrestrial Carbon Sequestration in Central Asia*, Taylor & Francis, London, pp.441-451.

Lioubimtseva, E. & G. Henebry. 2009. Climate and environmental change in arid Central Asia: Impacts, vulnerability, and adaptations. *Journal of Arid Environments* 73(11): 963 977.

Lioubimtseva, E. 2010. Global food security and grain production trends in Central Eurasia: do models predict a new window of opportunity? *National Social Science Journal* 41(1): 154–165.

Lioubimtseva, E. & G. Henebry. 2012. Grain production trends in Russia, Ukraine and Kazakhstan: new opportunities in increasingly unstable world? *Frontiers of Earth Science* 6(2): 157–166. doi:10.1007/s11707-012-0318-y.

Lioubimtseva, E., K. de Beurs & G. Henebry. 2013. Grain production trends in Russia, Ukraine and Kazakhstan in the context of the global climate variability and change. In Younos, T. & Grady, C.A., eds., *Climate Change and Water Resources, The Handbook of Environmental Chemistry*. Vol. 25, 2013, XVIII, 221 p. Berlin, Heidelberg: Springer.

Lobell, D. & M. Burke. 2010. On the use of statistical models to predict crop yield responses to climate change. *Agricultural and Forest Meteorology* 150 (11): 1443-1452.

Lobell, D. 2009. Crop Responses to Climate: Time-Series Models. Crop Response to Climate: Ecophysiological Models. In Lobell, D.B. & Burke, M.B., eds., *Climate Change and Food Security: Adapting Agriculture to a Warmer World*, Springer.

Lobell, D., M. Burke, C. Tebaldi, M. Mastrandrea, W. Falcon & R. Naylor. 2008. Prioritizing Climate Change Adaptation Needs for Food Security in 2030. *Science* 319(5863): 607-610.

Long S., E. Ainsworth, A. Leakey, J. Nösberger & D. Ort. 2006. Food for thought: lower-than-expected crop yield stimulation with rising CO_2 Concentrations. *Science* 312: 1918-1921.

Long, S., E. Ainsworth, A. Leakey & P. Morgan. 2005. Global food insecurity. Treatment of major food crops with elevated carbon dioxide or ozone under large-scale fully open-air conditions suggests recent models may have overestimated future yields. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 360(1463): 2011-2020.

Luo, Y., B. Su, W. Currie, J. Dukes, A. Finzi, U. Hartwig & C. Field. 2004. Progressive nitrogen limitation of ecosystem responses to rising atmospheric carbon dioxide. *Bioscience* 54(8): 731-739.

Mendelsohn, R., W. Morison, M. Schlesinger & N. Andronova. 2000. Country-specific market impact of climate change. *Climatic Change* 45(3-4): 553-569.

Menzel, A., T. Sparks, N. Estrella, E. Koch, A. Aasa, R. Ahas, K. Alm-Kublers, P. Bissoll, O. Braslavska, A. Briede, F. Chmielewski, Z. Crepinsek, Y. Curnel, A. Dahl, C. Defila, A. Donnelly, Y. Filella, K. Jatczak, F. Mage, A. Mestre, O. Nordli, J. Penuellas, P. Pirinen, V. Remisova, H. Scheifinger, M. Striz, A. Suznik, A. van Vliet, F. Wielgolaski, S. Zach & A. Zust. 2006. European phenological response to climate change matches the warming pattern. *Global Change Biology* 12(10): 1365-2486.

Miloserdov, V. 2006. In Russian: Милосердов В. В. Экономические интересы и отношения. Екатеринбург: Изд-во УралГСХА, 2006, 92 с.

Mitchell, T., M. Hulme & M. New. 2002: Climate data for political areas. *Area* 34: 109-112.

Modashev, A. 2012. In Russian: Молдашев, А. Социально-экономические аспекты повышения эффективности развития АПК Казахстана // Устойчивое развитие сельского хозяйства Беларуси в новых условиях : (материалы IX Международной научно-практической конференции 20 сентября 2012 г.) / Республиканское научное унитарное предприятие “Институт системных исследований в АПК Национальной академии наук Беларуси”. - Минск, 2013. - С. 111-114 .

National Communication Russia, 2010. Russia's fifth national communication to the Conference of the Parties of the United Nations Framework Convention on Climate Change. Ministry of Environment Protection, Moscow, 2010.

National Communication Kazakhstan, 2009. Kazakhstan's third, fourth, and fifth national communication to the Conference of the Parties of the United Nations Framework Convention on Climate Change. Ministry of Environment Protection, Astana, 2009.

O hode y resultatah … 2012, in Russian: О ходе и результатах реализации в 2011 году государственной программы развития сельского хозяйства и регулирования рынков сельскохозяйственной продукции, сырья и продовольствия на 2008-2012 годы. Москва: Министерство сельского хозяйства Российской Федерации. 2012. 203 с.

