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Grain potentials on abandoned cropland in European Russia

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Abstract

Widespread abandoned cropland suggests ample scope for increasing grain production in Russia. However, sound estimates of future grain production and export potentials of Russia are missing. We estimated climate-adjusted grain yields that represent average yields of non-drought years in the post-soviet period. We then utilized a cropland abandonment map, a spatial allocation model and the climate-adjusted grain yields to estimate potential future grain production from recultivation. We assume that recultivation starts with the most recently abandoned plots where the carbon stocks in the successional vegetation and soils are lower. The recultivation of the eight million ha that were abandoned since 2001 results in a potential production increase of 11.4 million t of grain at likely moderate CO_2 emission levels. If all 26 million ha of cropland abandoned since 1991 would be recultivated, approximately 42 million t of grain can be produced in addition to current production. The prospect for substantial increases in grain production with comparatively low carbon emissions suggest an important role for Russia in balancing the tradeoffs between securing global food production while avoiding dangerous climate impacts.

Keywords: Post-Soviet cropland change; agricultural abandonment; grain potentials; spatial model; Russia.

1. Introduction

The demand for agricultural products will increase substantially, driven by population growth, changing consumption pattern, climate change, and ambitious renewable energy targets (Foley, Monfreda, Ramankutty, & Zaks, 2007; Godfray et al., 2010). One strategy for increasing agricultural production is to expand cultivated areas, but most suitable arable land is already under cultivation (Ellis, Klein Goldewijk, Siebert, Lightman, & Ramankutty, 2010; Lambin & Meyfroidt, 2011; Ramankutty, Evan, Monfreda, & Foley, 2008; Ramankutty, Foley, Norman, & McSweeney, 2002) and the conversion of pristine land for agriculture, particularly in the tropics, comes at a substantial environmental cost because it threatens biodiversity and diminishes ecosystem services such as carbon sequestration (Foley et al., 2005; Post & Kwon, 2000; Stoate et al., 2009; Tilman, Cassman, Matson, Naylor, & Polasky, 2002; Tilman et al., 2001).

Cropland expansion can also involve the reclamation of previously cultivated but currently abandoned agricultural land. This is particularly promising in former Soviet Union countries where the transition to market economies triggered massive abandonment of agricultural land (Henebry, 2009). The vast unused land resources in combination with large crop yields gaps suggest considerable untapped agricultural production and export potentials (Lambin & Meyfroidt, 2011; W. Liefert, Liefert, Vocke, & Allen, 2010), which are important for enhancing global food production. Simultaneously, increasing global food prices elevate the economic incentives for investment in agricultural production and may cause the recultivation of abandoned agricultural land in this region. The recultivation of abandoned cropland in temperate Russia could also potentially compensate domestic grain production shortfalls as result of severe droughts. Particularly the southern breadbasket regions are confronted with an increasing intensity and frequency of droughts (Dronin & Kirilenko, 2011).

Recultivation requires investments for clearing the successional vegetation and these investments depend on the location and the amount of time elapsed since abandonment as well as on economic and institutional frameworks that effects the profitability of cultivation (Larsson & Nilsson, 2005; USDA, 2008). But abandoned land may store significant amounts of carbon depending on the biophysical characteristics and on the time since abandonment. Recultivation of abandoned lands with high accumulation of above and below ground carbon stocks can therefore lead to substantial greenhouse gas (GHG) emissions (Kurganova, Kudeyarov, & Lopes De Gerenyu, 2010; Vuichard, Ciais, Belelli, Smith, & Valentini, 2008; Vuichard, Ciais, & Wolf, 2009). Therefore, an assessment of the time since abandonment, the biophysical characteristics of the abandoned land, the current vegetation cover, and the economic barriers to recultivation is important to identify areas where recultivation causes comparatively low GHG emissions.

