Production Potential in the "Bread Baskets"

of Eastern Europe and Central Asia

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Abstract

Eastern Europe and Central Asia is a major food producer and exporter. Almost a quarter of world wheat exports come from the region, and especially from Kazakhstan, Russia and Ukraine (RUK). The potential of these countries to become a "bread basket" for the world has been emphasized because of already large production and exports and their "immense land and yield reserves", referring to the abandonment of more than 50 million hectares of cropland and the large drop in crop productivity in the 1990s. However, there is considerable uncertainty about the potential of this land for food production. In this paper we review interdisciplinary literature and empirical evidence, predictions of production potential and impacts of climate change; and discuss the potential of the region to become a reliable breadbasket of the world. From a biophysical (crop growth) perspective, under different scenarios of increased yields, land use and climate change effects, RUK could produce an additional 40 to 110 million tons of wheat compared to current production, which would be a substantial additional production. However economic incentives, in particular the evolution of food prices and competition from other crops, are likely to significantly constrain these potentials. In addition, the introduction of export restrictions during recent times of high prices raised concerns on the reliability of RUK as exporters.

1 Introduction

The "transition countries" of Eastern Europe and Central Asia (ECA) are major food producers, in particular for products like cereals and dairy (see Appendix A1 for country details). It is in particular their role as producer and exporter of wheat that has attracted much attention in the global food security debate. The region accounts for approximately 18% of the worlds' wheat production and 22% of global wheat exports. The major wheat producing countries are Russia, Ukraine and Kazakhstan (RUK). They account for almost all exports. Wheat exports from RUK already increased dramatically compared to the beginning of the 1990s: from around 5 million tons (Mt) in 1992-1994 to more than 34 Mt in 2010-2012.

The potential of these countries to become a "breadbasket" for the world has been emphasized because the already large production and exports can be further augmented with their "immense land and yield reserves" (Glauben et al, 2014). This potential is associated with the huge decline in land use and agricultural production during the transition process from a centrally planned economy to a more market-orientated economy. Between 50 and 60 million hectares (Mha) of land were abandoned – equivalent to almost 50% of the current land use in RUK alone. However, there is considerable uncertainty about the potential of all this land to be put back in use for food production and what the actual yield potential is (Kraemer *et al.*, 2015; Liefert and Liefert, 2015). In this paper we review the predictions of studies from different disciplines on this. Because of space constraints and because the vast majority of studies and simulations focus on grain production in RUK, we also concentrate on this in our review.

We start our paper with a brief discussion of the transition process and its implications, observations on output and productivity evolutions and the current state of agricultural production. Afterwards we discuss changes in land use and yields and predictions on the grain production potential for the future. We conclude with a discussion of the potential of the region to become a reliable breadbasket of the world.

2 The Transition Process and Its Implications

The transition of agriculture implied major adjustments and a dramatic initial decline in input use, productivity and output, taking the form of a J-curve. [1] Liberalization implied the removal of agricultural subsidies which caused output and inputs to fall. Liberalization, privatization and land reforms occurred in an environment characterized by the breakdown of institutions of exchange and the rise of transaction costs, which reinforced the fall in input use and output. After the initial collapse, reforms improved incentives and the reorganization of farms and supply chains. This improved the provision of inputs, farm productivity, and total production. However, as output and input use declined due to the price reforms but increased with technical efficiency gains due to property rights reforms, this implies that efficient output and input use (including land) may well be (substantially) below the levels under the distorted Socialist system (Macours and Swinnen, 2000, 2002; Rozelle and Swinnen 2004).

2.1 Agricultural Production

Empirically we observe this J-curve in production and productivity, albeit with significant differences between countries and commodities (see Table 1 and Figure 1).[2] In the 1990s, ECA wheat production fell from 108 Mt to 86 Mt by the end of the 1990s. Since then it has increased strongly to almost 120 Mt. The increase was most spectacular in RUK, the main wheat producing countries (Table 1).

[1] See Swinnen and Rozelle (2006) for a formal model.
[2] See Macours and Swinnen (2000, 2002) for details and explanations.

Livestock production did not recover as well.[3] Meat production declined from 21 Mt in 1992-1994 to 15 Mt by the end of 1990s and is currently at 19 Mt, 10% below the pre-reform level (Table 1). The same holds for dairy: in the period 1992-1994, the region produced 107 Mt of milk, which decreased to 85 Mt at the end of the 1990s. The 2010-2012 production of 90 Mt (is far below the pre-reform level).

The contraction of the livestock sector during transition is one of the reasons why Kazakhstan, Ukraine and Russia moved from an import to an export position in grain (Liefert and Swinnen, 2002). The collapse of the livestock sector dramatically reduced demand for feed grain (and for other feed crops). In contrast, wheat production increased during transition as did oilseeds, and in particular sunflower (Liefert and Liefert, 2015).

2.2 Farm Structures and Labor Productivity

Labor productivity is an important indicator of farm incomes and thus of rural poverty. Overall, agricultural labor productivity (ALP) declined with falling output in the initial stages of transition except in several Central and Eastern European (CEE) countries[4] where a rapid restructuring of farms induced labor shedding, causing an increase in ALP (Figure 2).[5] In other countries ALP was substantially lower as agriculture provided a buffer role during transition, both in terms of labor allocation and in terms of food security (Seeth *et al.*,1998). However, since 2000 ALP increased in many other countries, including in RUK.

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[3] These differences in recovery between commodity outputs, such as livestock versus cereal production, reflect differences in pre-reform distortions (Liefert and Swinnen, 2002). Livestock production was especially heavily subsidized. When subsidies were eliminated these countries were not cost-competitive in livestock production and output adjustments reflect a shift towards the comparative advantage of the region (Liefert *et al.* 2010).

[4] See Appendix A1 for regional country classifications.

[5] There is an important relationship between farm structures and labor use. The shift to small scale farming has been strongest in labor intensive production systems. Small farms also served as a labor absorbing institution, leading to a divergence of farming structures (Dries and Swinnen, 2002; Swinnen *et al.,* 2005).

Changes in labor productivity and labor use are strongly related to the farm restructuring (Swinnen *et al.*, 2005). Typically small farms absorbed labor during the transition process while privatized large scale farms increased productivity by laying off surplus workers. In countries where farm privatization went slower or with continued political interference in farm management, also large scale farms continued to employ excess labor.

By now there is a strong heterogeneity in farm structures in ECA: in some countries smallholders and family farms dominate the farm sector; in some other countries large scale farms dominate, and in others there is a mixture of large and small farms. There is no simple East-West divide in this. In Central Europe, large farms use most of the land in Slovakia and the Czech Republic, while family farms dominate in Poland. In Central Asia, large farms are important in the northern parts of Kazakhstan, while small farms are important in southern Kazakhstan and in Kyrgyzstan and Tajikistan.

Large farms play a very important role in grain production in RUK. For example, the 70 largest producers in Russia and Ukraine control more than 10 Mha. Several of these farms are part of large-scale vertically integrated agro-holdings. These farms and agribusiness structures have emerged as a consequence of the specific privatization program in these countries and the simultaneous financial constraints in agriculture (Serova 2007; Swinnen 2009).

3 Crop Land Use in RUK

Agricultural output can grow through the use of more inputs (the extensive margin) or through increased productivity (the intensive margin) (Babcock, 2015). Agricultural productivity refers to many inputs, including labor and knowledge. However, the vast majority of the literature in this field focuses on cropland use and yields and points to the extensive idle land resources and low concurrent productivity that (are argued to) translate into large untapped agricultural production potential (FAO and EBRD, 2008; Schierhorn et al., 2014b; Meyfroidt et al., 2016; Saraykin et al., 2017).

The combination of land privatization, farm restructuring and dramatic price changes led to widespread changes in land use and land abandonment (Kraemer et al. 2015; Lerman et al. 2004; Mathijs and Swinnen 1998; Sedik et al 2003). Land abandonment was caused by: (a) the reduced profitability of farming with the cut in agricultural subsidies and the move to market prices; and (b) uncertainties on land property rights. Both factors affected how much land was being used and also how intensely the land was cultivated (how many other inputs were used). Vranken *et al.* (2004, 2011) showed how land plots with uncertain ownership were more likely to be left abandoned or used less intensively.[6] While market imperfections and institutional constraints still exist in the land market and need to be addressed, the cut of market distorting subsidies and removal of government price regulations has lead to an economically more efficient use of land (Swinnen and Rozelle, 2006). This implies that many of these changes may be permanent, depending on global price evolutions for agricultural commodities.

Studies on the RUK agree that land abandonment was vast in the region, as is illustrated in Figure 3.[7] Estimates of abandoned cropland in RUK during transition are between 50 and 60 Mha (Official statistics; Meyfroidt et al. 2016).[8] Estimates varied on (a) the extent of land abandonment and (b) on the suitability of the abandoned lands and their potential for being

[6] The intensity of land use is also affected by the farm structures which are partly endogenous. Throughout the ECA region capital and labor intensity of farming is correlated with smaller farms dominate in more extensive farming areas (Swinnen, 2009) – see also Section 3.3. Official data sometimes suggest relatively small changes in land use, as indicated in Table 4. However, these data do not present an accurate picture of the changes since they often do not distinguish between crop land and pastures.