Obukhov, V.M.1927. Dvizhenie urozhaev zernovyx kul'tur v byvshej Evropejskoj Rosiii v period1883-1915 (Dynamic of cereals harvests in the former European Russia in 1883-1915). Vliyanie neurozhaev na narodnoe khozyajstvo Rossii (Impact of poor harvest on national economy). Pod red. (ed) V.G.Gromana. Moskva: Rossijskaya assotsiatsiya nauhcno-issledovatel'skix institutov obshhestvennyx nauk, 1927, part 1. 28-40. (http://istmat.info/node/21586).

OECD 2002. *Agricultural policies in transition*, Paris: Centre for Co-operation with Economies in Transition, Organization for Economic Co-operation and Development, Paris: OECD Publishing.

OECD-FAO 2008. OECD-FAO Agricultural Outlook 2008 2017. Paris: OECD Publishing.

OECD-FAO 2011. OECD-FAO Agricultural Outlook 2011-2020. Paris: OECD Publishing.

Osborne, S. & M. Trueblood. 2002. Agricultural productivity and efficiency in Russia and Ukraine: building on a decade of reform. Market and Trade Economics Division, Economics Research Services, USDA, Agricultural Economics Report No.813.

Parry, M., C. Rosenzweig, A. Iglesias, V. Livermore & G. Fischer. 2004. Effects of climate change on global food production under SRES emissions and socio-economic scenarios. *Global Environmental Change* 14(1): 53–67 doi:10.1016/j.gloenvcha.2003.10.008.

Pegov, S., D. Khomyakov & P. Khomyakov. 2000 Vliyanie global'nyh izmenenii klimata na social'noecomomicheskoye polozheniye Rossii (Global change impact on socio-economical processes in Russia). In Kotlyakov, V.M., ed., Global'nye i regional'nye izmenenija klimata i ikh prirodnye i social'noehkonomicheskie posledstvija (*global and regional climate change and its environmental and socioeconomical impacts*). GEOS, Moscow, pp 60–69 (in Russian).

Prishchepov, A., D. Müller, M. Dubinin, M. Baumann & V. Radeloff. 2013. Determinants of agricultural land abandonment in post-Soviet European Russia, *Land Use Policy* 30: 873 884.

Programma po razvitiju agropromyshlennogo kompleksa v Respublike Kazakhstan na 2013-2020 gody, 2012: In Russian: Программа по развитию агропромышленного комплекса в республике Казахстан на 2013-2020 годы (Агробизнес-2020). Астана, 2012, 98 с.

Prosterman, R., L. Rolfes & J. Duncan Jr. 1999. A Vision for Agricultural Land Reform in Russia. In: Farm profitability, sustainability and restructuring in Russia. Proceedings of the Workshop Held in Golitsyno, Moscow Region 1-2 October 1999, pp.120-140.

Rabbinge, R. & C. van Diepen. 2000. Changes in agriculture and land use in Europe. *European Journal of Agronomy* 13 (2-3): 85–100.

Ramankutty, N., A. Evan, C. Monfreda, & J. Foley. 2008. Farming the planet: 1. Geographic distribution of global agricultural lands in the year 2000, *Global Biogeochemical Cycles* 22, GB1003, doi:10.1029/2007GB002952.

Rau, V. 2012. In Russian: Рау В.В. Зерновой рынок России: от кризиса к возрождению. Проблемы прогнозирования, ИНП РАН, 2012, 2, 76-87.

Rau, V. 2009. In Russian: Рау, В. В. Аграрный сектор: Риски и шансы посткризисного развития Проблемы прогнозирования. - 2009. - N 1. - С. . 97-106.

ROSSTAT 2013 Федеральная служба государственной статистики http://www.gks.ru/wps/wcm/connect/rosstat_main/rosstat/ru/

Rozelle, S. & J. Swinnen. 2007. Transition and Agriculture. California Agricultural Experiment Station. Working Paper No. 00-021, October, 2000.

Rosenzweig, C. & F. Tubiello. 2007. Adaptation and mitigation strategies in agriculture: an analysis of potential synergies. *Mitigation and Adaptation Strategies for Global Change* 12: 855-873,

Rynok zernovyh.., 2013. In Russian: Рынок зерновых культур в Украине в 2011/2012 маркетинговом году http://www.eba.com.ua/static/members_reviews/Kreston_Grain_3_2013_RUS.pdf

Salputra, G., M. van Leeuwen, P. Salamon, T. Fellmann, M. Banse & O. von Ledebur. 2013. *The agri-food sector in Russia: current situation and market outlook until 2025*. In T. Fellmann, T., Nekhay,

O. & M'barek, R., eds., Luxembourg: Publications Office of the European Union, 2013, 73 pp.

Schierhorn, F., D. Muller, A. Prishchepov & A. Balmann. 2012. Grain potentials on abandoned cropland in European Russia. Paper prepared for presentation at the Annual World Bank Conference on Land and Poverty, World Bank, Washington, D.C., 23-26 April 2012,

Sedik, D., S. Sotnikov & D. Wiesmann. 2003. Food security in Russia. FAO Economic and Social Development Paper 153, FAO. Rome, 114 pp.