High grain production and export potentials were estimated by the Food and Agricultural Organization and the European Bank for Reconstruction and Development (FAO/EBRD, 2008). Significant increases of grain production and export volumes were also forecasted by the United States Department of Agriculture (W. Liefert et al., 2010) and the Organization for Economic Co-operation and Development (OECD-FAO, 2010). Similarly, increasing production and export volumes were also projected by the Russian Ministry of Agriculture and the Russian Institute for the Agrarian Market (Rau, 2012). In contrast to this, a stagnation in the Russian grain sector until 2025/26 was recently projected by the Food and Agricultural Policy Research Institute (FAPRI-ISU, 2011). However, all the reports neglect the location of abandoned agricultural land and the related recultivation potentials. We presume the large variation in these estimates is partly due to the incomplete and unreliable datasets for the location of cropland abandonment. This is unfortunate given the highly heterogeneous pattern of cropland abandonment as well as of crop yields throughout the country. The lack of cropland abandonment maps, varying assumptions about the future cropland supply area, and highly deviating crop yield predictions are the most important factors for the deviating grain potential estimates in Russia (Table 1).

Table 1. Grain potentials and forecasts from different sources

Given this background, our principal goal was to improve the estimation of grain potentials on abandoned cropland in European Russia using spatially explicit data and modeling techniques. We limit the estimation on European Russia because the required input data were only consistently available for this part. Nevertheless, the bulk of the Russian grain potential on abandoned cropland is captured because almost 75% of the contemporary abandoned cropland in Russia is located in European Russia (ROSSTAT, 2010). We simulated the future cropland supply with a spatial allocation model that controls recultivation of abandoned croplands depending on the duration of cropland abandonment. We also mapped climate-adjusted grain yields that represent average yields of average non-drought years in the post-Soviet period and then assigned the climate-adjusted grain yields to each plot of recultivated cropland to estimate the grain potential on abandoned cropland.

2. Methodology and Data

2.1 Simulating Recultivation of Abandoned Cropland

Additional grain production can originate from an expansion of grain acreage or from an enhancement of land productivity. This article concentrates on grain potentials based on scenarios of the recultivation of abandoned cropland and ignores increases in agricultural productivity, e.g., through technological progress. For estimating grain potentials on abandoned cropland we used a spatial allocation model that was developed to generate yearly cropland maps for post-Soviet European Russia, Ukraine, and Belarus (Schierhorn, Müller, Prishchepov, & Balmann, *in review*). For European Russia, the spatial allocation model used primary statistics on cultivated areas from the national statistical office that were available for 52 provinces (oblasts) and for the years from 1990 to 2009 (ROSSTAT, 2010). A validation with Landsat TM/ETM+ classifications showed that these statistical data well represent post-soviet cultivated areas (Prishchepov, Radeloff, Dubinin, & Alcantara, *in review*). Based on the cropland abandonment data the model starts recultivation with the most recently abandoned grid cells and subsequently integrates older abandoned fields. It thus respects the accumulation of carbon stocks above and below ground over time as well as the increasing microeconomic costs of recultivation due to the penetration of roots and the establishment of woody vegetation on abandoned plots (Vuichard et al., 2008). The yearly cropland maps therefore allow estimating both the location and the duration of cropland abandonment.

We then assigned the climate-adjusted and averaged grain yields (see following section 2.2) from each district to each plot of recultivated cropland to estimate the grain potential on abandoned cropland. We exclusively considered grain crops as potential cultivars for the abandoned croplands. Using crop specific coefficients the grain potentials presented in this article can be translated into other crop potentials. In sum, our approach facilitates the assessment of the grain potential in the study area as well as the analysis of grain potentials as a function of the age of the abandoned cropland to be recultivated.

2.2 Post-Soviet and Climate-Adjusted Grain Yields

The climate of the most important Russian agricultural regions, particularly the black soil regions, is characterized by variable temperature and rainfall, but is affected by severe drought risks (W. Liefert et al., 2010)). Several years with adverse weather conditions in the first decade after the collapse of the Soviet Union was one important driver for the large fluctuations in annual grain output and grain exports during this period (FAO, 2010; ROSSTAT, 2010). In turn, the steady increase of grain production after 2000, along with advancements in the production efficiency, was mainly caused by better climate conditions during this period (except in the drought year of 2010). We estimated grain yields on current abandoned croplands that represent the cropping productivity of the post-Soviet period excluding the years with climate-driven anomalies during the growing season.

