Grain Production Trends in Russia, Ukraine, and Kazakhstan in the Context of the Global Climate Variability and Change

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Abstract Russia, Ukraine, and Kazakhstan are the three major grain producers in Central Eurasia. In the context of the current food-price crisis, these countries might be presented with a window of opportunity to reemerge as the major grain exporters if they succeed in increasing their productivity. Global grain production is highly sensitive to a combination of internal and external factors, such as institutional changes, land-use changes, climate variability, water resources, and global economic trends. Agroecological scenarios driven by climate models suggest that land suitability in this region is likely to change in future, due to impacts of climate change, such as CO_2 fertilization, changes in the growing season, temperature, precipitation, frequency, and timing of droughts and frosts. Grain production in Russia, Ukraine, and Kazakhstan grew steadily between 2002 and 2010 following a 10-year long depression caused by collapse of the USSR. However, in the summer of 2010 Russia and its neighbors experienced an unprecedented heat wave, accompanied by severe wild fires. As news of this disaster became known international grain prices increased dramatically. The future of grain production in this region will be determined by the interplay of climatic variability and multiple non-climatic factors and is likely to have significant impact on both global and regional food security over the coming decades.

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1 Introduction

The current global food crisis clearly indicates that the world's food balance and agricultural livelihoods are highly vulnerable to economic instability and climatic variability. Global grain stocks and prices in 2000–2012 have been particularly volatile as a complex result of political, economic, and environmental factors, including shifting allocation of grain production towards biofuel, increasing global oil prices, changes in food consumption patterns in Asia, and the disruption of food production due to poor harvests in Europe and Australia [1], and massive withdrawal of arable lands in the newly independent countries of the former USSR [2–5]. With abundant highly fertile but under-utilized lands the grain-growing countries of the former USSR, such as Russia, Ukraine, and Kazakhstan, have an opportunity to take a lead on the global market and become top beneficiaries of this rapidly changing food-production landscape if they manage to increase their productivity.

Since collapse of the USSR in 1991, the agricultural systems of Russia, Ukraine, and Kazakhstan have undergone enormous institutional changes that have resulted in exclusion of approximately 23 million hectares of arable lands from production, 90% of which had been used for grain [5, 6]. This land-use transition was the largest withdrawal of arable lands in recent history [4, 7, 8]. The major factors of change in the 1990s were the disintegration of the centrally planned institutions in the agricultural sector and uncertainties in the legal status of land, which resulted in declines in agricultural subsidies, use of technology, and access to markets [9]. In turn, these forces precipitated significant declines of both cereal areas and grain productivity that bottomed out across the region around year 2000 [10–15]. Although the decline of grain production in Russia, Ukraine, and Kazakhstan was followed by slow recovery in 2000–2010, the productivity remains low as a result of combination of economic and environmental factors. In 2010 the wheat productivity was 2.6 t/ha in Ukraine, 1.9 t/ha in Russia, and 0.7 t/ha in Kazakhstan (compared to 7.0 t/ha in France, 4.7 t/ha in China, 3.1 t/ha in the United States) [16]. In summer 2010 the European part of Russia was hit by an extraordinary heat wave with the highest July temperatures since at least 1880 and numerous locations setting all-time maximum temperature records [17]. The heat wave and extreme drought also affected Ukraine, Belarus, and northern Kazakhstan, wildfires swept through some agricultural areas and severely damaged crops. The Russian government declared a state of emergency in 27 agricultural regions, 43 regions had been affected, and over 53 million acres of crops destroyed [18]. The 2010 heat wave cut grain yield in Russia by a third, the potato harvest by 25%, and vegetables by 6% [16, 18]. The Volga region – the biggest grain producer in Russia – was most severely hit by the drought, with an annual harvest drop of more than 70%, while the Central region harvest dropped by 54%. Prices for the staple crop increased about 50% [19]. Although the 2011–2012 summer temperatures in this region were not as high as during the 2010 heat wave, persistent droughts continued during the following 3 years through the entire grain-producing semiarid belt of Eurasia. The heat wave and drought impacted grain markets not only in Russia, Ukraine, and Kazakhstan but the entire world. First, as soon as it became clear that the Eurasian grain harvest was going to be severely affected by the drought, international grain prices increased dramatically [18, 19]. Second, in response to this increase, and in an effort to protect local consumers and local meat producers, the Russian government instituted a grain export ban that pushed grain prices even higher in the international markets.

To date, only a few studies have examined the determinants and the scale of grain production trends and volatility in the Former Soviet Union countries. The goal of this chapter is to examine the interplay of climate variability and other key factors that have determined the recent dynamics and trends of grain production in this region.

2 Factors Affecting Food Production

Food security and the associated risks of disruption to production and distribution networks depend on multiple biogeophysical, sociocultural, political, and economic factors. These can include the respective sensitivities of the agricultural sector to climatic variability, water resources, global market variations, country-scale political, institutional, and economic changes, local policies, and other factors.

2.1 Impacts of Climate Change

Agricultural production and export opportunities are highly sensitive to interannual climate variability as expressed in growing season weather. Climate change and increasing climate variability are likely to bring changes in land suitability and crop yields. Atmosphere-Ocean General Circulation Models (AOGCMs) predict that the temperature in the grain-producing areas of Central Eurasia will increase by

1.5–3.5°C by 2030–2050, with the greatest increase in winter [20]. Despite significant differences in the range of changes among the scenarios produced by different models, the majority of models tend to agree that summer precipitation is likely to decline all over the region and winter precipitation is projected to increase in parts of European Russia and Siberia [3, 4]. The models disagree about the range and pattern of precipitation changes. Lioubimtseva and Henebry [5] used MAGICC/SCENGEN 5.3.2 model [21] to analyze regional climate change scenarios projected by 20 different AOGCMs described in the IPCC Fourth Report [20]. All AOGCMs predict that under any policy scenario, maximum temperatures are likely to increase by 2050 both in summer and in winter; increases of the mean and maximum summer temperatures in combination with mean precipitation decreases, and droughts may become more likely [3].

Climate change projections indicate both increasing risks and opportunities for Russia and its neighbors. A number of food security studies have employed the AOGCM projections and FAO agroecological zoning (AEZ) combined with the IIASA (International Institute for Applied System Analysis) Basic Link Combination (BSL) economic models [22–25]. The scenarios based on the IIASA AEZ–BSL approach indicate that Russia, 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, and possible, though uncertain, increases in winter precipitation projected by some AOGCMs [24].