[7] For Russia alone land abandonment estimates vary from 20 Mha to more than 44 Mha of abandoned cropland -- see Table 5 for more details.

[8] Schierhorn *et al.* (2014) estimate 50 Mha; Meyfroidt *et al.* (2016) 59.3 Mha of cropland was abandoned between 1991 and 2009 in RUK (of which 35.9 Mha in Russia, 2.9 Mha in Ukraine and 20.6 Mha in Kazakhstan); while official statistics are 52 Mha.

returned to productive cropland. The disagreement with regards to the extent is largely due to differences in definitions of land abandonment, study periods and the quality of the datasets used (Alcantara *et al.*, 2013). There is a growing consensus that official Russian sown area statistics best approximate cropland dynamics (Ioffe and Nefedova, 2004; Saraykin et al., 2017; Schierhorn et al., 2013). These statistics show that from 1990 to 2013 the area used for cropland across RUK declined by 52.4 Mha (from 167.5 to 115.1 Mha), with 38.4 Mha of this decline in Russia. The vast majority of this decline occurred in "European Russia". Alcantara et al. (2013) estimate the decline in this region at 32 Mha. More generally, there is a major difference between Russia and Kazakhstan where crop land use declined between 30% and 40% and Ukraine where there was much less reduction in land use (see Figure 4).

In general, most abandonment was concentrated on socio-economically and agro-ecologically marginal lands (such as the non-Chernozem regions of north-western Russia and in the central and Volga regions of Russia), but croplands also contracted in areas with good soil, climate and infrastructure conditions (parts of southern Russia and northern Kazakhstan), albeit to lesser extent (Meyfroidt et al 2016; Prishchepov et al, 2013). Cropland abandonment was widespread both on rainfed and irrigated croplands in Kazakhstan (Kraemer et al. 2015; Löw et al. 2015).

Potential of Recultivating Abandoned Cropland

Figures 3a and 4a illustrate there has been some recultivation of abandoned cropland in the past decade, primarily in the areas with good agronomic conditions.[9] However, land use is

[9] This includes Southern European Russia (recultivation since 2003), Russia's Far East (in 2004), Central Russia (in 2007), northern Kazakhstan and Ukraine (in 1999) (Meyfroidt et al., 2016; Smaliychuk et al., 2016). By 2014, croplands only continued to decline in Northwestern Russia (Rosstat, 2016).

still much lower than before. Compared to 1990, land use in 2015 was still 40% lower in Kazakhstan, 30% lower in Russia, but about the same in Ukraine.

The recultivation of all abandoned former cropland would dramatically increase total cropland. However much of the abandoned land was only used in the past because of the state regulations and heavy subsidies before 1990. Hence, there is no economic rationale for returning all this land into crop production. For example, Uzun et al. (2014) estimated that 19Mha of abandoned cropland may be recultivated in Russia if grain export prices are as high as $400 per ton (the average world market prices for wheat were about $200 between 2012 and 2015). The authors also point out that the share of grain cultivation on abandoned croplands in northern European Russia, i.e., outside the fertile black soil areas, is low mainly because of biophysical constraints. Liefert and Liefert (2015) also argue that cropland recultivation may not necessarily lead to more grain production because of competing land demands from other crops, particularly oilseeds.

Moreover, croplands that have been abandoned in the 1980s or 1990s are often penetrated with deep-rooting vegetation that renders recultivation expensive (Larsson and Nilsson, 2005). Such costs should be kept in mind because approximately 3.5 Mha of agricultural lands from the Soviet period were covered with forest by 2012 in European Russia alone (Potapov et al., 2015). The secondary vegetation is important for biodiversity and ecosystem services (Kamp et al., 2011), and it stores substantial amounts of carbon in soil and vegetation that would, to a large part, be emitted in case of recultivation (Schierhorn et al., 2013; Kurganova et al., 2015).

In summary, there is a consensus that only a fraction of the abandoned crop land can be put back into production without significant costs or major environmental tradeoffs. Yet, actual estimates of abandoned cropland that is suitable for recultivation vary widely. A study by FAO and EBRD (2008) estimated that 11-13 Mha of abandoned land could be returned to production if only non-marginal land would be re-used in RUK. Meyfroidt et al. (2016), who identified almost 60 Mha of abandoned land in RUK of which 20% had already been recultivated until 2009, estimated that 8.5 Mha are potentially available for expanding crop production in RUK if only former cropland with high soil quality, low environmental trade-offs and few socioeconomic and accessibility constraints are considered (5.3 Mha in Russia, 2.4 Mha in Kazakhstan and 0.9 Mha in Ukraine). The Russian Ministry of Agriculture projects 3.5 Mha of abandoned croplands to be recultivated by 2020 (Ministry of Agriculture, 2013).

Hence, it is clear from the literature that agro-environmental and socio-economic constraints limit significant additional wheat output from reusing abandoned cropland in RUK. The large majority of high-quality land is already back in cultivation. Other, more marginal lands may be more suitable for other uses such as livestock grazing and development of livestock fodder base, and for ecosystem services.

4. Input Use and Yields

The abandonment of land was accompanied by a dramatic decline in input use, and especially fertilizer use (see Figures 3b and 4b). Deteriorating terms of trade between input and output prices and the ruble devaluation led to drastic declines in fertilizer applications while domestically produced mineral fertilizers were primarily exported abroad (URALCHEM, 2011). The application of organic fertilizers also drastically declined due to plummeting livestock numbers. For example, in Russia, the grain to fertilizer price ratio declined by more than 50% after the price liberalization, with the cut in subsidies, and fertilizer use declined by more than 70% (Swinnen and Rozelle, 2006). Reductions in fertilizer use and other inputs have obviously influenced yields. Yields declined for five years in Kazakhstan and almost a decade in Russia and Ukraine (Figures 3c and 4c).

Since 2000 there have been significant improvements in access to inputs in grain production and in yields. Fertilizer use has recovered significantly from its low point in the late 1990s, especially in Ukraine and Russia. Important structural and institutional changes over the past decade helped to overcome institutional constraints in the major grain producing regions and contributed to the emergence of large scale and vertically integrated farming operations (Nefedova 2016; Swinnen, 2009; Gataulina et al., 2005; Serova 2007). The Russian government also increased subsidies since 2005 (Liefert and Liefert, 2012). Increased government support to domestic farmers as well as higher returns from grain exporting with the substantial depreciation of the Russian ruble and high world market prices has contributed to increased investments in booming grain production (Kingwell et al., 2016).

Increasing investments and higher returns have been accompanied by significant increases in fertilizer use and yields. Grain yields started recovering in the late 1990s and have since increased by 50% to 70% in the RUK. However current fertilizer use per hectare is still considerably below the pre-transition levels, reflecting, among other things, the cut of the large fertilizer subsidies and possibly inefficient use of fertilizer under the Communist regime. Figure 3 also shows how today average fertilizer use is almost twice as high in Ukraine than in Russia and even much higher than in Kazakhstan.

Yield Gaps and Potentials

The yield potential of a crop cultivar is the yield that can be attained when water and nutrients have not been limiting and when biotic stress have been effectively controlled during crop growth (van Ittersum et al., 2013). However, actual yields are typically lower than potential yields, resulting in yield gaps.[10]

Several studies have identified high yield gaps in RUK wheat. Figure 5 summarizes their findings, and Figure 6 provides more information on the regional variations. The various studies yield rather consistent estimates for Russia and Kazakhstan but less so for Ukraine. On average, the estimated yield gaps for RUK were more than three tons per hectare under irrigated conditions. However, irrigation scenarios may be unrealistic in the near to medium future since the majority of irrigation networks have fallen into disrepair since the collapse of the Soviet Union. Under rainfed conditions, Schierhorn et al. (2014a) estimate average wheat yield gaps of 1.5-2.1 t/ha for European Russia, where approximately 75% of Russia's wheat is being produced; and Savin et al. (2001) estimated an average wheat yield gap of 1.7 t/ha for Russia as a whole. Most of the studies estimated the highest yield gaps for Ukraine (especially in the northwestern and central part), up to 6.9 t/ha. The yield potentials under rainfed conditions in Russia and Kazakhstan are lower than those in Ukraine mainly due to a shorter growing season, lower water supply and higher heat stress (Pavlova et al., 2014).The yield gaps are caused by a combination of factors. One is the low use of fertilizer, as discussed above; others are low-quality seeds and poor extension services (FAO, 2009; Kingwell et al., 2016). In Russia and Kazakhstan average yields are also low because volatile weather conditions result in frequent crop failures. In turn, these droughts and crop failures contribute to low applications of mineral fertilizers because profits from agriculture are highly uncertain in the

[10] There are different ways to measure yield gaps. Globally, Licker et al. (2010) and Mueller et al. (2012) approximated yield gaps by comparing observed and potential yields in locations with similar soil moisture and temperature characteristics. Neumann et al. (2010) combined an econometric approach with spatially explicit biophysical and land management-related data to estimate maximum attainable yields and yield gaps. Crop growth models have also been used to simulate optimal management conditions and hence potential yields at global scale (Fischer et al., 2002; Liu et al., 2007). Schierhorn et al. (2014a) and Savin et al. (2001) used crop growth models to assess yield potentials for wheat in Russia.

absence of adequate insurance schemes (Schierhorn et al., 2014a). Only 20% of crop farmers in Russia were insured in 2011 (Uzun et al., 2014).

