Crop production potentials in Russia and Ukraine – intensification versus cropland expansion

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Abstract

Russia and Ukraine are countries with large untapped agricultural potentials, both in terms of abandoned agricultural land and low yields. In this study, we apply a global economic agricultural sector model to provide a comprehensive analysis of different scenarios, simulating the utilization of different crop production potentials in Russia and Ukraine and their impacts on a regional and global scale. Our results show that substantial potentials in crop production do exist and that large parts of the additional production would be exported to world markets. Production potentials due to intensification are higher than potentials due to re-cultivation of abandoned land.

Keywords: *abandoned land, yield potentials, Russia, Ukraine, agricultural sector model*

1. Introduction

Global population and consumption levels, and consequently global food demand, are expected to increase substantially in the coming decades (Godfray et al., 2010; Tilman et al., 2011). Furthermore, the recent striving of many countries towards a transformation to "bio-based economies" indicates a growing competition for biomass for food, feed, fibre and fuel production purposes (Lewandowski, 2015).

These prospects have caused a discussion about how additional agricultural production can be facilitated in a sustainable way. The utilization of idle agricultural potentials is one identified option. On the one hand, agricultural production may be intensified, since many regions face large yield gaps, which means that only relatively low yields are currently achieved compared to potentially attainable yields (Godfray et al., 2010, Mueller et al., 2012). On the other hand, some potentially available cropland with low environmental or social trade-offs still exists at the global scale, which could be taken into production (Lambin et al., 2013).

Russia and Ukraine are countries with relatively large untapped agricultural potentials. After the collapse of the Soviet Union, during the 1990s, the agricultural sectors of former Soviet countries were suddenly faced with increasing international competition, while at the same time input- and output-subsides were drastically reduced, which lead to strong declines in land use and average yields (Nefedova, 2011, Schierhorn et al., 2014a; Ryabchenko and Nonhebel, 2016).

Despite recent re-cultivation trends, vast amounts of abandoned croplands are still frequently reported (Meyfroidt et al., 2016; Smaliychuk et al., 2016, Lambin et al., 2013; Schierhorn et al, 2013). Also yields increased again during the 2000s, but yield gaps in Russia and Ukraine remain significant, mainly due to limitations in nutrient and water application (Schierhorn et al., 2014b, Mueller et al., 2012).

To exploit the existing agricultural potentials in Russia and Ukraine, higher investments in the physical infrastructure are required (Liefert et al., 2013; Smaliychuk et al., 2016). Additionally, several institutional shortcomings hamper private investments and prevent an increase in productivity (Schierhorn et al., 2014a; Nizalov et al., 2015; Meyfroidt et al., 2016).

In the literature, several studies quantify existing yield gaps or the amount of available abandoned land for potential re-cultivation, but only a few studies quantify potentials of the region in terms of commodity production. Wheat production potentials for example are calculated by Schierhorn et al. (2014a) for Russia and by Ryabchanko and Nonhebel (2016) for Ukraine, taking land and yield potentials into account. An analysis of production potentials of rapeseed-based biofuels in Ukraine is provided by Schaffartzik et al. (2014).

The study at hand, to our best knowledge, is the first study applying a global economic agricultural sector model to provide a comprehensive analysis of different scenarios, simulating the utilization of different crop production potentials in Russia and Ukraine and their impacts on a regional as well as global scale. The underlying idea is to simulate a removal of institutional and investment obstacles and compare the impact of such a development to a business as usual development. To this end, we introduce spatially explicit datasets on abandoned land and crop yield potentials into the global agricultural sector model GLOBIOM.

2. Model and data

2.1. GLOBIOM – general structure

The Global Biosphere Management Model (GLOBIOM, Havlík et al., 2014) is a global recursive dynamic bottom-up partial equilibrium model integrating the agricultural, bioenergy and forestry sectors. It is a linear programming model with a spatial equilibrium approach (Takayama and Judge, 1973). An agricultural and forest market equilibrium is computed, based on a welfare maximizing objective function subject to resource, technology, demand and policy constraints. For the paper at hand, Russia and Ukraine are represented as single regions, in addition to 30 other regions either representing large single countries or country aggregates. GLOBIOM is calibrated to FAOSTAT data for the year 2000 (average 1998 - 2002) and runs recursively dynamic in 10-year time-steps.