Serova, E. 2007. Vertical integration in Russian agriculture. In Swinnen, J., ed., *Global supply chains, standards and the poor: How the globalization of food systems and standards affects rural development and poverty*, Wallingford, England: CAB International: pp. 188–206,

Sirotenko, O., H. Abashina & V. Pavlova. 1997. Sensitivity of the Russian agriculture to changes in climate, CO_2 and tropospheric ozone concentrations and soil fertility. *Climatic Change* 36: 217-232,

Sirotenko, O., G. Gruza, E. Rankova, E. Abashina & V. Pavlova. 2007. Modern Climate-Related Changes in Heat Supply, Moistening, and Productivity of the Agrosphere in Russia. *Russian Meteorology and Hydrology* 32(8): 538 546.

Smelansky, I. 2003. Biodiversity of Agricultural Lands in Russia: Current State and Trends. In Ladonina, N., Y. Gorelova & D. Chernyakhovsky, eds., 2003. Moscow: IUCN. 2003. 52 p.

Smith, S., T. Huxman, S. Zitzer, T. Charlet, D. Housman, J. Coleman, L. Fenstermaker, J. Seemann & R. Nowak. 2000. Elevated CO_2 increases productivity and invasive species success in an arid ecosystem. *Nature* 408: 79 82,

Spinoni, J., G. Naumann, H. Carrao, P. Barbosa & J. Vogt. 2013. World drought frequency, duration, and severity for 1951 2010. *International Journal of Climatology*, DOI: 10.1002/joc.3875,

Stolbovoi, V. & I. McCallum. CD-ROM land resources of Russia. IIASA, Laxenburg, Austria, 2002,

Tebaldi, C., K. Hayhoe, J. Arblaster & G. Meehl. 2006. Going to the extremes: an intercomparison of model-simulated historical and future changes in extreme events. *Climate Change* 79(3-4): 185–211 doi:10.1007/s10584-006-9051-4.

Tucker, C., W. Newcomb, S. Los & S. Prince. 1991. Mean and inter-year variation of growing-season normalized difference vegetation index for the Sahel 1981-1989. *International Journal of Remote Sensing* 12: 1113-1115,

United Nations, Department of Economic and Social Affairs, Population Division 2013. World Population Prospects: The 2012 Revision, Key Findings and Advance Tables. Working Paper No. ESA/P/WP.227.

UniSIS 2013. Unified Interdepartmental Statistical Information System (UniSIS) – http://www.fedstat.ru, accessed November 2013,

Uzun, V. 2005. Large and small business in Russian agriculture: adaptation to market. *Comparative Economic Studies* 47: 85-100,

Uzun, V., N. Shaigda & V. Saraikin. 2012. In Russian: Узун В.Я., Шагайда Н.И., Сарайкин В.А., Агрохолдинги России и их роль в производстве зерна. В Исследования по политике перехода сельского хозяйства, #2, 2012, 33 с.

von Cramon-Taubadel, S. 2002. Land reform in Russia. *Economic Systems* 26: 179 183,

Weigand, C. 2011. Wheat import projections towards 2050. Arlington: US Wheat Associates.

Welton, G. 2011.The Impact of Russia's 2010 Grain Export Ban, Oxfam Research Report, June 2011.

Wheatcroft, S.1977. The significance of climatic and weather change on Soviet agriculture (with particular reference to the 1920s and the 1930s). Discussion papers. Soviet Industrialization Project Series. #11, 48 P.

Wright, C., K. de Beurs & G. Henebry. 2012. Combined analysis of land cover change and NDVI trends in the Northern Eurasian grain belt. *Frontier of Earth Science* 6(2): 177 187. doi:10.1007/s11707-012-0327-x,

Zhou, L., C. Tucker, R. Kaufmann, D. Slayback, N. Shabanov & R. Myneni. 2001. Variations in northern vegetation activity inferred from satellite data of vegetation index during 1981 to 1999. *Journal of Geophysical Research* 106: 20069-20083,

Zogolva, E.1997. In Russian: Жоголева Е. Е. Разработка приоритетов аграрной политики России: Дис. … д-ра эконом. наук. М., 1997, 257,