The IIASA BSL models driven by the HadCM3-A1FI scenario suggest that, due to the regional climate changes by 2080, the total area with agroecological constraints could decrease and the potential for rain-fed cultivation of major food crops could increase in Russia due to changing regional climate (primarily due to temperature increase and the CO_2 fertilization effect on C_3 plants). Pegov et al. [26] estimated that grain production in Russia may double due to a northward shift of agricultural zones. A study by Mendelsohn et al. [27] based on the Global Impact Model experiments that combined AOGCM scenarios, economic data, and climate-response functions by market sector suggested that a 2°C temperature increase could bring Russia agricultural benefits of US$124–351 billion, due to a combination of increased winter temperatures, extension of the growing season, and CO_2 fertilization (Table 1).

Other modeling studies, however, indicate that the predicted shift of agroecological zones is unlikely to result in increasing agricultural productivity. Dronin and Kirilenko [3] and Alcamo et al. [28] have shown that although large portions of Russia might increase their agricultural potential under warming scenarios, agriculture of the most productive chernozem zone in the Russia and Ukraine, area between the Black and the Caspian Seas, could experience a dramatic increase in drought frequency. These regions are the main commercial producers of wheat and any decline in productivity would be detrimental to exports [5].

Golubev and Dronin [29] have developed an integrated model “GLASS”, which provide a consistent method for examining changes in agricultural production and water supply in the Russian Federation as a result of global climate change. As a

Table 1 Climate and agroecological scenarios from climate and agroecological modeling experiments

Study	Experiment	Scenario summary
Fischer et al. [24]	FAO agroecological zoning (AEZ) combined with the IIASA Basic Link Combination (BSL) economic models	Total area with agroecological constraints will decrease, the potential for rain-fed cultivation of major food crops will increase due to temperature increase and the CO_2 fertilization effect
Pegov et al. [26]	FAO agroecological zoning (AEZ) combined with the IIASA Basic Link Combination (BSL) economic models	Significant increase of grain production due to a northward shift of agroecological zones
Mendelsohn et al. [27]	Global Impact Ricardian Model-combined AOGCM scenarios, economic data, and climate-response functions by market sector	A 2°C temperature increase can bring agricultural benefits of US $124–351 billion, due to a combination of increased winter temperatures, extension of the growing season, and CO_2 fertilization
Alcamo et al. [28]	The Global Assessment of Security (GLASS) model (containing the Global AgroEcological Zones (GAEZ) crop production model and the Water-Global Assessment and Prognosis (WaterGAP 2) water resources model)	Increase in average water availability in Russia, but also a significantly increased frequency of high runoff events in much of central Russia, and more frequent low runoff events in the already dry crop growing regions in the South. The increasing frequency of extreme climate events will pose an increasing threat to the security food system and water resources
Dronin and Kirilenko [3]	Adapted the GAEZ and WaterGap2 model	Temperature and precipitation increase throughout Russia, precipitation decline and increase of drought frequency in the key grain-producing regions, net decline of grain production
Golubev and Dronin [29]	GLASS model examining changes in agricultural production and water supply as a result of global climate change	Production increase in the more humid central and northern regions. The net average yield in Russia will decrease considerably due to a severe increase in droughts in the most productive regions

consequence of climate change, the GLASS model predicts a considerable decrease of cereal yields in the most productive parts of Russia. Even though cereals will grow in the more humid central and northern regions, the average yield in Russia will decrease considerably due to a severe increase in droughts in the most productive regions. In Stavropolsky Krai, the key agricultural region of the Northern Caucasus, potential cereal production would decrease by 27% in the 2020s and by 56% 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 contributes little to the total grain production of the country (Table 1).

Global and regional climate models agree that the major grain-producing regions of the semiarid belt of Southern Russia, Ukraine, and Kazakhstan are likely to experience more intense and frequent droughts and the events of summer 2010 are likely to repeat in future more often. A study by Dole et al. [17] explored whether early warning can be issued through knowledge of natural and human-caused climate change. The authors used model simulations and observational data to determine the impact of observed sea surface temperatures (SSTs), sea ice conditions, and greenhouse gas concentrations. Results of model simulations suggest that the heat wave and drought of 2010 were mainly due to internal atmospheric dynamical processes that produced and maintained a strong and long-lived blocking event, and that similar atmospheric patterns have occurred with prior heat waves in this region [17]. The study suggested that neither human influences nor other slowly evolving ocean boundary conditions contributed substantially to the magnitude of this heat wave. Results also provide evidence that such an intense event could be produced through natural variability alone. Based on this modeling experiment, slowly varying boundary conditions that could have provided predictability and the potential for early warning did not appear to play an appreciable role in this event.

2.2 The Impact of Land Use and Agricultural Practices

Following the collapse of the USSR at the end of 1991, the period of reforms through the early 2000s was characterized almost everywhere by the following phases in the agricultural sector: (1) loss of subsidies and access to markets, (2) deintensification of agriculture, including reduction of livestock, longer fallow periods, and apparent abandonment of marginal croplands, (3) reduction in crop yields, (4) conversion of marginal arable lands to pastures, and (5) localized deforestation due to increasing demand for firewood [5, 12, 30, 31].

The crop yields declined during the 1990s in each country as the high price of imported herbicides, fungicides, and insecticides caused farmers to cut back on their use. Fertilizer use fell by 85% in Russia and Ukraine and by almost 90% in Kazakhstan between 1990 and 2000; the grain production fell by more than 50% during the same period of time [16]. The loss of state subsidies following the collapse of the Soviet Union in 1991 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. Livestock inventories and demand for forage continued to shrink. Russia lost almost half of its meat production between 1992 and 2006: (1) the number of cattle dropped from almost 20 to 10.3 million heads,

(b) the number of pigs fell from more than 36.3 to 18.7 million, and (3) the number of sheep dropped from 20 to 7 million [16]. Similar trends occurred in Kazakhstan and to a lesser extent in Ukraine [5].

The increasing inability of large agricultural enterprises to maintain livestock operations, due largely to inefficient management and farms' inability to secure adequate supplies of feed, resulted in increased dependence on private producers and household farms to satisfy demands for meat [18]. 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 were lost between 1995 and 1999 [5]. The drop in livestock inventories led in turn to a drop in demand for feed grain 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 toward crop production [32]. Thus, total livestock inventories have continued to decrease, particularly in the areas with extensive herding, such as Central Asia and semiarid and arid zones of Russia [5, 31]. Although the area cultivated for cereals has overall declined since the disintegration of the Soviet Union, the major crops have shown distinct trajectories (Fig. 1).

Wheat is the primary cereal crop in terms of area harvested and continues to cover significant area in each country. Wheat production shows increases since the early 2000s following a long decline since peak area following the end of the Virgin Lands Program in the early 1960s. Barley has been a significant secondary crop, but declines in area harvested started in the mid-1970s and became precipitous in the mid-1990s. Rye and oats are largely restricted to Russia and have declined substantially since 1991 and show no evidence of recovery. Maize continues to be a minor crop regionally, but the harvested area has been increasing steadily in Ukraine and Russia since the mid-1990s.