On the supply side, the model is built on a spatially explicit, bottom-up setting. The basis is a detailed disaggregation of land into Simulation Units – clusters of 5 arcmin pixels belonging to the same country, altitude, slope and soil class and to the same 0.5° x 0.5° pixel (Skalský et al., 2008). In the model version applied for the work at hand, simulation units are re-aggregated to 2° x 2° degree cells disaggregated by country boundaries and by three agro-ecological zones. Production technologies are specified for each spatial land unit through Leontief production functions, which imply fixed input – output ratios.

Regarding crop production, GLOBIOM represents globally 18 major crops[1] and 4 different management systems simulated by the biophysical process based crop model EPIC (Williams, 1995; Izaurralde et al., 2006). The livestock sector component of the model considers 8 different animal groups[2] and 4 production systems. The parameterization of livestock production relies on a dataset by Herrero et al. (2013).

On the demand side, a representative consumer is modelled for each region. Food demand projections are determined by exogenously introduced population and income growth rates as well as endogenously represented reactions on price changes.

[1] Barley, beans, cassava, chickpeas, corn, cotton, groundnut, millet, palm oil, potato, rapeseed, rice, soybean, sorghum, sugarcane, sunflower, sweet potato, wheat.

[2] Bovine dairy and meat herds, sheep and goat dairy and meat herds, poultry broilers, poultry laying hens, mixed poultry and pigs.

2.2. Abandoned land

To explicitly implement abandoned land into GLOBIOM, we refer to the existing abandoned land in Russia and Ukraine as estimated in Schepaschenko et al. (2015) on a 300 m resolution level, integrating different land cover maps as well as official statistical data on land use (Figure 1). For Russia and Ukraine a total of 31.2 and 2.6 Mio. ha (Million hectare) are estimated, respectively. Abandoned agricultural land is defined as land that has been under production in 1990 and was abandoned for more than 5 years until 2008-2012.

The identified abandoned land is integrated into GLOBIOM as an own land use category. Before, cropland extension in Russia and Ukraine could be sourced from grassland and other natural vegetation[3]. The new land cover class "abandoned land" now facilitates scenario simulations of better accessibility of abandoned land in Russian and Ukraine due to potential future improvements of institutional settings and infrastructural investments.

2.3. Yield potentials and high-input systems

For the implementation of intensification potentials in the economic model, as a first step, bio-physical crop yield potentials and their respective input requirements for major staple crops in Russia and the Ukraine were estimated with the global gridded crop model based on EPIC (Balkovič et al. 2014). A spatially explicit analysis was conducted to generate rain-fed (water-limited) yield potentials and irrigated (climatic) yield potentials. The (climatic) yield potentials reflect yields simulated for a crop cultivar when water and nutrients are not limiting while other biotic stresses are not considered. The potentials are estimated for historical climate of 2000–2010 assuming the present-day distribution of crops.

On the one hand, yield potentials are a theoretical concept and it has been observed that yields hardly exceed 80% of their estimated potential yields (Lobell et al., 2009). On the other hand, experience shows that EPIC tends to underestimate yields at higher yield levels (Balkovič et al., 2013, 2014) due to underrepresenting the high-performing cultivars in advanced agricultural systems. For the work at hand, we assume that both effects compensate each other and thus, we apply 100% of the estimated EPIC yields for our high-input systems.

We compare our yield assumptions to attainable yield potentials as estimated by Mueller et al. (2012) (Figure 2). Their estimates rely on the assumption that the highest yields observed in a region with a specific climate is a good proxy for the maximum attainable yield for all other regions with a similar climate. In general, our yield potentials are similar to the attainable yields of Mueller et al. (2012).