We obtained grain yield data for 1,387 districts (*rayons*, comparable to US counties or the Nomenclature of Territorial Units for Statistics (NUTS) 3 of the EU) for several years between 1990 and 2009 (www.radford.edu/~agrorus/index.htm). To determine drought years, we calculated the Hydrothermal Coefficient (HTC) during the summer seasons at the district level for all the years where grain yields were reported. The HTC is the sum of precipitation in the growing season multiplied by 10 and divided by the sum of the daily average temperatures within the growing period (Dronin & Kirilenko, 2008). The growing period is defined as the period with daily temperatures above 10°C. The HTC typically ranges between 0.4 and 2, and an HTC below 0.7 exhibits drought conditions during the growing season (Dronin & Kirilenko, 2008). To estimate the yearly HTC, we used daily gridded precipitation and maximum temperature data at a half-degree spatial resolution (Schuol & Abbaspour, 2007) and computed the area-weighted mean at the district level. The grain yields from years with non-drought conditions (HTC above 0.7) were then averaged to obtain an estimate of climate-adjusted grain yields for the post-Soviet period (Figure 1).

 # Figure 1. Climate-adjusted grain yields #

3. Study Area

European Russia stretches across 4 million square kilometers. Agro-climatic patterns shape the agricultural activities and the productivity of cropping throughout the study region (Ioffe & Nefedova, 2004). Natural conditions exhibit a strong north-south gradient. In most parts of northern European Russia the conditions for cropping are poor to moderate, because of widespread infertile soils and a short growing season (Alcamo, Dronin, Endejan, Golubev, & Kirilenko, 2007; Dronin & Kirilenko, 2008). Climate conditions become gradually more appropriate for agricultural production towards southern European Russia. The average daily temperatures increase and the growing season is longer. Moreover, soil conditions improve towards the south since the fertile black soils (Chernozem) increasingly prevail. The improvement in agro-climatic conditions from north to south is mirrored in higher average crop yields (Figure 1) and a higher share of cropland at lower latitudes (ROSSTAT, 2010). Yet, a stable anticyclone circulation in the southern part of European Russia with dry air during summer periodically results in severe droughts. Over the 20th century major droughts occurred in southern Russia at least 27 times (Meshcherskaya & Blazhevich, 1997). That is, every fourth year is statistically affected by severe weather constraints and shortfalls in food production as a consequence of droughts regularly occur (Alcamo et al., 2007). The high drought risk is also of global relevance because of the importance of this region for agricultural world markets.

4. Results

Abandoned cropland and surplus grain production potentials are clustered in the northern parts of European Russia, but also in the southern and central regions along a northwest-southeast precipitation gradient with a spatial concentration in the steppe region at the border with Kazakhstan (Figure 2). The central and southern regions that enjoy favorable soil and climatic properties have few areas of abandoned cropland. It is also important to note that almost 70% of cropland abandonment in the study area occurred within the first 10 years of the transition from a state-command to a market-driven economy. After 2000, cropland abandonment significantly slowed, particularly in the productive agricultural areas in southern Russia. In contrast, cropland abandonment has continued unabated after 2000 in the northern part of European Russia, but at lesser pace than in the first decade of the transition (Schierhorn et al., *in review*).

 # Figure 2. Distribution of cropland (left) and abandoned cropland (right) #

We utilized the cropland abandonment map for 2009 and our spatial allocation model for the estimation of grain potentials on abandoned cropland. In general, more recently abandoned cropland sequestered lower amounts of carbon than plots that were abandoned longer ago (Post & Kwon, 2000) and are more difficult to be reverted back to cultivation. We therefore started with an assessment of recultivating the 9.6 million ha of abandoned cropland, which have not been farmed since 2001. Under this scenario 11.4 million t of additional grain production is attainable (Figure 3). However, this is only 27% of the grain potential on the total 26 million ha abandoned cropland in European Russia although 37% of the total abandoned cropland was included in this scenario. Available areas for recultivation under this scenario are mainly located in the northern and temperate regions of the study area, where medium to low grain yields prevail on abandoned land (Figure 3). Nevertheless, the 11.4 million t of additional grain is equivalent to Russia's export volume of wheat in 2008 (FAO, 2010) and is likely attainable at comparatively low ecological and economical costs. More grain potentials on abandoned cropland likely existent in Asian Russia. The spatial distribution and the scale of the grain potentials are depicted in the Figure 4.