Steady recovery of crop production observed between 2002 and 2009 and followed by a sharp decline in 2010 was due to the unprecedented heat wave, crop failures, and fires affecting this region [17]. Due to recovery of some agricultural subsidies and at least a partial success of reforms, fertilizer and machinery use has increased during the past few years. The use of mineral fertilizer has tripled since 1999 in Kazakhstan and doubled in Russia and Ukraine, but current application rates represent only a fraction of the amounts applied in the late 1980s [16]; however, a return to the 1980s application rates is neither likely nor desirable as they were frequently above recommended levels. Another important technological factor contributing to the apparent improvement in Kazakhstan grain yield is the increase in the use of certified planting seed. By 2004, the use of certified seed had increased to 94%, including an increase in the use of top-quality certified seed from 37% to 57% [33].

Crop yields in Ukraine have shown a long-term increasing trend with a substantial deviation following 1991 and a return to higher yields in later years (Fig. 2). Yields in Russia have continued a slow but steadily increase over the past half

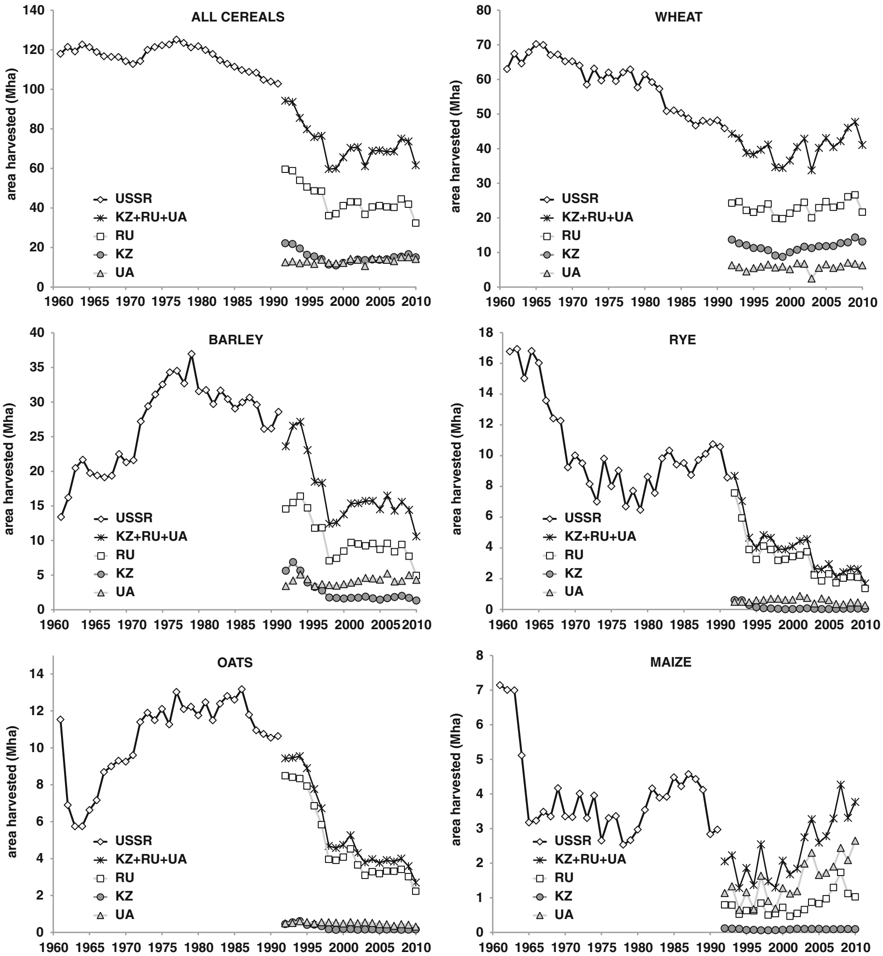

Fig. 1 Areas harvested for major cereals crops in the USSR, Russian Federation, Kazakhstan, and Ukraine (Source: FAOSTAT [16])

century despite some set-backs in the 1990s. Yields in Kazakhstan have shown little improvement over half a century, though recent yields have been mostly better than during the late 1990s. However, the impacts of extreme heat wave years – 2003 and 2010 – are evident in the yield data: Ukraine was more affected in 2003, while Kazakhstan was more affected in 2010, with Russian yields dropping in both years (Fig. 2).

While agricultural statistics provide critical information about land-use dynamics, remote sensing offers a complementary perspective on land change. Remote sensing based land cover classification products from 2003 through 2010 reveal relatively little apparent change in the chernozem (black earth) region of Ukraine, Russia, and Kazakhstan at a spatial resolution of 0.05° (Fig. 3). The variational land

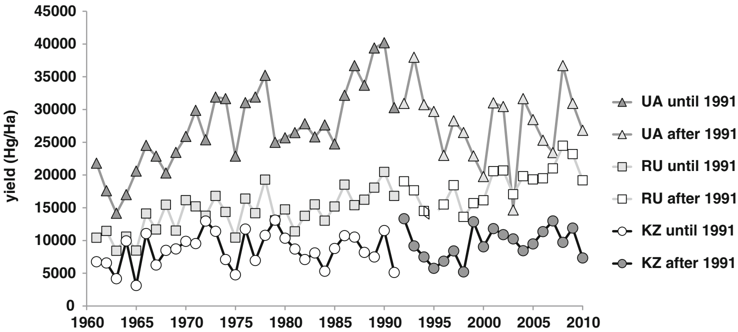

Fig. 2 Wheat yields from Russia, Kazakhstan, and Ukraine during and after the Soviet era (Source: FAOSTAT [16])

cover analysis in Fig. 3 highlights degrees of temporal stability in land cover and reveals the gradual ecotone between cropland and grassland at the southern limit of the chernozem. Post-classification change analysis, in which areal changes across categories are quantified, shows differences at local and trans-boundary scales [6]. However, it is very difficult to parse what land cover changes arise from changes in land use rather than from disturbance or even methodological instability [34].

Land surface phenology studies the timing and magnitude of seasonal patterns in the vegetated surface as observed at spatial resolutions that are very coarse relative to individual plants [12, 35]. In the absence of obscuring clouds, the vegetated land surface is readily viewed from space due to 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% of incoming light. The normalized difference vegetation index (NDVI) exploits this spectral contrast.