Based on our EPIC estimates, new "high-input" production systems are implemented into GLOBIOM by the combination of yields and inputs with corresponding, spatially explicit production costs. The production costs for the new high-input production systems have been provided by the IIASA AgriCostModel (ACM). ACM calculates production costs for different crops and management systems at the spatial resolution level of the GLOBIOM model.

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[3] Also deforestation in principle is an option for the generation of new cropland, however, in the paper at hand, we restrain from that option.

To simulate costs in a geographically explicit way, a detailed cost analysis for several reference locations was conducted at first, to identify cost parts and drivers. Direct and overhead costs are analyzed to determine input amounts and prices[4]. Subsequently, cost items are extrapolated to the grid cell. For every grid cell, yields, fertilization rates and irrigation rates are given by EPIC. For cost components which are not covered by EPIC, an intensification factor is applied to reflect that costs per hectare increase with increasing intensification.

High-input production systems are defined for wheat, barley, corn, rapeseed, sunflower, soybeans and potato production, which together represent 80% of the area harvested in Russia and 90% in Ukraine, respectively (FAO, 2016).

3. *Scenario description, assumptions and quantification*

With the described model and model extensions, we run several scenarios, reflecting different investment and institution development efforts. These scenarios are compared to a reference scenario which reflects future developments without these additional efforts, the so-called baseline.

For the baseline scenario, we refer to the Shared Socio-economic Pathway 2 (SSP2) scenario which is a middle-of the-road scenario (O'Neill et al., 2014) and often serves as a baseline in GLOBIOM (a detailed description is presented in Herrero et al., 2014). For biofuel demand, we refer to OECD/FAO (2015). Furthermore, we assume that 0.6 Mil. ha of the identified abandoned land are converted to cropland in Ukraine as well as in Russia for the baseline. Other additional cropland can be sourced from natural land or grassland, while deforestation is prohibited.

3.1. *Re-cultivation of abandoned land*

The under 2.2 identified abandoned land refers to land that has already been under production in Soviet times and at least parts of it can potentially be taken back into production. However, it is clear that several constraints for the uptake of abandoned land exist and that re-cultivation of some land can be associated with high trade-offs (Meyfroidt et al., 2016; Kurganova et al., 2015; Schierhorn et al., 2013).

Thus, we specify two scenarios with different levels of re-cultivation attempts of abandoned land. For the definition of a more conservative scenario ('*CONS*') that sets a relatively small share of the abandoned land as de facto available, we refer to Meyfroidt et al. (2016). In their paper, they categorize abandoned cropland in Russia and Ukraine according to the strengths of different constraints (socioeconomic, accessibility, agro-environmental) and also define land that is connected to high-environmental trade-offs. Out of 31.4 Mil. ha total abandoned land in Russia and 2.6 Mil. ha in the Ukraine, they specify 5.3 Mil. ha and 0.9 Mil. ha, respectively, as potentially available cropland with no strong trade-offs, low socio-economic and accessibility constraints and good agro-environmental conditions. We calibrate the GLOBIOM model to re-cultivate the potentially available cropland as identified by Meyfroidt et al. by 2030. To this end, the land-conversion function in GLOBIOM is

[4] Nitrogen Input, phosphor input, Irrigation, seeds, fuel consumption to execute all field activities, labor requirement, cost (prices) of other fertilization, cost of plant protection, cost of financing, cost of other field activities (including machinery costs), cost of infrastructure (farm buildings & other immovable assets).

parameterized accordingly. When land is re-cultivated the assumption is that productivity is the same as in the already existing neighboring cropland.

For the more advanced scenario (‘*ADV*’), we assume a higher rate of re-cultivated abandoned land until 2030 and calibrate the land-conversion function of the model accordingly. In Russia 9.5 out of 31.2 Mil. ha are assumed to be re-cultivated and for the Ukraine 1.6 out of 2.6 Mil. ha. These figures are higher than the potentially available cropland as identified in the ‘*CONS*’ scenario, with the underlying assumption that some of the restraining constraints are being removed. Furthermore, at least for Russia, other studies estimate similar amounts of abandoned land with few constraints and no major trade-offs (Lambin et al. (2013): 8,7 Mil. ha; Schierhorn et al (2013): 9.5 Mil. ha).