 # Figure 3. Grain potential on abandoned cropland #

Grain potentials increase exponentially if older abandoned cropland plots are sequentially recultivated stepwise (Figure 3). The inclusion of older abandoned cropland plot also results in in the recultivation of more productive plots, mainly in southern parts of Russia (Figure 1). A complete recultivation of cropland abandoned since 1991 (26 million ha) can potentially generate an additional yields output of approximately 42 million t. This is more than the 2009 combined grain exports volumes of Russia and the United States in 2009, the world's top wheat export countries.

 # Figure 4. Grain potentials on abandoned land at the district level #

5. Discussion

We presented the first spatially explicit assessment of grain potentials on abandoned agricultural in European Russia. The improvement in the estimation of potential additional grain output was achieved with the utilization of the best available agricultural statistics for cultivated areas and te combination with a spatial allocation model that enabled to approximate grain potentials as a function of the age of the abandoned cropland plots.

The recultivation of the ~9.6 million ha of cropland abandoned since 2001 can increase Russia's grain production to approximately 106 million t, if grain production in 2009 is kept constant. This quantity is in the higher ranges of existing grain production forecasts (Table 1). The recultivation of all 26 million ha of abandoned cropland can elevate total grain production to 136.8 million t, which is significantly more than the maximum potential estimated by FAO and EBRD (2008). These estimates are conservative, because future yield increases as well as production increases on abandoned croplands in Asian Russia were not included in our assessment. The FAO/EBRD report assumed that 6 million ha of currently abandoned croplands will be returned to production. But the FAO/EBRD report is based on the FAO land resource statistics, which only reports a decline of arable land since 1990 of about 10 million hectares (FAO, 2010). However, remote sensing estimates and a literature review showed that the Russian statistics for cultivated areas from ROSSTAT (2010) are far more reliable than FAO data (Schierhorn et al., *in review*).The ROSSTAT data suggest that almost 40 million hectares of cropland have been abandoned since 1990 in entire Russia (ROSSTAT, 2010). Analysts from the USDA Foreign Agricultural Service estimated the recultivation potential of abandoned cropland for up to 10 million ha. The former Russian Minister of Agriculture, Alexey Gordeyev, assumed that even 20 to 25 million ha can be recultivated (AGRA-EUROPE, 2007). Both assessments confirm our findings that the recultivation scenario implemented in the FAO/EBRD report is too conservative.

Most cropland abandonment already occurred at the onset of the post-Soviet period, and these areas most likely already sequestered large amounts of carbon in the successional vegetation (Kuemmerle et al., 2011; Kurganova et al., 2010; Vuichard et al., 2008). Hence, the recultivation of 26 million ha of abandoned cropland in European Russia would be associated with high carbon emissions and therefore jeopardize climate change mitigation strategies. However, our allocation model considers only the timing of the cropland abandonment to control the recultivation, but does not spatially differentiate among the multitude of succession dynamics throughout the study area. It is possible that some older abandoned agricultural plots particularly in the southern parts of European, the central Volga Valley, and western Siberia are still suitable for recultivation in terms of the management costs and the ecological footprint, because the intensity of successional regrowth is likely lower (USDA-FAS, 2008).

We adjusted grain yields to climatic anomalies during the post-Soviet period. We considered the climate-adjusted grain yields as a suitable proxy for agricultural productivity levels on abandoned cropland. However, in the mid- to the long-term, habitual grain yields will not adequately capture future crop yields in the study area. For instance, the effect of climate change in the important breadbaskets of Southern Russia may exert considerable pressures on future crop yields (Alcamo et al., 2007; Dronin & Kirilenko, 2008).

Russia has not yet reached the capacity to realize the untapped agricultural production and export potential. At present, major bottlenecks exist in grain handling and storage facilities, transportation infrastructure, and port capacities (FAO/EBRD, 2008; Rau, 2012). For example, the deficit in elevator capacities may reach 33 million t in the short term if the Russian grain production will increase to 120 million t per year (Rau, 2012). However, food security has already been declared by the Russian Government a national priority and the high political interest to decrease the domestic food dependency culminated in a Doctrine of Food Security for the Russian Federation (Wegren, 2011). Hence, the Russian Government currently attempts to remove structural bottlenecks that still curb agricultural growth. This is an urgent task, because the environmental and economic costs of recultivation increase steadily with longer fallow periods. Such policies are not only of national interest to cash in on the opportunities from agricultural exports, but are also globally relevant to increase the supply of agricultural products.