Production Impact of Closing Yield Gaps

For European Russia, Schierhorn et al. (2014b) estimated that increasing yields on existing cropland to 100% of their technical potential could generate an additional 44 Mt of wheat under rainfed conditions and 90 Mt under irrigated conditions. However, there are several factors which make this an unrealistic scenario. First, farmers strive to maximize profits rather than yields. As a result they typically obtain less than 80% of the yield potential, even in the most developed countries (Lobell et al., 2009). Second, in the absence of irrigation the production potential in a year with drought conditions is substantially lower than for a year with sufficient precipitation (Schierhorn et al., 2014b). Seasonal droughts and aridity are particularly severe in the fertile steppes of Russia and Kazakhstan where water shortage cause wheat yields to drop by up to 40%, in spite of adoption of improved wheat cultivars (Pavlova et al., 2014). Third, irrigation can alleviate water stress, but water shortages, poor water management and high investment costs will likely prohibit the establishment of irrigation facilities at large scale (Alcamo et al., 2007; Lioubimtseva and Henebry, 2009).[11] Fourth, climate change will likely reinforce these constraints in the regions with the best soils (see section 5). Considering the increasingly volatile weather conditions and thus higher risk of investment losses, it seems unlikely that inputs levels will substantially increase in the southern breadbaskets of RUK, particularly if effective crop insurance schemes remain absent (Schierhorn et al., 2014b; Fehér et al., 2017). It appears more likely that input applications will

[11] Moreover, poor use of irrigation in combination with high fertilizer use could trigger soil salinization and increase soil pH, potentially leading to yield losses, as was the case in parts of Central Asia in the Communist era (Qadir et al., 2009), but also decline of irrigated areas land use in the post-Soviet period (Horion et al., 2016).

increase in the northwestern and northern part of both Ukraine and Russia, where climate conditions are less volatile and climate change projections suggest increasing suitability for cropping. Taking these factors into account (e.g. accounting for weather variability in the calculation of production potentials), Schierhorn et al. (2014b) estimate that closing the yield gap to 80% of the yield potential would generate an additional 23 Mt of wheat under rainfed conditions.

5. Climate Change

The impact of climate change on the grain production potential will vary across the RUK because it is such a vast area. The northern parts may benefit from warmer weather and longer growing seasons, but the soil quality there limits its growth potential. Production in the southern regions, where most of the good soils are, is likely to become more vulnerable with climate change.

Climate change projections by the Intergovernmental Panel on Climate Change (IPCC) suggest a significant increase in temperature in RUK (IPCC, 2014). With higher temperature, the fertile black soil belt in southern European Russia and Southeastern Ukraine will likely suffer from more frequent and intense droughts (Dronin and Kirilenko, 2011). Precipitation trends are less distinct, but it is likely that the main part of the black soil belt in Ukraine and Russia may suffer from a modest decrease of precipitation during summer months. Lower precipitation in combination with higher average temperatures will cause higher evapotranspiration rates and reduce soil water content (Lioubimtseva et al., 2013).

This region already suffers regularly from water stress and may become increasingly vulnerable because aridity and water scarcity will likely increase. In addition, extreme heat waves (such as the one that causes caused the plummeting of grain production in 2010 and contributed to the increase in international wheat prices) may become more likely under climate change (Hauser et al., 2016). As a result, average yields may decline and yields may become more volatile in these southern black soil belt regions of Russia and Ukraine without adaptation measures (Alcamo et al., 2007; Dronin and Kirilenko, 2011; Müller et al., 2016; Teixeira et al., 2013). The World Bank (2010) expects yields in Ukraine to decrease by approximately 15% as a result of climate change.

Crop production in northern Kazakhstan, a region that produces approximately 80% of Kazakhstan's wheat output and provides the bulk of Kazakhstan's wheat exports, may only be slightly affected by climate change (Sommer et al., 2013; ASK, 2014; Bobojonov and Aw-Hassan, 2014). Sommer et al. (2013) estimated that slight increases in rainfall will be offset by increasing evaporation, leading to a low net impact on yields. These results contradicts with Fehér et al. (2017), who estimated that wheat yields in northern Kazakhstan will decrease until 2050 in the absence of adaptation to climate change. Bobojonov and Aw-Hassan (2014) investigated the economic impact of climate change in Central Asia and suggested positive income gains in north Kazakhstan, specifically for large-scale commercial farms that enjoy better adaptive capacity to climate change.[12]

Agriculture in higher latitudes could benefit from an extended growing period, higher temperatures, increasing precipitation and a lower risk of frost damage to crops (Kiselev et al., 2013; Müller et al., 2016; Tchebakova et al. 2011). Climate change may contribute to yield

[12] Farmers may adapt their production systems to perceived changes in climate. For example, farmers may adjust planning and harvesting dates, put better adapted crops into practice, alter soil and fertilizer management, or invest into irrigation facilities (Hertel and Lobell, 2014). Farm structure, technology and rural infrastructure (including irrigation) are important determinants of the resilience of agricultural sector to climate change (Sutton et al., 2008). Sutton et al. (2013) argue that smaller farms, especially subsistence farms, might be the most vulnerable, whereas corporate farms with better physical and financial capacity will be better capable to adjust to climate change. Mirzabayev (2013) argues that agricultural producers operating in inherently stressed environments may be better able to adopt to weather variability and changing environment. He estimates the effects of weather variability at less than 1% of total crop production revenues.

increases in these areas and cause a northward shift of the frontier for grain production in Russia (World Bank 2010). However, limited availability of high-quality croplands dampens expectations for much higher crop production in Northern Ukraine and Northern Russia (Dronin and Kirilenko, 2011).

6. Wheat Production Potential in RUK

The significant contraction of agricultural production at the extensive and intensive margin during the early years of transition was followed by recultivation of abandoned croplands in some regions and a rebound of yields starting in the late 1990s. To assess how much production increases may still be attainable we combine insights on increasing land use (section 3) and achieving higher yields (section 4). We first use statistical assessments of potentially available cropland and of yield gaps within specific agro-climactic and/or agro-environmental zones (drawing on the models of Mueller et al (2012) and Meyfroidt et al (2016)) to calculate RUK wheat production under several scenarios. In a second step, we interprete these estimates using economic arguments.

1. Baseline. As a base for comparison we used the average land area used for grains and the average wheat yields between 2008 and 2013 (assuming that wheat can be cultivated on all land used for grains).
2. Cropland Re-cultivation (see Section 3): Following Meyfroidt et al. (2016) we assume that an additional 8.5 Mha are potentially available for crop production in RUK. This amount only includes abandoned cropland on fertile soils (i.e., black soils) with low environmental trade-offs and low or moderate socioeconomic and infrastructural constraints.

3. Intensification (Reducing the Yield Gap) (see Section 4): We consider two scenarios of yield gap closures, to respectively 60% and 80% of the yield potential. We use the wheat yield potential indicators from Mueller et al. (2012) which are in the middle range of the estimates and are available for entire RUK. These indicators also capture that the highest yield increases will likely occur in the northwestern and northern part of both Ukraine and Russia.
4. Climate Change (See section 5): We assume that the negative yield effects of climate change in the southern regions are compensated by positive yield effects in the northern regions and that average wheat yields are not affected. However, as climate change will make it possible to use more land for grain production in some of the northern regions of RUK, we assume that wheat cultivation in the northwestern and northern part will increase by 25%.

Table 2 presents production under various scenarios. Under the RECULTIVATION scenario, wheat production would expand by 8.5 Mha, mostly in Russia, and this would result in an extra 12.5 Mt of wheat under current yields in RUK.

Closing the yield gap (the INTENSIFICATION scenario) leads to more production increases than the RECULTIVATION scenario. If the yield gap increases to 60% of potential yield (Table 2A) on existing croplands, this would generate additional wheat production of 23.9 Mt (of which 12.2 Mt in Russia, 7.7 Mt in Ukraine and 4.0 Mt in Kazakhstan).[13] This potential seems realistic, partly because relatively small increases in input use could result in substantive

[13] In this scenario, the additional wheat production in Ukraine is 58% of Russia's additional production, while total area under grain cultivation in Ukraine is only 37% of the cultivated area in Russia. Yield gap closure in Ukraine results in more additional production in relation to Russia because of the higher yield potentials and higher yield gaps in Ukraine (see Figure 5). Despite the higher share of wheat cultivation in total sowing area in Kazakhstan (16% higher than in Russia and Ukraine), the production potentials in Kazakhstan on existing croplands are relatively small because of the low current yields and small yield gaps.

yield increases. The additional production is roughly equal to the annual RUK export of 26.6 Mt of wheat (average from 2008 to 2013 (FAO, 2017)). Closing the yield gap to 80% of the yield potentials, which is probably unrealistic, would increase wheat production on existing cropland by 85.4 Mt, compared to the baseline (Table 2B). This would be more than a 50% increase of wheat production.