Time series of NDVI data provide important windows onto land surface phenology and land change dynamics. Studies comparing the land surface phenologies before and after the collapse of the Soviet Union found significant differences that appeared as an "earlier onset of spring" were attributable to the deintensification of agriculture [12, 36]. However, land surface phenologies are also responsive to climatic variability and change as well as growing season weather. In the chernozem region land surface phenologies are influenced by the Northern Annular Mode, evident through the North Atlantic Oscillation and the Arctic Oscillation indices [37].

Analysis of significant changes in the temporal pattern of NDVI over the longer term reveals the impacts of broader scale disturbances like drought (Fig. 4). Applying this approach at two scales enables extensive changes in northern Kazakhstan due to weather and climate to be distinguished from localized changes in southern Russia due to human land-use decisions [38].

Recent analyses of the agricultural conditions in the grain belt have found strong divergence between areas within and outside of the chernozem zone. The

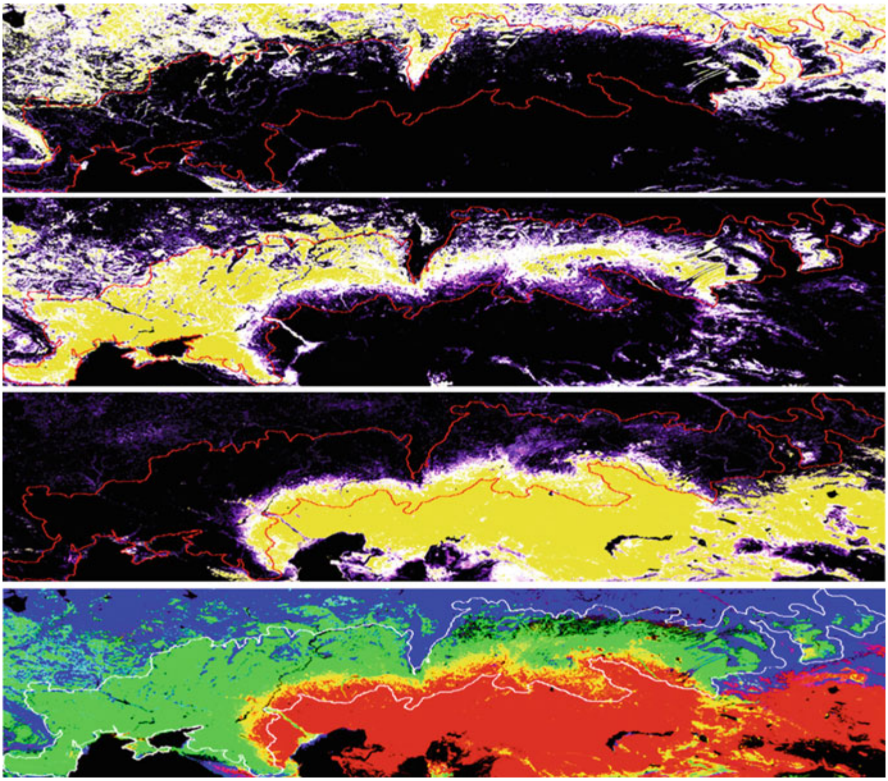

Fig. 3 Temporal stability of major land cover types in the black earth (chernozem) region 2003–2010. (*Top*) False color composite displays maximum, average, and range of percent IGBP land cover class from MODIS 0.05° product. *Black* indicates absence of class; *yellow* denotes stable core area; *white* shows unstable core; *magentas* are unstable but persistent periphery; and *blues* are erratic periphery. *Top three panels* show mixed forest, cropland, and grassland classes, respectively. *Bottom panel* shows maximum percentages for the three classes (*red* = grassland, *green* = cropland, *blue* = mixed forest)

agricultural sector has been disintegrating since at least 1991 outside of the chernozem zone, for example, Kostroma; yet, in the black earth lands agriculture is vigorous and diversifying, for example, Samara [32, 39].

2.3 Changes in Regional and Global Economy

In the Soviet era, agriculture had been supported by budget subsidies and favorable relative prices, and benefitted from fuel and transportation subsidies that were not specific to agriculture but helped farmers more than most other producers. Very

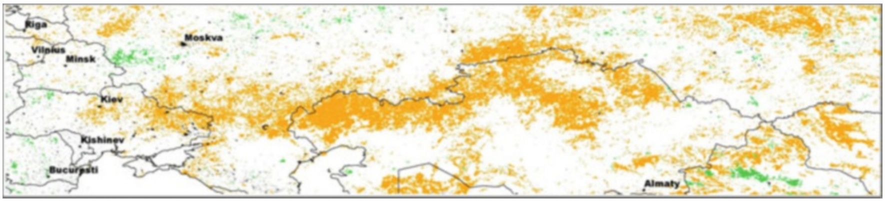

Fig. 4 Significant changes ($p < 0.01$) in the vegetated land surface over the 2001–2010 growing seasons as revealed by the nonparametric Seasonal Kendall test. *Orange* (*green*) indicates a significant negative (positive) change. Data are from MODIS NBAR 16-day composites at 0.05° resolution

abrupt price liberalization of the early 1990s led to an increase in the cost of key inputs that was much larger than the increase in the market value of farm outputs.

The Organization for Economic Cooperation and Development (OECD) producer support estimates for Russia, Ukraine, and Kazakhstan indicate substantial positive support for farmers up to 1991, in which then almost fell to zero in the following few years [40]. Among the three countries, Ukraine had most drastically reduced its agricultural subsidies during the years of transition. Although agricultural subsidies have increased in former-USSR countries in past few years and are now comparable with the US level, they are significantly lower than those in Europe or Japan [5]. According to the FAO, the level of overall support given to agricultural producers as a share of their total farm receipts amounted to 15% and 12%, respectively, in Russia and Ukraine, compared to 33% in the EU, 55% in Japan, and 16% in the USA [16]. Russia declared a national priority area for agriculture in 2005 and increased federal support for agricultural development from US$2.6 billion in 2006 to US$5.2 billion in 2008 [41]; the same tendency is observed in Kazakhstan, and to a lesser extent in Ukraine [41].

One of the more serious problems associated with implementation of agricultural reforms in all three countries has been the lack of long-term support for agricultural reforms by the key stakeholders – the rural population – resulting in weak public and private governance in the agricultural sector. Several studies conducted in this region reveal the lack of public support for the land reform and rather negative public perception of land ownership and the land market [2, 14, 42]. In a study conducted in the Russian countryside, about 90% of the respondents disagreed with a concept of cropland privatization and were against the idea of private land ownership and market [43]. Interviews in several former-USSR countries indicate that food security is generally perceived in this region as one of the key responsibilities of the state and people generally tend to blame poor economic situation and increasing food prices on the failure of the government [44]. There is still negative attitude of the population to the removal of agricultural subsidies and institution of the land market [45]. These attitudes of stakeholders might be the key factor explaining why the three countries have been slow and inconsistent in implementation of their new land codes, and returned to some agricultural policies that are not in line with market orientation [2, 14].