Future research should focus on the conditions that are necessary to increase crop production. These include the economic and political frameworks that are necessary to attract long-term investments in agricultural production. Moreover, spatially explicit and process driven models are required to better assess the trade-offs between additional crop production and the greenhouse gas emissions from recultivation of abandoned lands. Moreover, such tradeoff analysis would also benefit from the identification of areas with exceptional values of biodiversity that may warrant the exclusion from the pool of land available for recultivation. Hence, the identification of sustainable production potentials needs to go far beyond a mere mapping and assessment of potential recultivation and yield increases. Spatially explicit and interdisciplinary research is required in order to identify sustainable pathways to increasing the supply of agricultural products in this globally important agricultural region at low environmental costs. The, Russia has great potential to contribute to global food security and to release the pressure on natural resources elsewhere.

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Tables

	Wheat; Production	Barley; Production	Maize (corn); Production	Coarse grain; Production	Grain total; Production	Grain total; Export	Yield changes considered Yes/no	Abandoned cropland considered Yes/no
OECD-FAO Outlook (2010)	66543			38709	105252	28357	no	no
FAPRI (2011)	59954	20171	4919				no	no
Liefert et al. (2009)	69857	19408	6016		95281	31558	yes	Yes; Wheat area grow of 2.6 mio ha until 2019/20
Russian Ministry of Agriculture 2020					120000-130000	30000-40000	?	?
Russian Institute for the Agrarian Market, in 2019					125000	45000-50000		?
FAO and EBRD (2008) *2016/2017*					98000		yes	Yes; Grain area grow of 5.8 mio ha until 2016/2017
FAO and EBRD (2008) *Max. potential*					126000		yes	Yes, Grain area grow of 6 mio ha

Table 1. Grain potential estimates and forecasts from different sources. Thousand Metric Tons.