The impact of climate change to the intensification impact is an additional 4 to 5 Mt of wheat, depending on the yield gap assumptions (compare column INTENSIFICATION with CLIMATE CHANGE+INTENSIFICATION). This production comes from additional land that can be used for grain production in the northern regions, but the yields are expected to be relatively low on these lands.

The last column is the combination of the three effects (recultivation of land, climate change and closing of yield gaps). Under the 60% intensification scenario, this would yield a total production of 203.8 Mt, which is 42.3 Mt (or 26 %) more than current production. Under the very optimistic 80% intensification scenario, this would result in a total production of 271.5 Mt of wheat, which is 110 Mt more than current production, an increase of 68 %.

In all scenarios, most of the gains would come from yield increases. This is consistent with several studies that have argued that the major share of future production increases will likely stem from increasing yields on existing croplands (FAO and EBRD, 2008; Liefert et al., 2010; Schierhorn et al., 2014b).[14] The production increase varies from 42 Mt to 110 Mt with yield gap closure increasing from 60% to 80%. However, based on the studies we reviewed, it appears that obtaining 80% closure will be very difficult to achieve because of the large input

[14] The production potentials in Table 2 are comparable to early estimates of FAO and EBRD (2008) who predicted a maximum production potential (albeit in total cereal production) of 230 Mt or +80% compared to levels of 2004 to 2006. These numbers are approximately consistent with our most optimistic intensification scenarios for current croplands (80% of yield potential).

investments required and climate conditions and is most likely not a realistic assumption. An in-between scenario of 70% intensification would yield almost 80 Mt extra production. While 70% is also quite optimistic, the 60%-70% intensification scenario still represent substantive increases in production.

However, there are important economic factors to keep in mind when interpreting these numbers for actual future wheat production and exports. The most important ones are the future evolution of prices for wheat and competition from other crops for land. While food price spiked between 2007 and 2012, prices have fallen back to lower levels since. International organizations such as FAO and OECD predict that grain prices will further decline in real terms between 2015 and 2025. This should reduce incentives for using more land (at higher costs) and more inputs, thereby lowering both land expansion and intensification.

The second important consideration is that wheat is competing with other grains (such as corn and barley for feed) and other crops (such as oilseeds). Both have grown stronger than wheat production in recent years, mostly due to increased demand for animal feed in RUK (with increased subsidies and trade protection for the livestock industry) and for exports to countries such as China where feed demand has increased with demand for animal products as incomes are increasing (Liefert and Liefert, 2015, 2017). This competition is significant. Land use for oilseeds has increased from around 6 Mha in the late 1980s to more than 21 Mha in recent years (Table 3). While land use for wheat has increased around 6% over the past decade, land used for oilseeds has doubled over the same period. If this continues in the future with growing demand for feed and lower prices for food grains, this will reduce the attractiveness of producing wheat in RUK. Hence, while biophysical conditions may still allow a very substantial expansion of wheat production in RUK (as summarized in Table 2), economic conditions may significantly constrain these and may result in considerably lower potential for expansion of wheat production and exports.

7. Conclusions: The Potential and Reliability of the Region for Global Food Security

The countries of Eastern Europe and Central Asia have attracted attention in the global food security debate for their potential as producer and exporter of grains (and especially wheat). The region currently produces 18% of the worlds' wheat and accounts for 22% of global wheat exports, and most of this is from Russia, Ukraine and Kazakhstan (RUK). Many reports have pointed at the potential of these countries to become a "breadbasket" for the world because these production and exports can be augmented with their "immense land and yield reserves". During the transition process of the 1990s more than 50 Mha of cropland had been abandoned and yields had declined strongly as well.

However, several studies warn against too much optimism on the potential of putting all this land put back in use for food production and on the actual yield potential. Growth in grain production can result from expansion of the intensive (productivity, including yields) and extensive (more inputs, including land) margin. Studies vary quite significantly in terms of their assumptions on the potential for growth in productivity and land use, and thus their predictions for future growth.

RUK cereal production recovered substantially over the past decade: a 26% increase of average annual production from 127 Mt to 161 Mt between 2004-06 and 2012-2014. However, this growth was almost entirely due to an increase in yields (+33%), and much less due to more land use (+2%), despite the fact that grain prices increased strongly. These observations thus support more pessimistic predictions on wheat production increase by using abandoned lands.

Calculations based on statistical agro-ecological and agro-climatic models (taking into account yield increases, re-cultivation of abandoned land, and climate change) suggest that the wheat production potential in RUK could be somewhere between 200 and 270 Mt per year (of which more than 120 to 160 Mt in Russia alone). This would be an increase of approximately 40 Mt to 110 Mt compared to current production, which implies that even under more pessimistic scenarios RUK could satisfy a substantial share of the projected increase in global wheat demand.

However, economic conditions may significantly constrain this potential. While food prices spiked in the late 2000s, they have fallen back to lower levels since and food grain prices are not expected to increase in real terms in the coming decade. In addition, wheat is increasingly competing with other crops, such as feed grains and oilseeds, which have expanded in land use due to increased demand for animal feed in RUK and for exports. Both factors should reduce incentives for using more land (at higher cost) and more inputs for wheat production, thereby lowering both wheat land expansion and intensification.

That said, it is important to point out that the focus on wheat is obviously understandable from the perspective of reports pointing at the potential of these countries to become a "bread basket" for the world because of "their immense land and yield reserves". However, this may also be misleading for global food security, and ECA's role in it. Changing diets with income growth imply a larger role for other types of food than staple grains as wheat. RUK, and he ECA region more broadly, is a major producer of food products beyond wheat, such as meat, dairy products (and feed grains), fruits and vegetables, which obviously can have major implications for global food security. Some ECA countries are important exporters of these products.

A related aspect is that other sources of productivity growth than land and yields (such as labor productivity growth) are very important as well and total factor productivity is a better indicator of potential for agricultural growth, as emphasized by Hertel *et al.* (2016). We have shown that different sources of agricultural productivity growth have evolved sometimes very differently across the ECA region (Rozelle and Swinnen, 2004; Swinnen *et al.*, 2006; Swinnen and Vranken 2010), which is an important issue to take into account.

A final consideration is the region's reliability as a source of grain supplies when food is globally in need. While RUK grain exports have increased significantly in recent years, a study by Sedik (2013) found that the volatility of production and especially exports was much larger in RUK than in other major grain exporters, such as the US or Canada. This volatility in exports is an important consideration in assessing how the region could contribute to global food security as the importing countries may (not) be able to rely on a stable level of imports.

In many countries in the world, the global food crisis of 2007-2011 triggered policy actions to ensure domestic food supplies. Exporting countries banned, taxed or restricted the exports of food and importing countries reduced import tariffs. Also RUK implemented export restrictions to secure their domestic supply of grain and protect their local consumers from increasing food prices (World Bank, 2011; Jones and Kwiecinski 2010; Sedik, 2011). These export restrictions by the major ECA grain producers in the region had a major impact on the grain importing countries in the region. This is certainly a cause of concern for the future in particular for countries relying on imports from RUK exclusively.[15]

[15] Interestingly, Sedik (2011, 2013) showed that the effect of the grain export restrictions was mitigated because of a rapid shift of the importers towards import of flour and other cereals where exports were not (or less) restricted.