Many national-scale institutional changes in the post-Soviet economies have developed as direct or indirect responses to globalization after the newly independent states emerged from the closed and highly regulated economic spaces of the USSR and Council for Mutual Economic Assistance (COMECON) into the more open and volatile spaces of regional and global markets [5]. Economic globalization has led to liberalization of trade and investment, formation of the regional economic agreements, implementation of structural adjustment programs, and removal of subsidies, tariffs, and price supports [46, 47]. A select group of larger agricultural enterprises in Russia, Ukraine, and Kazakhstan may benefit from economic globalization by focusing on production of export commodities. However, many small to medium size farms in the post-Soviet states are threatened with failure due to removal of subsidies, volatile crop prices, competition with cheaper and/or better quality imports, inability to obtain credit, limited access to international markets, and shortage of inputs, such as high-quality seed, fertilizers, herbicides, machinery, and irrigation [45, 47, 48]. As Leichenko and O'Brien [47] demonstrated in a study on agriculture in southern Africa, farmers must adapt simultaneously to change in climate and in global markets; thus, the vulnerability/resilience of food production to the change must be considered from multiple perspectives.

Globalization brought significant change to the food trade of the post-Soviet states, as per capita incomes in the 1990s fell sharply and the level of inequality increased dramatically. Accordingly, poverty grew more quickly in the transitional economies of the former USSR during the 1990s than in any other part of the world [49]. The standards of living have begun to recover only after 2000. However, as indicated by several assessments and datasets, globalization has never led to deterioration of food security in Russia, Ukraine, and Kazakhstan, despite the deterioration of their agricultural sectors [16, 50, 51].

While agricultural production, livestock inventories, and per capita incomes all have plunged and partially recovered during the past 16 years, anthropometric and dietary indicators show that food consumption in terms of calories remained steady, and indicators of food inadequacy were very moderate [49, 52]. The predominant dietary problems are the same as before independence: namely, a high prevalence of overweightness and obesity, related to very high consumption levels of meat, dairy products and eggs, and low consumption of fruits and vegetables. This condition arose because average food consumption in these countries before 1991 was as high or higher than in developed countries, and far higher than in the developing world. From 1992 to 2000 agricultural production of Russia fell by 29% but per capita caloric consumption did not change [50, 53]. Per capita food consumption fell moderately during the period of reforms – in Ukraine by 15% and by 11–12% in Kazakhstan – but, as a study by Wehrheim and Wiesmann [54] indicates, this reduction reflects a shift away from overconsumption of meat rather than true malnutrition. Still the calorie reduction in the diet of post-Soviet republics is generally seen as a serious threat to the national food security by the local population, politicians, and occasionally by the national scientific community. For example, an article by Baydildina et al. [55] based on the data from the Ministry of Agriculture of Kazakhstan documents reductions in consumption of meat, dairy products, and sugar between 1990 and 1996, but the consumption of fruits, vegetables, potatoes, and grains during the same period remained almost unchanged. The authors interpret these data as an evidence of growing malnutrition in Kazakhstan. For example, milk and dairy product consumption at the end of 1980s was close to 1 kg/day per person in Kazakhstan and dropped by about 30% in 1997 [55]. However, protein and sugar consumption had been excessive during the Soviet period when food prices were kept extremely low.

While the rates of protein consumption in Russia, Kazakhstan, and Ukraine have been comparable to EU levels, the proportion of fruits and vegetables in the diet remains significantly lower than recommended. This problem, however, is cultural: it results from the traditional diets of these countries. During the Soviet years and into the 1990s, consumption of fruits and vegetables was typically much lower in Kazakhstan than in Russia and Ukraine, and it was significantly below western standards in all three republics. Although there is little evidence that globalization has seriously threatened food security in Russia, Ukraine, or Kazakhstan, the popular opinion is that it is indeed threatened [49, 53].

Globalization impacts after independence have led to changes of import and export partners and geography of trade flows. While livestock inventories in the post-Soviet economies declined rapidly during the period of reforms, high levels of consumption of meat and dairy products have been maintained. Russia and Ukraine, previously importers of feed grains, have recently become the major importers of beef, poultry, and dairy products from the US and EU. Meat and dairy product imports have also grown in Kazakhstan. Economic reforms and related land-use changes in Russia, Ukraine, and Kazakhstan have also impacted food security worldwide due to the changes in their trade structure. USSR was an important exporter of grain in the 1960s, but became a major importer of grain in the 1970 and 1980s due to increasing meat consumption and growing need for feed grains to support livestock. During the past few years Russia, Ukraine, and Kazakhstan have been becoming, once again, important players in global grain markets, with geographic proximity to the buyers in the EU countries, Middle East, and Northern Africa, stable export markets and domestic prices showing close correlation with world reference prices [44].

As the cereal production in Russia, Ukraine, and Kazakhstan is projected to increase [33, 41, 56], domestic demands are likely to continue to decline. Populations of Russia and Ukraine are projected to decline and the regional per capita incomes are expected to increase with consumer diets shifting from cereals. With appropriate policies, this combination of rising prices and demand on the international market and decreasing domestic demand is likely to benefit export opportunities in Russia, Ukraine, and Kazakhstan.

Table 2 Grain production scenarios for Russia, Ukraine, and Kazakhstan. Adapted from Lioubimtseva [4]

	Grain production, million metric tons					
				Scenarios for 2016–2017		
Countries	1992–1994	2004–2006	2010	OECD–FAO	IKAR	EBRD maximum potential scenario
Russia	93	77	60	n/a	98	126
Ukraine	37	37	39	n/a	44	75
Kazakhstan	23	14	12	n/a	22	29
Total	152	128	111	159	164	230

Table 3 OECD–FAO projections of the global grain exports in 2016. Adapted from Lioubimtseva [4]

Producer	Share of global grain exports (%)	Cumulative share of global grain exports (%)
USA	34	34
CIS	14	48
EU-27	13	61
Australia	11	72
Canada	9	81
All others	19	100

3 Uncertainties in Future Agricultural Production

Total grain production scenarios for 2016 for Russia, Ukraine, and Kazakhstan together range from 159 to 230 million tons projected by European Bank for Reconstruction and Development (EBRD) "maximum potential scenario" [41]. Table 2 shows grain production scenarios for Russia, Ukraine, and Kazakhstan.