Figures

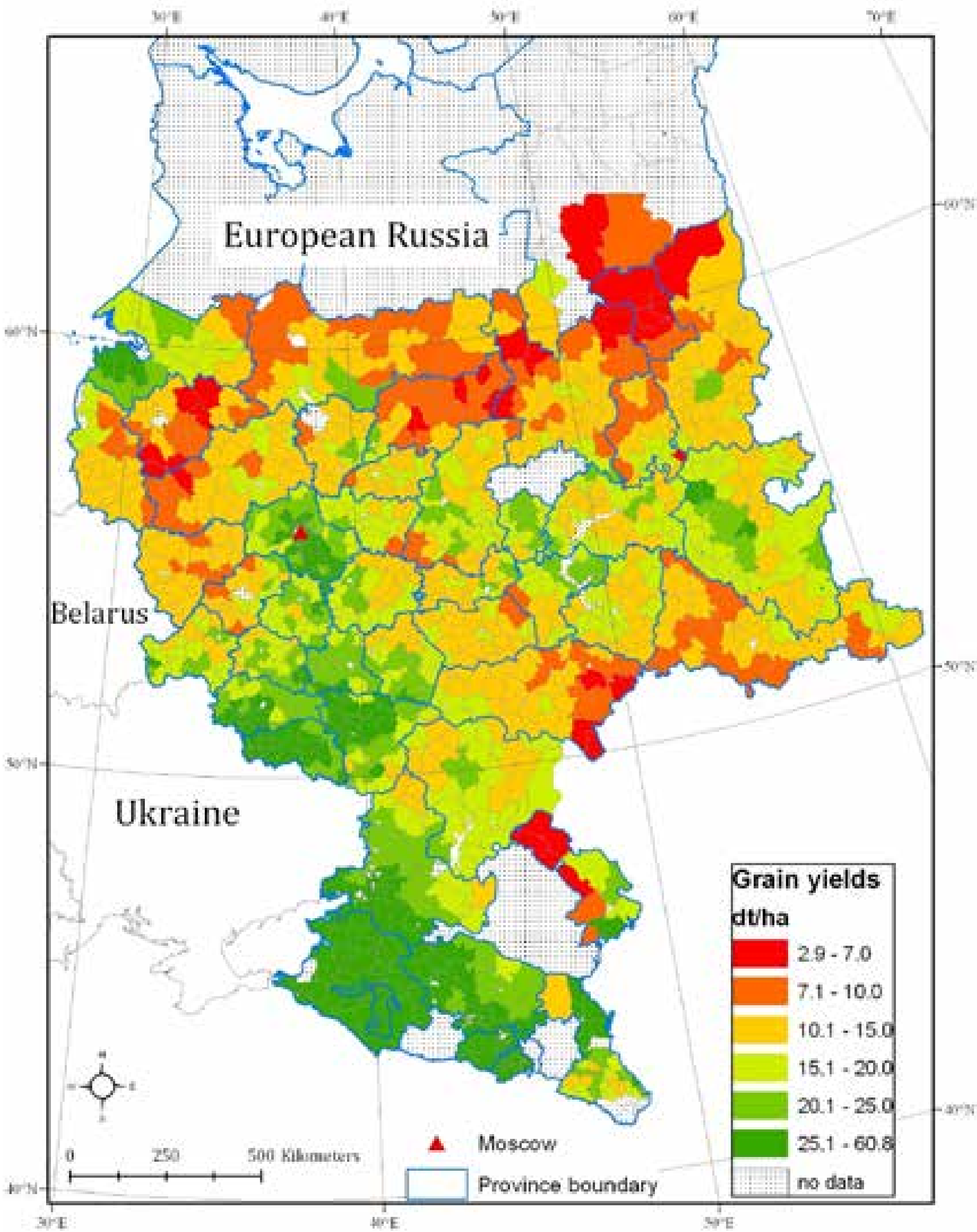

Figure 1. Climate-adjusted grain yields

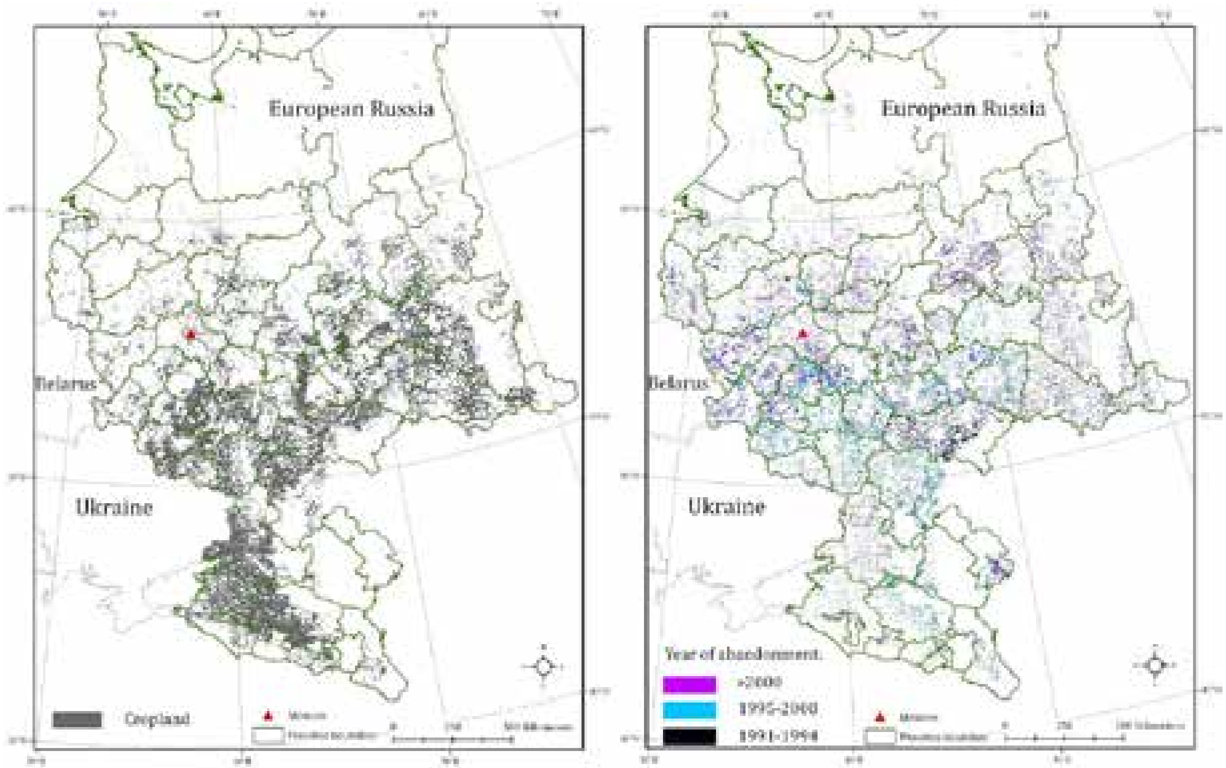

Figure 2. Distribution of cropland (left) and abandoned cropland (right). The cropland map (left) represents cropland in 2009 for European Russia. Colors indicate