3.2. Increasing yields due to high-input system application

The new high-input production systems (as developed in chapter 2.3) are activated to run investment scenarios until 2030. This means that the model can choose between the standard production systems from the baseline and the newly implemented high-input production systems for each grid cell, depending on the cost-effectiveness of the system. The uptake of irrigated high-input systems is restricted to areas where already irrigated production systems exist in the baseyear.

We run scenarios with two different intensification settings: in the first setting the high-input production systems as developed under 2.3 are implemented into the model (‘*YD100*’) while in the second setting production systems are implemented closing only 50% (‘*YD50*’) of the yield gap between the actual yields and the maximum attainable yields as defined for the high-input production systems. For the latter scenario we assume a linear relation between yields and input requirements.

Since we run scenarios up to the year 2030, some assumptions need to be made on the developments of yields over time. For our baseline scenario, exogenous yield growth shifters are applied, which are based on estimated yield response functions to GDP per capita for different income groups of countries (Havlík et al. 2012). These shifters represent a mixture of partly closing yield gaps and increasing yield potentials over time. Thus, growth rates for our estimated attainable potentials need to be adjusted to reflect only the increase that is coming from research and development. To this end, we assume that yields increase with the same rate that is applied for mid-western Europe in our baseline. The underlying assumption is that in mid-western Europe, nutrient-limitations have already been closed to a large extent and hence, estimated shifters capture the increase of yield potentials by research and development. Resulting potential yields for the year 2030 are presented in Figure 2.

3.3. Scenario combinations

It is likely that improved institutions and higher public investments in the agricultural sector would affect both, land use change and production system changes, at the same time. Thus, we combine our re-cultivation options and high-inputs production systems in the following way (Table 1), to reflect the uncertainty of the single assumptions on land use change and production systems, with the baseline being the reference scenario with no additional re-cultivation attempts and no implementation of high-input production systems.

		Re-cultivation options		
		NON	**CONS**	**ADV**
High-Input Production system scenarios	**100%**	***YD100***	***YD100_CONS***	***YD100_ADV***
	50%	***YD50***	***YD50_CONS***	***YD50_ADV***
	0%	***Baseline***	***LD_CONS***	***LD_ADV***

Table 1: Scenario combination.

4. Results

When looking at the results for cereals (barley, corn and wheat) production and trade as presented in Figure 3, we can see that the impact from intensification on the existing cropland is larger than the impact from re-cultivation of abandoned land. This effect can be observed for both countries but is more distinct in Ukraine – mostly because land reserves are higher in Russia than in Ukraine.

All scenarios have in common, that large shares of the additional production translate into net exports. Domestic consumption (including human consumption, feed demand, processing demand, seed demand) appears to be relatively stable. Yet, it has to be mentioned that in our scenarios, we do not change assumption on livestock productivity compared to the baseline. With an increasing productivity in the livestock sector, however, it is likely that more feed demand arises within Russia and Ukraine which in turn could increase domestic demand for crops and impact international livestock markets.

For the scenario with the strongest impacts (*YD100_ADV*), the full provision of the defined high-input systems and relatively easy access to abandoned land for re-cultivation is assumed. Compared to the baseline, cereal production increases from 163 Mt (million tons) in 2030 in Russia and the Ukraine to 279 Mt in the *YD100_ADV* scenario, which reflects a 70% increase. The domestic consumption increases by less than 20% of baseline levels, but net-export figures almost triple. In comparison to the baseline, common net exports of Ukraine and Russia increase by 93.6 Mt of barley, corn, and wheat, which represent 4.3% of the global production of these crops.

A similar result also can be observed for oilseed production and trade: In the *YD100_ADV* scenario, common net-exports of sunflower seeds, rapeseeds and soybeans increase by 17.6 Mt in 2030 compared to the baseline, which represents 3.75% of global production of these crops in 2030.

With increasing intensification, we also can observe some specialization effects. Russian cereal production increases by 75%, while Ukrainian cereal production increases by 46% in the strongest intensification scenario (*YD100*). A reverse picture arises for oilseed production impacts where Russian production increases by 46% and the Ukrainian production more than doubles, in comparison to oilseed production in the baseline.