As shown in Table 3, the share of Russia, Ukraine and Kazakhstan in agricultural production is expected to reach 14–15% by 2016 and surpass the share of the EU, Canada, and Australia [40]. These projections, however, are highly uncertain. The "estimated maximum potential" scenario developed is based on assumptions that (1) grain yields in Kazakhstan would be comparable to those in Australia; (2) yields in Russia will be similar to the current yields in Canada; and (3) yields in Ukraine will approach yields in France [41]. These analogies are based on similarities in temperature and precipitation but do not take into account socioeconomic and cultural differences and, therefore, are quite simplistic.

The ERBD–FAO scenario also assumes that 13 million hectares of abandoned land would be returned to production and devoted to grain, and no change in crop distribution was assumed for already cultivated land [41]. As a result, the grain export potential is also likely to increase: wheat export projections for 2016/2017 vary in the assessments by different agencies between 11 and 17 million tons of wheat for Russia [40, 51, 57], and between 6 and 10 million tons for Ukraine [40]. Export of Kazakhstan and other Central Asian states of FSU is projected to approach

4–7 million tons of wheat [40]. Export of coarse grains is also expected to reach about 1–2 million tons in Russia and 6–9 million in Ukraine [33]. The OECD–FAO projected that wheat and coarse grain exports from Russia, Ukraine, and Kazakhstan would reach 35 million tons by 2016 (a 14% increase from 2007) [41].

3.1 Uncertainties Related to Climate and Land Changes

Projections of grain production increase in the countries of the former USSR are based primarily on assumptions of expansion of areas suitable for agriculture and increasing productivity. These assessments are based on modeling changes and geographic shifts of mean temperature and precipitation, but do not take into account how changes in climate variability and extreme events might be detrimental to crop production. Numerous studies have documented that extreme events are disproportionately responsible for weather-related damages and, furthermore, the sensitivity of extreme events to climate change may be greater than simple linear projections of climatological distributions [3, 28, 58]. The potential changes in variability and extreme events – frosts, heat waves, droughts, and deluges – are likely to have stronger impacts on food production than modest temporal shifts in mean temperature and minor changes in precipitation.

The grain productivity projections also do not taken into account possible changes in the land suitability due to impacts of climate change, such as CO_2 fertilization, changes in the growing season, temperature, precipitation, frequency and timing of droughts and frosts. Although several modeling studies have shown that a warmer climate would be beneficial in general for agriculture in Northern Eurasia [22–24, 26], geographic distribution of benefits is unlikely to be uniform. CO_2-enrichment studies in greenhouses, growth chambers, and open-top chambers have suggested that growth of many crops could increase in the short term about 30% on average with a doubling of the atmospheric CO_2 concentration. The results of FACE (free air CO_2 enrichment) experiments, however, suggest that CO_2 fertilization effects may be seriously overestimated by ecological models [59]. When the CO_2 fertilization is not taken into account, the warmer climate benefits for the CIS agriculture are modest at best and production gains due to theoretically possible expansion of arable lands might be lower than the losses caused by increasing aridity [5].

Although the agricultural productivity of non-chernozem zones is expected to increase (particularly in Siberia), it is unrealistic to expect swift adaptation of the agricultural sector to newly emerging agroecological conditions. Any projection of agricultural expansion based on climate change scenarios should be viewed with caution, if they do not take into account regional socioeconomic factors [3, 5]. Expansion of climatic zones suitable for agriculture does not necessarily imply that the local population currently employed in other sectors would seek out new opportunities in agriculture. On the other hand, declining productivity due to increasing aridity may result in the loss of human capital as skilled farmers may be forced to switch to other livelihoods. Assessment of human vulnerability and adaptations to climate change needs to become a key component of agricultural policies. Adaptations, such as introduction of drought-resistant crop varieties and introduction of irrigation into rain-fed croplands, may alleviate some consequences of increasing aridity and variability of climate.

3.2 Policy-Related Uncertainties

Food-production projections assume no drastic institutional changes and continuation of current agricultural policies. However, many former-USSR countries are still in the process of restructuring their agricultural policies. Two other critical variables to increasing grain production and export are the development of credit institutions and the modernization of infrastructure [41, 45, 53]. Renewing existing agricultural machinery and purchasing the new equipment would require large capital investments, but the existing credit system and leasing arrangements limit the flow of capital for investments. According to IKAR, the total investment required for modernization of grain handling systems in Russia, Ukraine, and Kazakhstan would amount to approximately US$4.5 billion [41, 56]. Modernization of transportation networks and port infrastructure in Russia and Ukraine necessary for increasing export capacity would require substantially larger investments.

Changes in the trade policies incorporated in the global and regional food-production scenarios are difficult to project. Such policies may include price controls, quotas, tariffs, subsidies, and interventions using state reserves. In the face of rising international food prices, Russia, Ukraine, and Kazakhstan have already imposed some export restrictions to protect their domestic consumers. The Russian government made several agreements in 2007–2009 with retailers to freeze prices on some basic foodstuffs [56]. Ukraine has been using export quotas on wheat, barley, and maize to ensure sufficient supply of the domestic market [41] and Kazakhstan has introduced licensing measures to control the exports of wheat and also lowered import duties on all basic foodstuffs. While such policies may protect domestic consumers in the short term, they can also harm agricultural producers in the longer term, particularly in the CIS countries where agricultural subsidies are relatively low. By restricting the translation of international prices into the national markets, such policies significantly reduce the profits of domestic agricultural producers and limit opportunities for rural development.

3.3 Uncertainties Related to Global Factors

Climatic variability, extremes, and change can affect food production across the planet. Increasing variability in local and regional climates is likely to increase volatility in the food supply. Other global factors, including the rapidly expanding demand for biofuels, volatility of oil prices, increasing demand for agricultural products in the emerging economies, and changing diets in developing countries, are likely to continue increasing demand for agricultural production. Grain producers in Russia, Ukraine, and Kazakhstan are likely to benefit from this window of opportunity in the global market, only if national policies and international investments support the current trend of increasing productivity and assist in bringing back into production some of the arable lands idled during the transitional decade of the 1990s.

4 Conclusions

Agroecological models driven by climate change scenarios and land change analysis suggest that Russia, Ukraine, and Kazakhstan have a great potential to increase their grain productivity and future exports. A combination of winter temperature increase, extension of the growing season, and CO_2 fertilization could increase water availability and land suitability for agricultural crops. However, projections based on biophysical modeling alone should be considered with caution as they do not take into account regional socioeconomic and political factors. Human adaptations to climate change are likely to take several generations – much longer than the agroecological responses to climate change. Expansion or geographic shifts of climatic zones suitable for agriculture do not necessarily imply that the local population currently employed in other sectors would seek out new opportunities in farming.