the duration of cropland abandonment (right) from 1990 to 2009. Yearly cropland and cropland abandonment maps are available from the authors upon request.

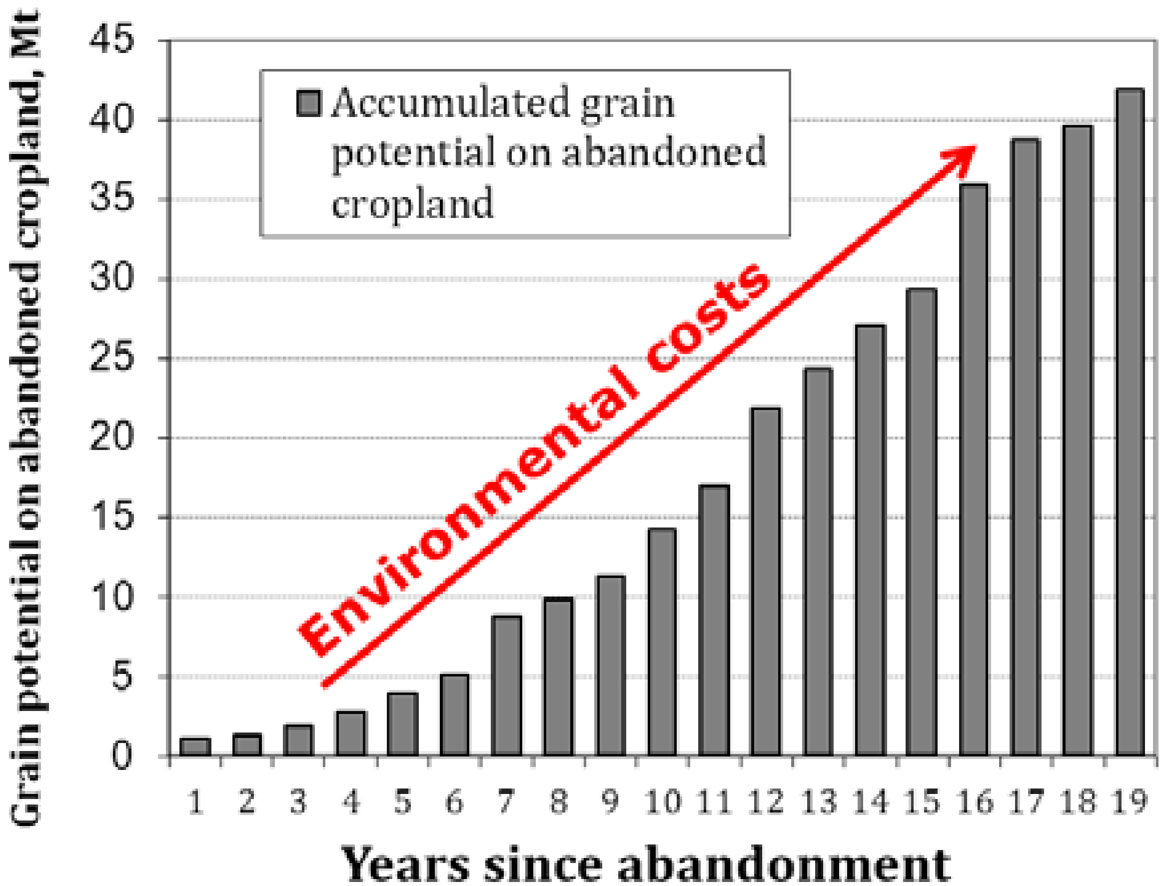

Figure 3. Grain potential on abandoned cropland. See text for the explanation of the Figure.