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Table 1. Agricultural Production in Eastern Europe and Central Asia (ECA) 1992-2015

A. WHEAT production (three year average in million tons)

	1992-1994	1995-1997	1998-2000	2001-2003	2004-2006	2007-2009	2010-2012	2013-2015
ECA	101,04	94,10	86,09	107,86	116,57	135,43	119,01	
of which Kazakhstan	12,97	7,71	8,35	12,31	11,53	15,35	14,07	14,17
Russia	40,61	36,43	30,82	43,90	46,01	58,29	45,16	55,90
Ukraine	18,40	16,07	12,91	15,17	16,72	20,24	18,31	24,30

B. MEAT production

	1992-1994	1995-1997	1998-2000	2001-2003	2004-2006	2007-2009	2010-2012	2013-2015
ECA	20,78	16,67	15,19	15,31	15,74	17,66	19,75	
of which Kazakhstan	1,26	0,85	0,63	0,67	0,77	0,87	0,91	0,90
Russia	7,53	5,33	4,49	4,70	5,05	6,25	7,59	9,07
Ukraine	2,96	2,09	1,69	1,63	1,64	1,91	2,14	2,37
Poland	2,73	2,84	2,97	3,09	3,23	3,38	3,68	4,07

C. MILK production

	1992-1994	1995-1997	1998-2000	2001-2003	2004-2006	2007-2009	2010-2012	2013-2015
ECA	107,04	91,56	85,35	87,63	89,29	91,02	90,58	
of which Kazakhstan	5,38	3,86	3,55	4,12	4,74	5,19	5,16	5,00
Uzbekistan	3,69	3,48	3,56	3,80	4,56	5,43	6,75	
Russia	45,31	36,42	32,61	33,26	31,59	32,37	31,74	30,80
Ukraine	18,54	15,62	13,26	13,74	13,57	11,88	11,24	11,07
Poland	12,67	11,82	12,26	11,90	11,93	12,34	12,47	12,97

Source: FAOstat 2015, KAZAKHSTAT (2016), ROSSTAT (2016), UKRSTAT (2016), GUS (2016)

Table 2. Potential Wheat Production in RUK Under Different Scenarios

INTENSIFICATION @ 60% of the Yield POTENTIAL	**Baseline**	**INTENSIFICATION**		**RECULTIVATION**		**CLIMATE CHANGE + INTENSIFICATION**		**INTENSIFICATION + RECULTIVATION + CLIMATE CHANGE**	
AREA Harvested Grain (Mha)	*2013*			Total	Extra Land				
Russia	46.2	46.2		51.5	5.3	47.2		52.5	
Ukraine	16.1	16.1		16.9	0.9	16.4		17.3	
Kazakhstan	15.4	15.4		17.8	2.4	15.5		17.8	
Total	77.6	77.6		86.2	8.5	79.1		87.6	
YIELDS WHEAT (t/ha)	*2008-2013*	60% of Yp		80% of actual yields		60% of Yp		60% of Yp	
Russia	2.1	2.3	2.3	2.0	1.6	2.3	2.3	2.3	2.3
Ukraine	3.2	3.6	3.6	3.0	2.0	3.5	3.5	3.5	3.5
Kazakhstan	1.2	1.4	1.4	1.1	0.9	1.4	1.4	1.3	1.3
PRODUCTION WHEAT (Mt)		TOTAL	**GROWTH**	TOTAL	**GROWTH**	TOTAL	**GROWTH**	TOTAL	**GROWTH**
Russia	95.0	107.2	**12.2**	103.5	**8.6**	110.1	**15.2**	120.0	**25.1**
Ukraine	49.3	57.0	**7.7**	51.0	**1.7**	58.1	**8.8**	60.0	**10.7**
Kazakhstan	17.2	21.2	**4.0**	19.4	**2.2**	21.3	**4.1**	23.8	**6.6**
Total	161.5	185.4	**23.9**	174.0	**12.5**	189.5	**28.0**	203.8	**42.3**

INTENSIFICATION @ 80% of the Yield POTENTIAL	**Baseline**	**INTENSIFICATION**		**RECULTIVATION**		**CLIMATE CHANGE + INTENSIFICATION**		**INTENSIFICATION + RECULTIVATION + CLIMATE CHANGE**	
AREA Harvested Grain (Mha)	*2013*			Total	Extra Land				
Russia	46.2	46.2		51.5	5.3	47.2		52.5	
Ukraine	16.1	16.1		16.9	0.9	16.4		17.3	
Kazakhstan	15.4	15.4		17.8	2.4	15.5		17.8	
Total	77.6	77.6		86.2	8.5	79.1		87.6	
YIELDS WHEAT (t/ha)	*2008-2013*	80% of Yp		80% of actual yields		80% of Yp		80% of Yp	
Russia	2.1	3.1	3.1	2.0	1.6	3.1	3.1	3.0	3.0
Ukraine	3.2	4.7	4.7	3.0	2.0	4.7	4.7	4.6	4.6
Kazakhstan	1.2	1.8	1.8	1.1	0.9	1.8	1.8	1.8	1.8
PRODUCTION WHEAT (Mt)		TOTAL	**GROWTH**	TOTAL	**GROWTH**	TOTAL	**GROWTH**	TOTAL	**GROWTH**
Russia	95.0	142.7	**47.7**	103.5	**8.6**	146.6	**51.6**	159.8	**64.8**
Ukraine	49.3	76.0	**26.7**	51.0	**1.7**	77.5	**28.2**	80.0	**30.7**
Kazakhstan	17.2	28.2	**11.0**	19.4	**2.2**	28.4	**11.2**	31.7	**14.5**
Total	161.5	246.9	**85.4**	174.0	**12.5**	252.4	**90.9**	271.5	**110.0**

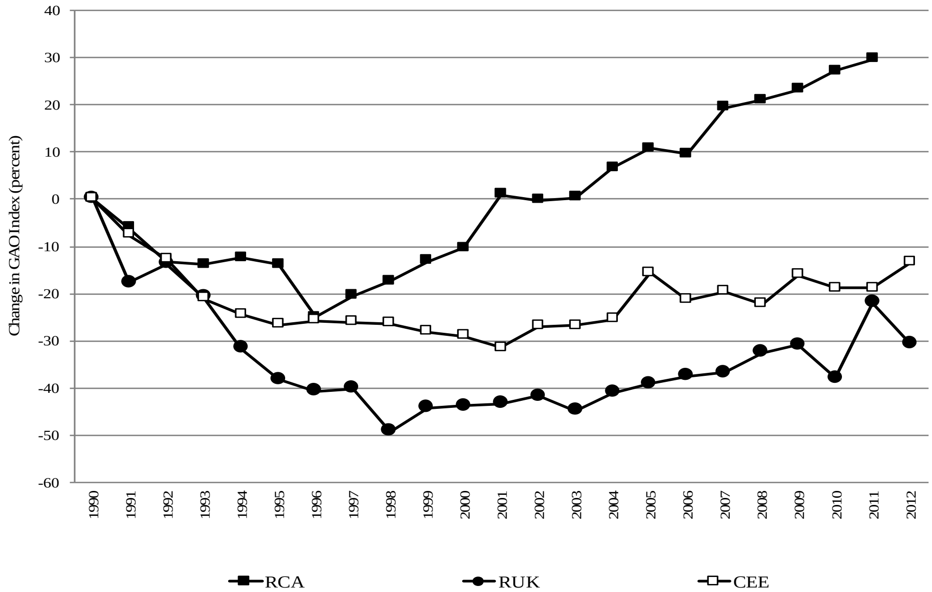
Source: Own calculations based on Mueller et al. (2012), Meyfroidt et al. (2016), ROSSTAT (2016), UKRSTAT (2016), KAZSTAT (2016)

Table 3. Land Use for Wheat, Other Grains and Oilseeds in RUK (Mha and Change)

CROP:		1987-91	1992-95	1996-00	2001-05	2006-10	2011-15
WHEAT	Million hectares	44.6	40.9	37.5	39.9	43.1	42.4
	Change (%)	100.0	91.7	84.1	89.4	96.8	95.1
OILSEEDS	Million hectares	6.2	7.0	8.3	9.8	15.4	21.3
	Change (%)	100.0	113.0	133.4	157.2	247.1	342.8
OTHER GRAINS	Million hectares	56.8	48.5	31.1	29.3	27.1	29.1
	Change (%)	100.0	85.2	54.6	51.5	47.7	51.1

Source: KAZAKHSTAT (2016), ROSSTAT (2016), UKRSTAT (2016)

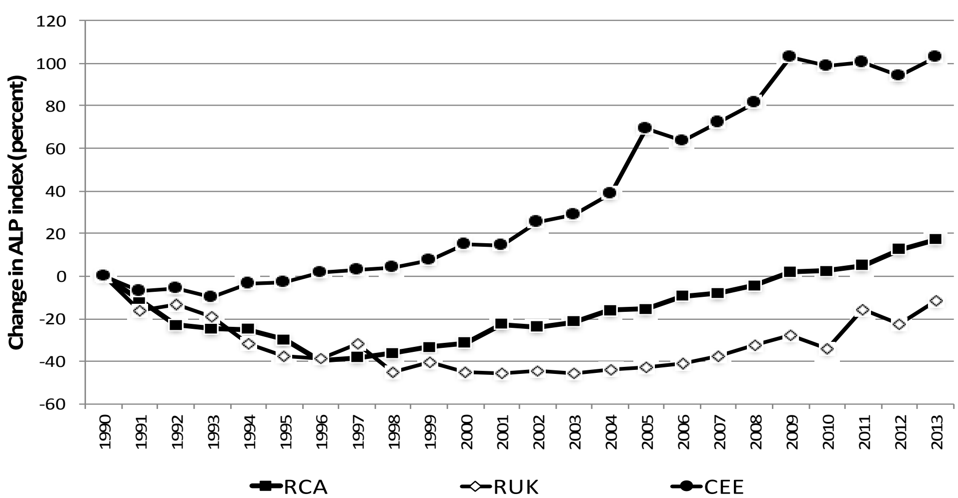
Figure 1: Evolution of gross agricultural output (GAO) (% change since 1990)