During the 1990s and early 2000s, the agricultural systems of this vast region underwent enormous land-use changes accompanied by massive withdrawals of arable land, contraction of livestock inventories, and catastrophic decline of grain production. The decline of agriculture in the FSU countries had little to do with climate change but was a direct result of ineffective agricultural and economy-wide reforms, lack of competition, loss of agricultural subsidies, nonexistent land market, poor infrastructure, and a lack of support by the stakeholders.

It has been projected by several international agencies that within the next decade countries of the former Soviet Union could become the second major grain exporter after the United States and also surpass the European Union. Scenarios based on the climatic analogies and climate change scenarios are quite uncertain, as they do not take into consideration cultural differences, the role of stakeholders, continuous changes in the land code of the CIS region, slow land market development, national financial systems, local infrastructure, and price fluctuations of the international market.

To realize their full potential as the major grain producers, Russia, Ukraine, and Kazakhstan have to overcome many challenges. Underdeveloped land markets remain one of the major unresolved issues. The governmental policies currently clearly favor large agricultural companies, particularly in Russia and Kazakhstan.

Two other critical variables to increasing grain production and export are the development of credit institutions and the modernization of infrastructure. Renewing existing agricultural machinery and purchasing new equipment would require very significant investments, but the existing credit system and the current financial crisis in the FSU (Former Soviet Union) nations and worldwide are likely to limit the flow of capital available for investments.

Development of effective and sustainable food-production strategies in the grain belt of Eurasia requires further basic, applied, and translational research in the following areas: (1) more accurate modeling of climate change and its impacts on water availability and agroecological zones, particularly at the regional scale; (2) synoptic monitoring and stochastic modeling of extreme events, such as droughts, heat waves, wild fires, frosts, and floods; (3) field and chamber experiments to improve understanding of CO_2 fertilization on agricultural crops; (4) synoptic monitoring and simulation modeling impacts of land-use and land cover changes on the regional hydrometeorology and meso-climatic and agroecological changes; (5) research on human adaptations to climate change, such as geographic and economic mobility and behavioral changes, including changes in livelihoods, lifestyles, diets, and cultural practices; and (6) how adaptation measures can be embedded in ongoing activities such as land-use planning, water resource management, drought and heat-wave early warning, and diversification of agriculture.

Finally, due to the cross-scale contingent dynamics of coupled human/natural systems, it is critical to approach the planning, assessment, and implementation of adaptation tactics and strategies at the national, regional, and international levels simultaneously.

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References

1. Rosset P (2008) Food sovereignty and the contemporary food crisis. Development 51:460–463. doi:10.1057/dev.2008.48
2. Koester U, Brümmer B (2006) Institutional changes for agricultural and rural development in the CEEC and CIS region. Electron J Agric Dev Econ 2(2):144–179
3. Dronin N, Kirilenko A (2008) Climate change and food stress in Russia: what if the market transforms as it did during the past century. Climate Change 86(1–2):123–150
4. Lioubimtseva E (2010) Global food security and grain production trends in Central Eurasia: do models predict a new window of opportunity? Natl Soc Sci J 41(1):154–165
5. Lioubimtseva E, Henebry GM (2012) Grain production trends in Russia, Ukraine and Kazakhstan: new opportunities in increasingly unstable world? Front Earth Sci 6(2):157–166. doi:10.1007/s11707-012-0318-y

6. Wright CK, de Beurs KM, Henebry GM (2012) Combined analysis of land cover change and NDVI trends in the Northern Eurasian grain belt. Front Earth Sci 6(2):177–187. doi:10.1007/s11707-012-0327-x
7. Henebry GM (2009) Carbon in idle croplands. Nature 457:1089–1090
8. Prishchepov AV, Müller D, Dubinin M, Baumann M, Radeloff V (2013) Determinants of agricultural land abandonment in post-Soviet European Russia. Land Use Policy 30:873–884
9. Lerman Z, Sedik D, Pugachev N, Goncharuk A (2007) Rethinking agricultural reform in Ukraine. Leibniz Institute of Agricultural Development in Central and Eastern Europe, vol 38, IAMO, Halle
10. Zhang B (1996) Total factor productivity of grain production in the former Soviet Union. J Comp Econ 24:202–209
11. Meng E, Longmire J, Moldashev A (2000) Kazakhstan's wheat system: priorities, constraints, and future prospects. Food Policy 25(6):701–717
12. de Beurs KM, Henebry GM (2004) Land surface phenology, climatic variation, and institutional change: analyzing agricultural land cover change in Kazakhstan. Remote Sens Environ 89:497–509
13. Muratova N, Terekhov A (2005) A five-year experience of satellite monitoring agricultural crops in Northern Kazakhstan. Опыт пятилетнего оперативного мониторинга сельскохозяйственных угодий Северного Казахстана с помощью спутниковых данных (in Russian). In: Laverov NP (ed) Actual problems in remote sensing of the Earth from space, vol 2. Institute of Space Research of Russian Federation, Moscow, pp 277–283
14. Uzun V (2005) Large and small business in Russian agriculture: adaptation to market. Comp Econ Stud 47:85–100
15. Bokusheva R, Hockmann H (2006) Production risk and technical inefficiency in Russian agriculture. Eur Rev Agric Econ 33(1):93–118. doi:10.1093/erae/jbi036
16. FAOSTAT (2012) Food and Agriculture Organization Statistics. http://www.fao.faostat.org. Accessed July 2012
17. Dole R, Hoerling M, Perlwitz J, Eischeid J, Pegion P, Zhang T, Quan X-W, Xu T, Murray D (2011) Was there a basis for anticipating the 2010 Russian heat wave? Geophys Res Lett 38: L06702. doi:10.1029/2010GL046582
18. Welton G (2011) The impact of Russia's 2010 grain export ban. Oxfam Research Reports. Oxfam, UK. www.oxfam.com/grow
19. USDA FAS (2010) Effects of the summer fires and droughts and Russian agriculture, GAIN report. USDA Foreign Agriculture Service, Washington, p 5
20. IPCC (2007) In: Metz B, Davidson OR, Bosch PR, Dave R, Meyer LA (eds) Climate change 2007: mitigation, contribution of working group III to the fourth assessment report of the IPCC. Cambridge University Press, Cambridge
21. Wigley TML (2008) MAGICC/SCENGEN 5.3: USER MANUAL (version 2), NCAR, Boulder. http://www.cgd.ucar.edu/cas/wigley/magicc/UserMan5.3.v2.pdf. Accessed 14 January 2013
22. Fischer G, Shah M, van Velthuizen H (2002) Climate change and agricultural vulnerability. International Institute for Applied Systems Analysis, Vienna
23. Parry ML, Rosenzweig C, Iglesias A, Livermore V, Fischer G (2004) Effects of climate change on global food production under SRES emissions and socio-economic scenarios. Glob Environ Chang 14:53–67
24. Fischer GM, Shah M, Tubiello FN, Van Velhuizen H (2005) Socio-economic and climate change impact on agriculture: an integrated assessment, 1990–2080. Philos Trans R Soc B 360:2067–2083
25. Schmidhuber J, Tubiello F (2007) Global food security under climate change. Proc Natl Acad Sci 104(50):19703–19708
26. Pegov SA, Khomyakov DM, Khomyakov PM (2000) Vliyanie globalnih izmenenii klimata na socialnoeconomicheskoye polozeniye Rossii (Global change impacts on the socio-economic situation in Russia). In: Kotlyakov VM (ed) Globalniye I regionalnye izmeneniya klimata i ikh