Figure 4 shows the development of cropland use in Russia and Ukraine for the different scenarios. The overall bars indicate the total cropland use for different scenarios. The upper - dark green - part refers to abandoned land that has been re-cultivated since 2010 and is used as cropland in 2030. The amount of re-cultivated land in the baseline and the scenarios *LD_CONS* and *LD_ADV* reflects the calibrated re-cultivation assumptions as described in chapter 3.1.

For the two latter scenarios, we observe an increase in total cropland in comparison to the baseline, due to the better re-cultivation options, but at the same time also a reduction in other cropland. The mechanism behind this process is that with increasing production, prices decrease and production at some marginal areas is not profitable any longer. Thus, marginal cropland falls out of production and is substituted be re-cultivated abandoned land. Similar land use patterns can be observed when analyzing the impacts of better re-cultivation options on scenarios with higher yield per hectare[5].

Analyzing the impact of intensification, a land savings effect can be observed due to the introduction of high-input production systems. However, the land saving effects in *YD50* is very small, while the additional effect from *YD50* to *YD100* is much stronger. The mechanisms behind this result is, that in the model increasing marginal trade costs are assumed. Thus, when yields are increased only moderately (*YD50*), most of the additional production will be exported. However, with a strong increase of yields and respectively production in comparison to the baseline, marginal trade costs increase stronger and thus, additional production remains in the country and domestic commodity prices decrease more which leads to less extensions of cropland.

In Figure 5 global impacts of the scenarios are presented for the year 2030. The axis of ordinate shows global crop price impacts, which are displayed by a price index taking all endogenously calculated crop prices as a weighted average into account. The index is set to 1 for the year 2010 (since scenarios are only specified for the years 2020 and 2030). This means for the baseline, that global crop prices are on average 0.4% higher in 2030 than in 2010. At the axis of abscissae, the global cropland use is indicated. Global cropland refers to the sum of cropland that is used for production of endogenously represented crops in GLOBIOM.

At the global scale, results are in line with the regional scale: impacts from intensification measures are stronger than the impacts resulting from better access to land re-cultivation.

Globally observed land use effects from intensification are even stronger than in Russia and Ukraine, themselves. A cropland reduction of 0.66 Mh (2.85 Mh) in Russia and Ukraine for the *YD50* (*YD100*) scenario (compared to the baseline) translates globally into a reduction of 11.3 Mh (21.8 Mh) of cropland. This reflects that due to trade effects, marginal land with, on average, lower yields is set free from agricultural production in other regions. At the same time, additional production in Russia and Ukraine has also to compensate the additional demand that arises due to lower commodity prices.

Global price impacts show as well, that the strongest production gains arise in the intensification scenarios. Instead of a 0.4% increase of average crop prices compared to 2010, as shown for the baseline, the *YD100* scenario leads to a price drop of 3.2%. The *LD_ADV* scenario, in contrast, leads to a price drop of only 0.4%.

In contrary to the intensification scenarios, better re-cultivation options in Russia and Ukraine lead to an increasing land use at the global scale. However, the additional land use in Russia and Ukraine in the *LD_CONS* and *LD_ADV* scenarios is stronger than the global land use impacts, which indicates that some land is taken out of production in other regions of the world.

The impact of re-cultivation on global land use, however, is almost zero when high intensification is assumed in the background (i.e., *YD100_ADV* versus *YD_100*). Since we observe increasing land use in

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[5] I.e.: *YD50_COSN* and *YD50_ADV* in comparison to *YD50* and *YD100_COSN* and *YD100_ADV* in comparison to *YD100*.

Russia and Ukraine, this means that for every additional hectare in this region almost one hectare cropland is saved elsewhere.

5. Conclusion and Outlook

In this paper, we analyze the crop production potentials of Russia and Ukraine, which could be utilized with higher investments and institutional improvements in their agricultural sectors. In doing so, we take economic as well as bio-physical factors into account and provide impacts on a regional as well as global level.