RCA: Kyrgyzstan, Uzbekistan, Tajikistan, Turkmenistan; RUK: Russia, Ukraine and Kazakhstan; CEE: Czech Republic, Hungary, Poland, Slovakia, Albania, Bulgaria, Romania, Slovenia, Estonia, Latvia, Lithuania and Belarus

Source: National Statistics and FAOstat 2015

Figure 2 Agricultural Labor Productivity (ALP) (index, 1990=0)

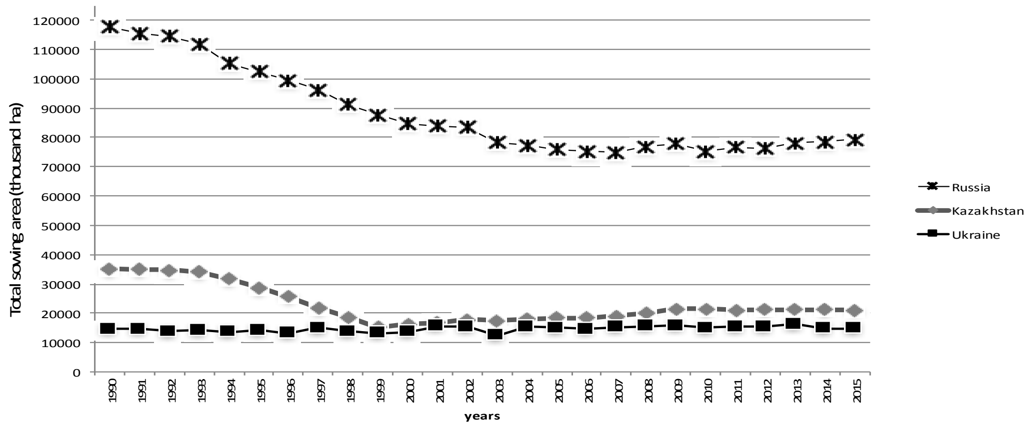


RCA: Kyrgyzstan, Uzbekistan, Tajikistan, Turkmenistan; RUK: Russia, Ukraine and Kazakhstan; CEE: Czech Republic, Hungary, Poland, Slovakia, Albania, Bulgaria, Romania, Slovenia, Estonia, Latvia, Lithuania and Belarus

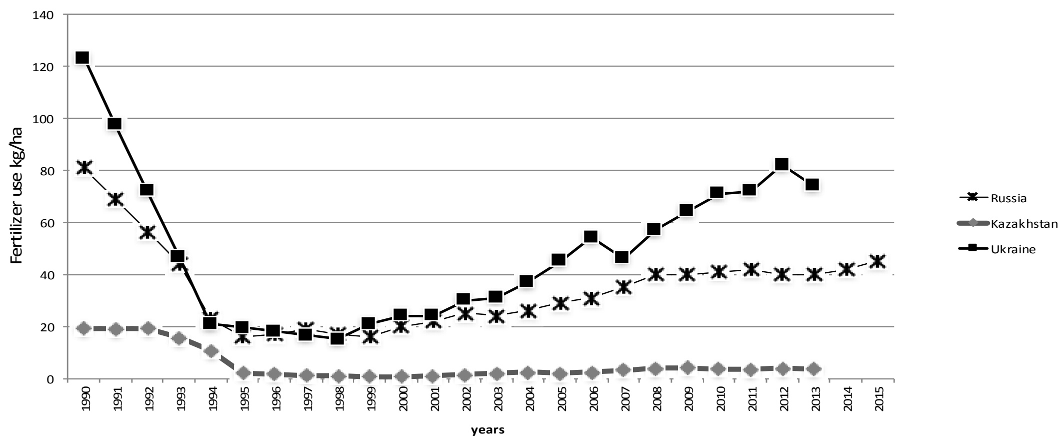
Source: National statistics, ILO 2011, Asian Development Bank 2011, FAOstat 2015