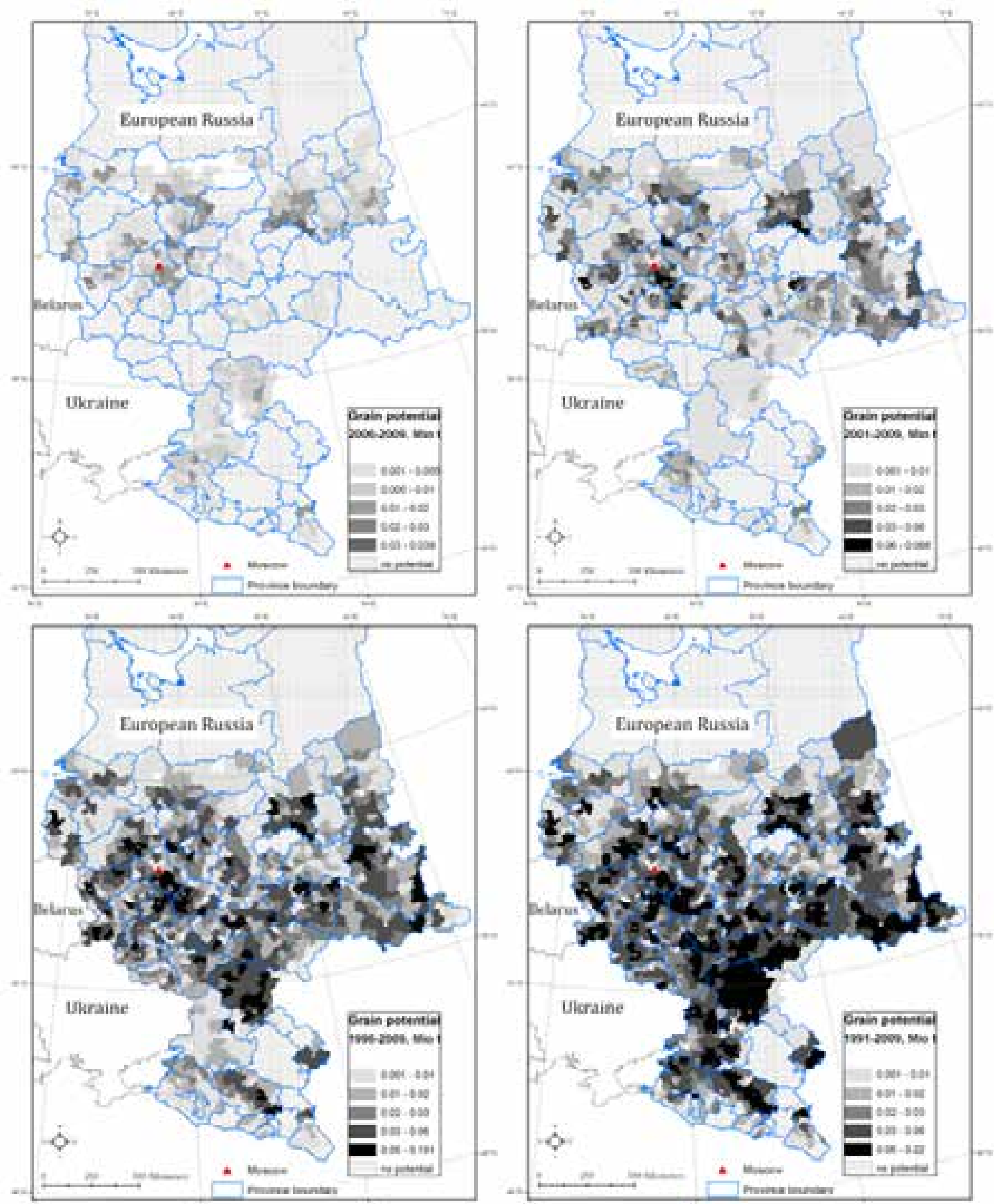

Figure 4. Grain potentials on abandoned land at district level. Grain potentials are calculated by recultivation of plots which were abandoned from 2006 to 2009 (top left), from 2001 to 2009 (top right), from 1996 to 2009 (bottom left), and 1991 and 2009 (bottom right).