Our results show that substantial potentials in crop production do exist in Russia and Ukraine and that large parts of the additional production would be exported to world markets. These results, however, are strongly related to the fact that we do not assume any changes in livestock production capacities or productivity in Russia and Ukraine. With an increasing capacity, it is likely that a larger share of crops would be used as inputs for animal production instead of being exported. As a consequence, impacts on world livestock markets would stronger. This scenario is not unlikely to happen, especially since recently more subsidies are directed to the livestock sectors in the region (see for example, Liefert and Liefert, 2012).

Our analysis reveals that production potentials due to intensification are higher than potentials due to re-cultivation of abandoned land. These findings correspond with findings of other studies (Schierhorn et al., 2014a; Ryabchenko and Nonhebel, 2016), which also report that cropland expansion is of less importance compared to higher land productivity. Consequently, we also find stronger impacts from intensification at the global scale. However, both, intensification and re-cultivation in Russia and Ukraine lead to decreasing crop prices and reduced land use in other parts of the world.

Finally, production and price effects of a certain scenario are determined by the interplay of supply and demand. In our paper, we do not exogenously alter our assumptions of the demand side, however, the endogenous effects show that on the global scale more production is provided to lower prices, which is an important finding from a food security perspective.

Our paper clearly answers a hypothetic what-if question, because within the given time frame until 2030, it is relatively unlikely that all major problems relating to the Russian and Ukrainian agricultural sectors can be solved. Nevertheless, the scope and direction of potential developments are plausible and indicate tendencies towards which direction Russia and Ukraine may be heading into the future.

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FIGURES

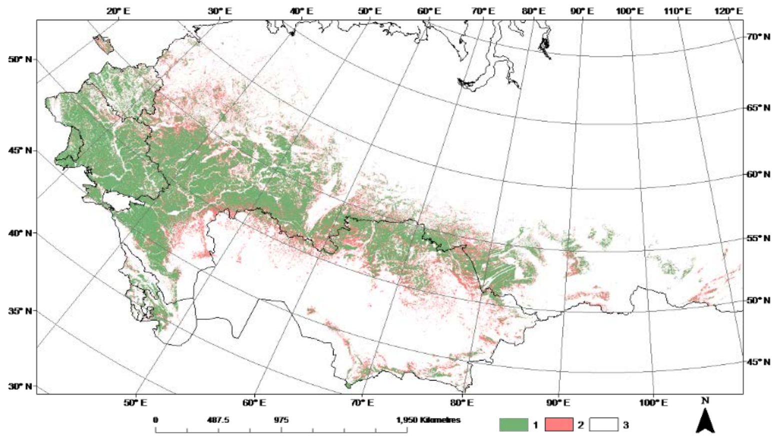

Figure 1: *A hybrid abandoned agricultural land map. Legend: (1) active cropland; (2) abandoned agricultural land; (3) other land cover/land use types.*