Figure 3. Land use, fertilizer use and yield for grains in RUK

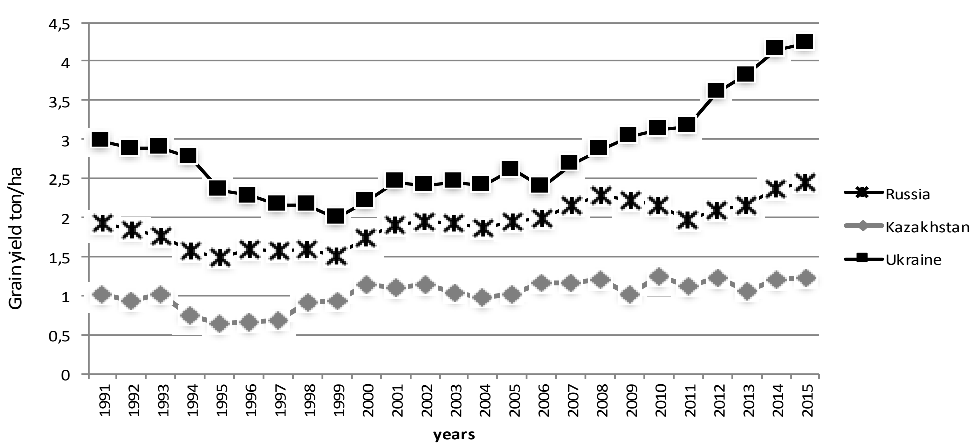
a. Land use



b. Fertilizer use



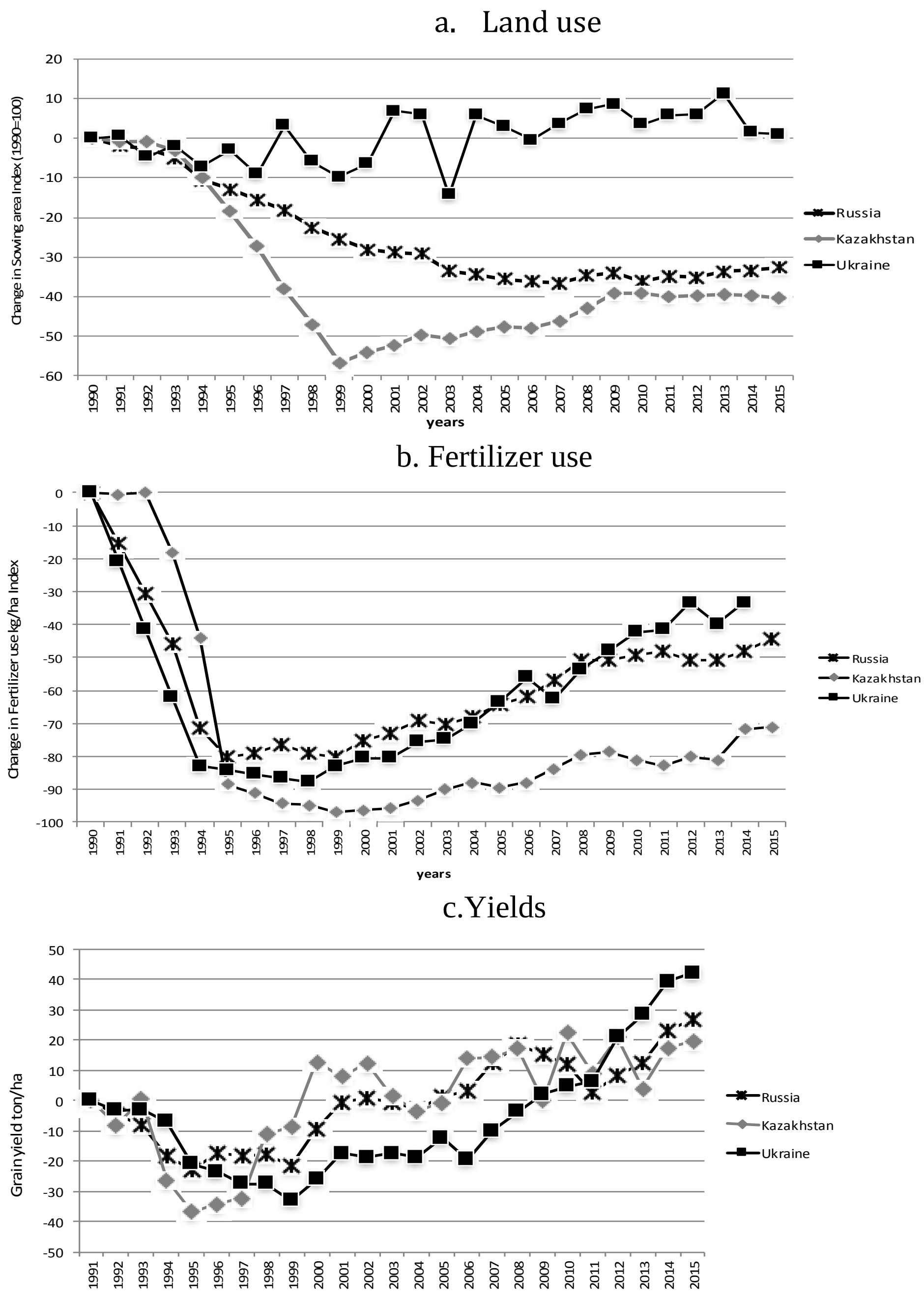
c.Yields



*Yields are expressed as three year moving averages

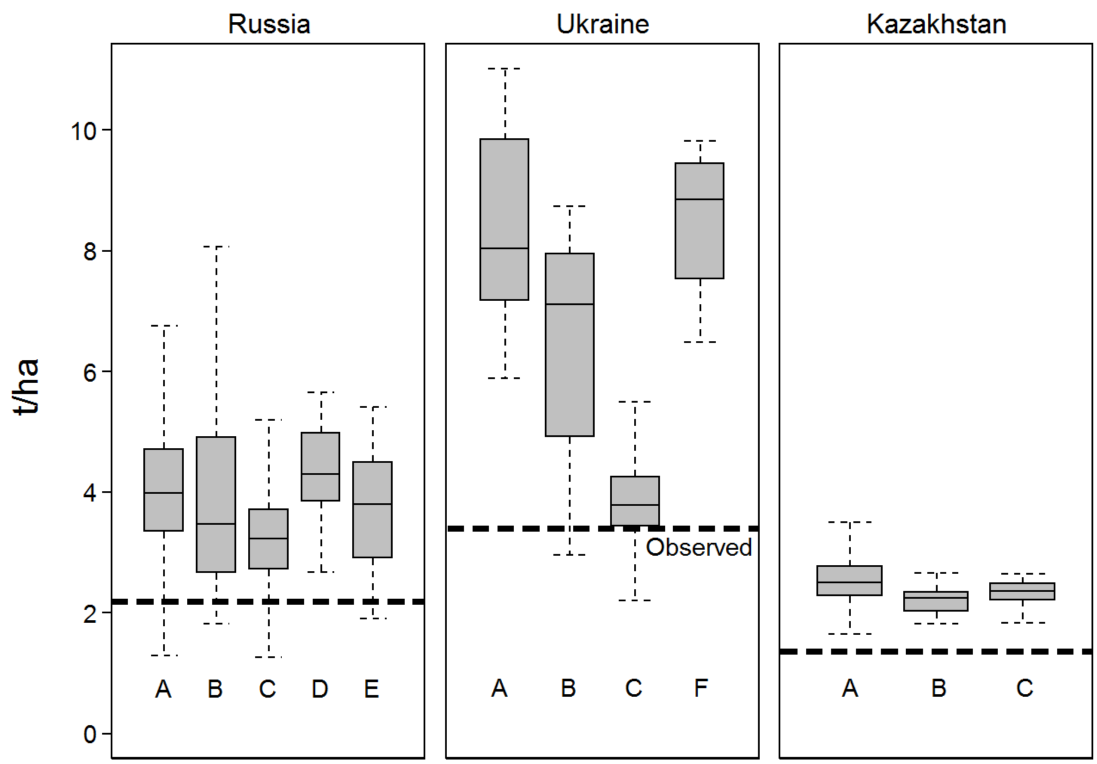
Source: Rosstat 2016, KAZSTAT 2016, UKRSTAT 2016

Figure 4. Change in land use, fertilizer use and yield for grains in RUK (1990=0)



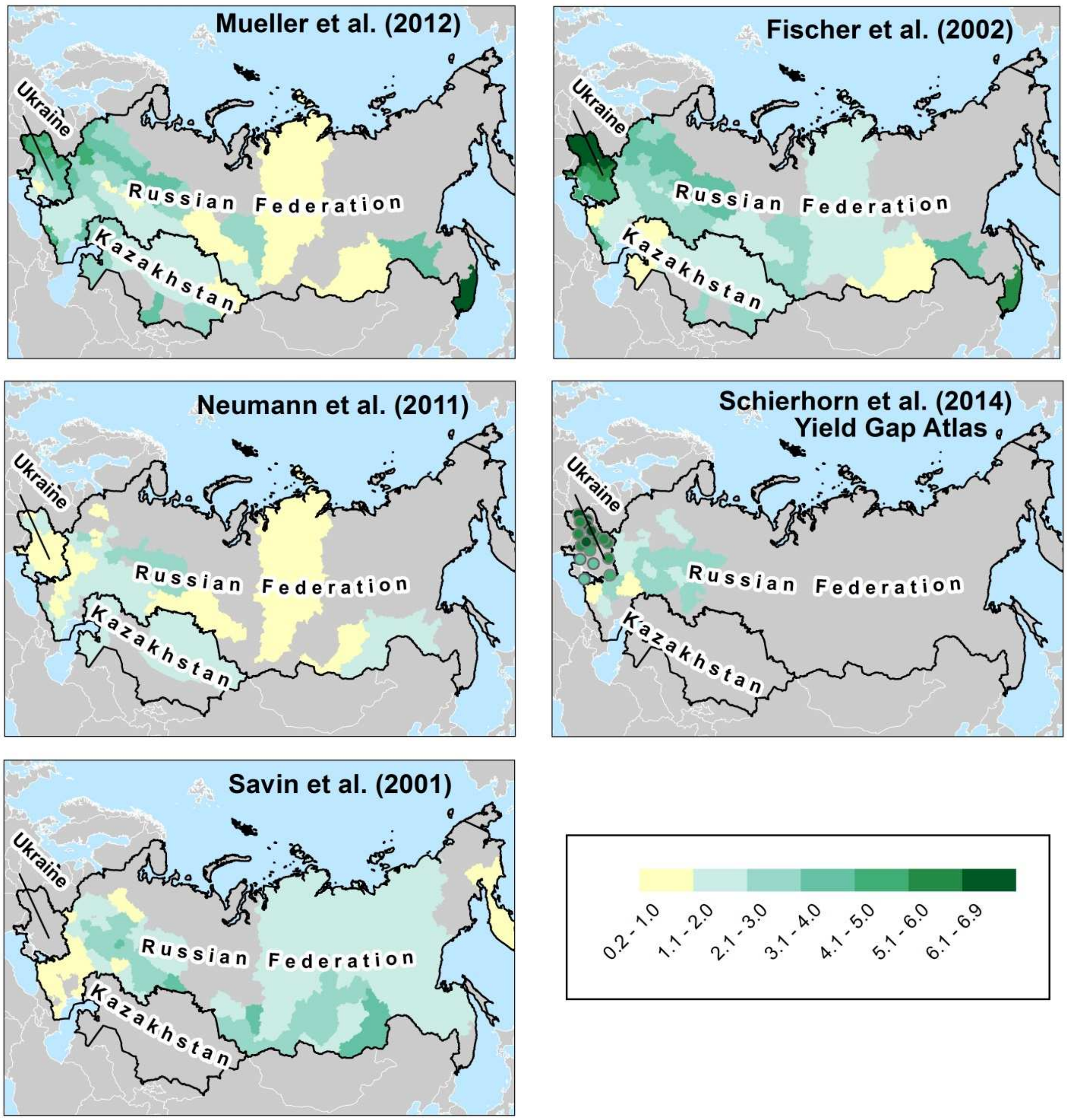
Source: Rosstat 2016, KAZSTAT 2016, UKRSTAT 2016

Figure 5. Comparison of Actual Wheat Yields (2008-13)* and Potential Yields**



* The horizontal dashed line represents average actual wheat yields between 2008 and 2013 (Source: FAO 2017)
** The potential yields estimated by different studies (A-E) are represented by the boxes with the bottom of the box representing the 25th to 75th percentile estimated yield potential. The horizontal line inside the box is the median yield potential. The whiskers represent the absolute minimum and maximum yield potentials. The estimates are from the following sources: **A**: Fischer at al. (2012), **B**: Mueller et al. (2012), **C**: Neumann et al. (2011), **D**: Schierhorn et al. (2014), **E**: Savin et al. (2001), **F**: Yield Gap Atlas (http://www.yieldgap.org). See Figure 6 for details on regional variations.