prirodniye i socialnoeconomicheskiye posledstviya (Global and regional climate change and its environmental and socio-economic impacts). Geos, Moscow (in Russian)
27. Mendelsohn R, Morison W, Schlesinger ME, Andronova NG (2000) Country-specific market impact of climate change. Clim Chang 45(3–4):553–569
28. Alcamo J, Dronin N, Endejan M, Golubev G, Kirilenko A (2007) A new assessment of climate change impacts on food production shortfalls and water availability in Russia. Glob Environ Chang 17(3–4):429–444
29. Golubev G, Dronin N (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
30. Lioubimtseva E, Henebry GM (2009) Potential impact of climate change on the grain productivity in Central Eurasia: human vulnerability and adaptations. In: Nickolova N (ed) Global changes: vulnerability, mitigation, and adaptation. Sofia University St. Kliment Ohridski University Press, Sofia, pp 22–27
31. Lioubimtseva E, Henebry GM (2009) Climate and environmental change in arid Central Asia: impacts, vulnerability, and adaptations. J Arid Environ 73(11):963–977
32. Ioffe G, Nefedova T, de Beurs KM (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
33. USDA FAS (2010b) USDA foreign agricultural service. http://www.fas.usda.gov/. Accessed January 2013
34. Friedl MA, Sulla-Menashe D, Tan B et al (2010) MODIS Collection 5 global landcover: algorithm refinements and characterization of new datasets. Remote Sens Environ 114:168–182
35. Morisette JT, Richardson AD, Knapp AK, Fisher JI, Graham E, Abatzoglou J, Wilson BE, Breshears DD, Henebry GM, Hanes JM, Liang L (2008) Unlocking the rhythm of the seasons in the face of global change: challenges and opportunities for phenological research in the 21st Century. Front Ecol Environ 5(7):253–260. doi:10.1890/070217
36. de Beurs KM, Henebry GM (2005) A statistical framework for the analysis of long image time series. Int J Remote Sens 26(8):1551–1573
37. de Beurs KM, Henebry GM (2008) Northern Annular Mode effects on the land surface phenologies of Northern Eurasia. J Climate 21:4257–4279
38. de Beurs KM, Wright CK, Henebry GM (2009) Dual scale trend analysis distinguishes climatic from anthropogenic effects on the vegetated land surface. Environ Res Lett 4:045012
39. de Beurs KM, Ioffe G, Nefedova TG (2012) Agricultural change in the Russian grain belt: a case study of Samara oblast. Geogr Environ Sustain 5(2):95–110
40. OECD-FAO (2011) OECD-FAO agricultural outlook 2008–2017. OECD, Paris, p 230
41. 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
42. Koester U, Striewe L (1998) Huge potential, huge losses – the search for ways out of the dilemma of Ukrainian agriculture. In: Siedenberg A, Hoffmann L (eds) Ukraine at the crossroads: economic reforms in international perspective. Physica, Heidelberg, pp 259–270
43. Serova EV (2000) Russia's agro-food sector: state of the art. In: Wehrheim P, Frohberg K, Serova E, Von Braun J (eds) Russia's agro-food sector: towards truly functioning markets. Kluwer Academic, Dordrecht, pp 81–106
44. Liefert WM, Liefert O, Serova E (2009) Russia's transition to major player in world agricultural markets. Choices 24(2), http://www.choicesmagazine.org/magazine/article.php?article=78. Accessed January 2013
45. Lissitsa A, Odening M (2005) Efficiency and total factor productivity in Ukrainian agriculture in transition. Agric Econ 32(3):311–325
46. Castells M (1999) End of millenium. Blackwell, Malden
47. Leichenko RM, O'Brien KL (2002) The dynamics of rural vulnerability to global change: the case of southern Africa. Mitigation Adap Strat Global Climate Change 7:1–18

48. Almaganbetov N (2005) The impact of land reforms on economic development of Kazakhstan. The Center for Policy Studies, Central European University/Open Society Institute, Budapest
49. Sedik D, Trueblood M, Arnade C (2002) Corporate farm performance in Russia, 1991–95: an efficiency analysis. J Comp Econ 27(3):514–533
50. WHO (2009) World Health Organization Databases. http://www.who.org. Accessed January 2013
51. World Bank (2009) The World Bank Data. http://www.worldbank.org. Accessed January 2013
52. Dudwik N, Fock K (2007) Land reform and farm restructuring in transition countries: the experience of Bulgaria, Moldova, Azerbaijan, and Kazakhstan. World Bank, Washington
53. Sedik D (2004) Missing pillars: the failures of rural finance in Ukraine. In: Macey DAJ, Pyle W, Wegren SK (eds) Building market institutions in post-communist agriculture: land, credit, and assistance. Lexington Books, Lanham
54. Wehrheim P, Wiesmann D (2006) Food security analysis and policies for transition countries. J Agric Dev Econ 3(2):112–143
55. Baydildina A, Akshinbay A, Bayetova M, Mkrytichyan L, Haliepesova A, Ataev D (2000) Agricultural policy reforms and food security in Kazakhstan and Turkmenistan. Food Policy 25(6):733–747
56. IKAR (2010) Institute for Agricultural Market Studies. http://www.ikar.ru/eng/. Accessed January 2010
57. USDA (2009) Global crop production review. USDA's Joint Agricultural Weather Facility. http://www.usda.gov/oce/weather/pubs/. Accessed December 2009
58. Tebaldi C, Hayhoe K, Arblaster JM, Meehl GA (2006) Going to the extremes: an intercomparison of model-simulated historical and future changes in extreme events. Clim Chang 79:185–211
59. Long SP, Ainsworth EA, Leakey ADB, Nösberger J, Ort DA (2006) Food for thought: lower-than-expected crop yield stimulation with rising CO_2 concentrations. Science 312(5782):1918–1921. doi:10.1126/science.1114722