Figure 6.
Regional Distribution of Wheat Yield Gaps Estimations (t/ha) in RUK



Appendix Table A1. Key characteristics of ECA in 2013

	GDP/capita (in constant 2005 prices)	Share of agr. in empl. (%)	Agric land use (million ha)	Agric production (mil. $)*	Agri land in indiv farms (%)	Labour/land (Pers./ha)	Wheat Production (Mtons)
Central Asia							
Kazakhstan	5581	24,0	217,0	9180	50	0,010	13,9
Kyrgyzstan	637	32,0	10,6	2005	76	0,074	0,8
Tajikistan	507	53,0	4,9	1901	86	0,306	0,9
Turkmenistan	3874	45,8	33,8	2867	93	0,028	1,6
Uzbekistan	960	34,0	26,8	13715	84	0,139	6,8
Caucasus							
Armenia	2362	36,3	1,7	1177	99	0,278	0,3
Azerbaijan	3276	36,8	4,8	2923	87	0,356	1,8
Georgia	2254	53,1	2,6	874	72	0,423	0,08
European CIS							
Belarus	4998	9,6	8,7	7579	12	0,046	2,1
Moldova	1191	28,8	2,5	1689	50	0,135	1
Russia	6844	6,7	216,8	56753	27	0,022	52,1
Ukraine	2081	14,8	41,3	30682	38	0,077	22,3
Baltics							
Estonia	12382	4,0	1,0	654	48	0,026	0,4
Latvia	9671	7,3	1,9	950	88	0,036	1,4
Lithuania	11108	9,0	2,9	2143	86	0,042	2,9
Central Europe							
Czech Rep	14955	2,7	4,2	4042	29	0,032	4,7
Hungary	11933	4,6	5,3	5992	51	0,034	5
Poland	11258	11,2	14,4	21060	88	0,127	9,5
Slovakia	15798	3,5	1,9	1597	19	0,043	1,7
Balkans							
Albania	3897	44,1	1,2	1316	90	0,402	0,3
Bulgaria	5031	6,9	5,0	3616	39	0,041	5,5
Romania	6257	25,4	13,9	10415	56	0,162	7,3
Slovenia	19170	7,7	0,5	653	94	0,148	0,1

Note: * in constant 2004-2006 $

Note: * latest years available o

According to FAO and World Bank, the amount of agricultural land used in Russia and Kazakhstan are almost the same. Agricultural land use includes arable land, under permanent crops and under permanent meadows and pastures

Source: FAOSTAT 2015, World Bank database, EU Parliament, AGRICISTRADE

Appendix Table A2. Predictions from various studies

Do not account for climate change

Study	Geographic coverage	Commodity	Baseline	Predicted growth/fall in Land use	Predicted growth/fall in Yields	Predicted growth/fall in Output	Time horizon
Lambin et al. (2013)	Global	Cropland	Cropland map for 1993 combined with abandonment rate between 1990-	Of a total of 43.5 Mha of abandoned land in Russia only 8.4-8.7 Mha are not associated with major tradeoffs, socio-economic constraints etc.	n.a	n.a	n.a
Alcantara et al. (2013)	Central and Eastern Europe	Farmland	Times series data for 2003-2009	Of total 52.5 Mha of abandoned farmland, 27.7 Mha are in regions with very high and high suitability for agriculture, especially in Russia (19 Mha), Ukraine (6 Mha), and	n.a	n.a	n.a
Bruinsma (2012)	Europe and Central Asia	Cereals, livestock, vegetable oil and oil crops, sugar	Three year average for 2005/2007	Decrease in arable land in Eastern Europe, Caucasus and Central Asia and Russia by 2, 3 and 10 Mha respectively. Harvest will fall less due to more intensive use of arable	Wheat yields will increase in Eastern Europe from 2.71 to 3.13 ton/ha, form 1.25 to 1.52 ton/ha in Caucasus and Central Asia, from 1.96 to 3.94 ton/ha	Cereal production increase to 190 Mtons in Russia and Ukraine in 2050. Europe and Central Asia's share in world meat production would fall from 22%	2030-2050
EBDR/FAO (2008)	Russia, Kazakhstan, Ukraine	Grain	RUK yields reach levels of other countries with similar climatic	Max Potential of land use in RUK 82 Mha (19 Mha in Kazakhstan, 47 Mha in Russia, 17 Mha in Ukraine)	Max yield potential 2.8 tons/ha on average in RUK (1.56 tons/ha in Kazakhstan, 2.70 tons/ha in Russia, 4.5 tons/ha in Ukraine)	Max potential of grain production 230 Mtons in RUK (29 Mtons in Kazakhstan, 126 Mtons in Russia, 75 Mtons in Ukraine)	n.a
IKAR (from EBDR/FAO 2008)	Russia, Kazakhstan, Ukraine	Grain	2004-2006	Max potential of land use in RUK 80 Mha (17.5 Mha in Kazakhstan, 46.5 Mha in Russia, 16 Mha in Ukraine)	Max yield potential 2.05 tons/ha on average in RUK (1.27 tons/ha in Kazakhstan, 2.11 tons/ha in Russia, 2.75 tons/ha	Max potential of grain production 164 Mtons in RUK (22 Mtons in Kazakhstan, 98 Mtons in Russia, 44 Mtons in Ukraine)	2016/2017
Fischer et al. (2012) (cited in EU Comission 2015)	Russia, Kazakhstan, Ukraine	Crops	1961-1990	Assuming land use remains constant	and potential grain yields is 10-40 %, 25-40 % gap in wheat yields	Wheat production could be increased by 30-60 % of current prod level	n.a
Meyfroidt et al. (2016)	Russia, Kazakhstan, Ukraine	Cropland and wheat	Croplands abandoned after 1991 and yields between 2004-	8.5 Mha of potentially available cropland among 47.3 Mha of abandoned cropland investigated	n.a	Increase in wheat production by 9.9 (6.6-12.4) Mtons in Russia, 5.9 (3.3-10.9) Mtons in North Kazakhstan and 2.5 (1.8-3.4)	n.a
Schierhorn et al. (2014)	Russia	Wheat	Average wheat yileds between 1995 and 200	Assume that out of 27.2 Mha of abandoned cropland 9.5 Mha of cropland could be recultivated due to lower carbon emissions. Yet only 4.4 Mha would be available for recultivation with wheat.	Assume that the wheat yields on the currently cultivated croplands and on abandoned croplands increase to 60 % and to 80% of the yield potential under rainfed	Based on the assumptions about crop land expansion and yield increase, authors project additional production potentials for wheat in the range of 9–32 Mtons	n.a
Uzun et al. (2013), Saraykin et al. (2016)	Russia	Cropland, wheat, livestock	2009-2011	Maximum grain area expantion posibility in Russia is 24 Mha	Crop yields are expected to increase by factors of 1.3-1.6 for all crops.	The estimated increase in grain production of 40 Mtons	2018-2020
Liefert and Liefert (2015)	Russia	Grain area	Regional production costs data during the late Soviet period	The economic potential for Russia to expand grain area is low, Grain prices would have to more than double to cover the high marginal	n.a	n.a	n.a

Fieldsend (2014) (cited in EU Comission 2015)	Kazakhstan	Wheat	n.a	Area harvested will increase by 4 %	Yields are expected to increase from 1.13 tons/ha to 1.24 tons/ha	wheat production is expected to increase from around 18 Mt currently to 19.5 Mt	2023/24
Kraemer et al. (2015)	North Kazakhstan	Cropland	1990-2000-2010	Little potential for cropland expansion because of remaining idle lands' low suitability for crop production. Only one third of 14 Mha of abandoned croplands can be	n.a	n.a	n.a
Lyuri et al. (2008)	Russia	Cropland	1990-2003	44 Mha of abandoned cropland, including reduction in clean fallowing (part of crop rotation	n.a	n.a	n.a
Nefedova (2016)	Russia	Cropland and wheat	1985-2014	42 Mha of cropland abandoned by 2014. Roughly 20 Mha available for grain/ wheat production	n.a	n.a	n.a
RF Ministry of Economic Development,(2014)	Russia	Cropland and wheat	1990-2014	56 Mha of abandoned croplans	n.a	n.a	n.a
Altuhov (2013), RF Ministry of Agriculture (2013)	Russia	Cropland and wheat	1990-2014	57 Mha of abandoned croplans, should be recultivated for wheat prodution 3.5 Mha	n.a	n.a	n.a

Do account for climate change

Study	Geographic coverage	Commodity	Baseline	Predicted growth/fall in Land use	Predicted growth/fall in Yields	Predicted growth/fall in Output	Time horizon
Fischer (2009)	Global	Cereals, biofuels	2000	Rain-fed wheat production potential of current cultivated land in Central Asia, Europe, and Russia is increasing. Although the net global balance is projected to be a reduction of production potential by	The impacts of climate change on crop yields and production could become severe in the second half of this century.	Production potential for cereals will not be negatively affected by climate change until 2050. Negative effect are projected during the half of the century due to negative impact on yields.	2000-2080
Eitzinger et al. (2012)	CEE; case studies Czech Rep and Slovakia	Crops	Baseline period 1961–1990	n.a	Positive trend for crop yields (wheat, barley rye) until 2050 (exact numbers are not	n.a	2050
Sutton et al. (2013)	ECA & cases: Moldova, Albania, Macedonia and Uzbekistan	Crops		n.a	Yield decline for most crops (maize, wheat, apples, grapes, vegetables/tomatoes). Longer and warmer growing seasons for crops grown in winter (winter wheat), alfalfa or	n.a	2050
Lioubimtseva and Henebry (2009)	Arid and Semi arid Central Asia	Climatic and land cover trends	Baseline climatology for the period 1961–1990	n.a	Increased aridity in Central Asia (Turkmenistan, Uzbekistan and Kazakhstan). Temperature increases during summer and fall, decrease in precipitation.	n.a	2050
Sommer (2013)	Central Asia	Wheat	1961–1990	n.a	On average increase in grain yields by 12 % (from 1.75 tons/ha of historical average to	n.a	n.a