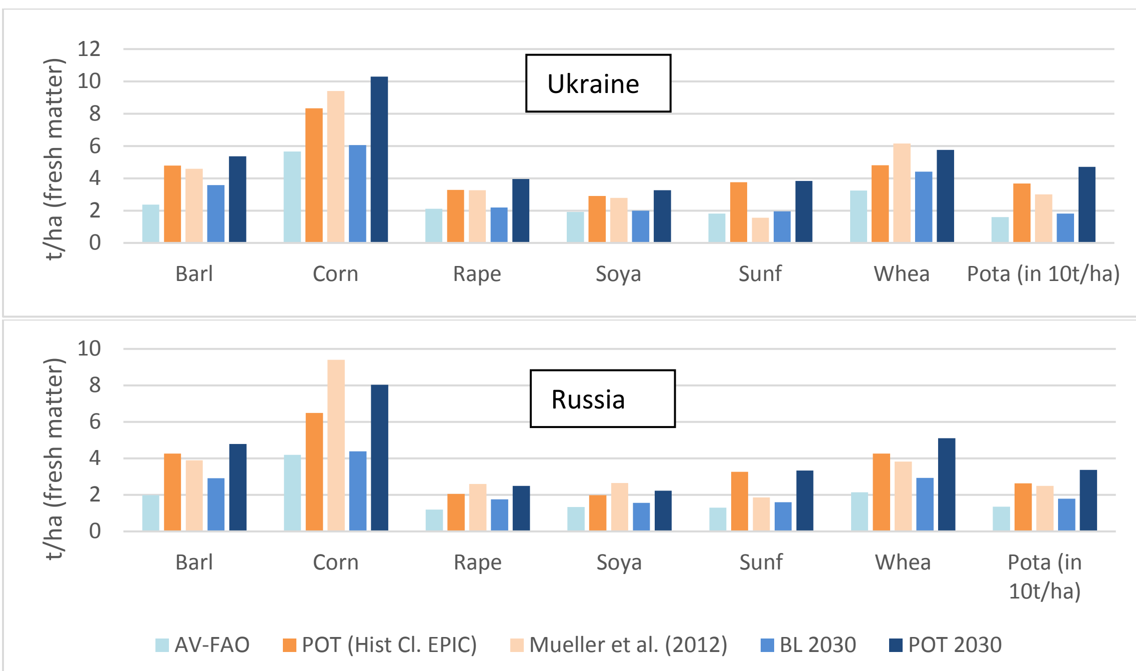

Figure 2: *Yields and yield potentials (t/ha); AV-FAO: Average of observed yields of the period 2010-2014; POT (Hist Cl. EPIC) – average yield potentials based on EPIC figures under historical climate (compare 2.3); Mueller et al. (2012) – attainable average yields as presented in their publication; BL2030 – GLOBIOM base year yields plus assumed exogenous growth trends; POT2030 – EPIC yield potentials plus assumed technical change until 2030. For the calculation of POT (Hist), BL2030 and POT2030, spatially explicit yields are applied on the area distribution of the GLOBIOM base year.*

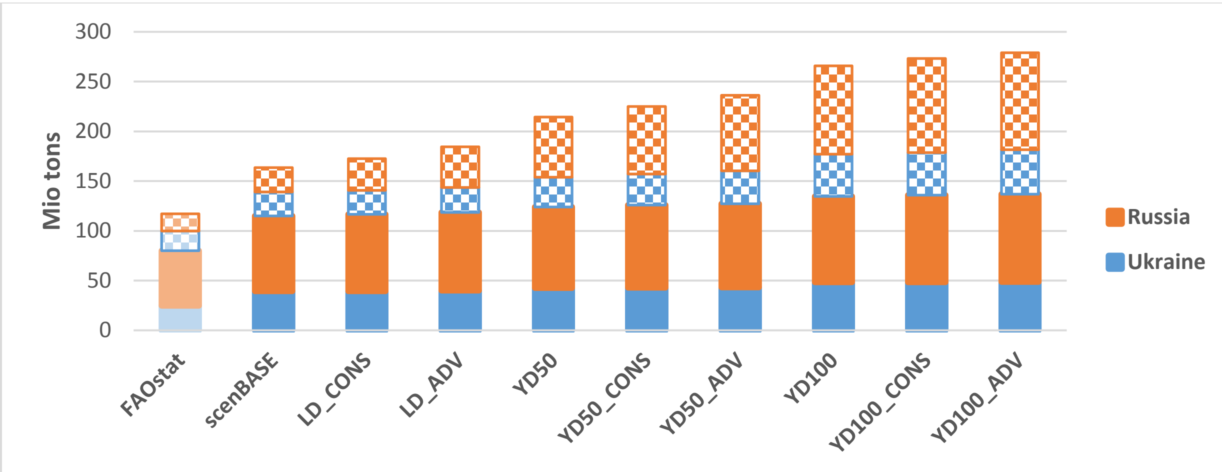

Figure 3: *Cereals (Barley, Corn, Wheat) production and net-trade; Overall bar: total production; Plain area: domestic consumption (human consumption, feed, seed and processing); Patterned area: net-exports; The FAOstat bar refers to an average of 2010-2014 values from FAO (2016).*

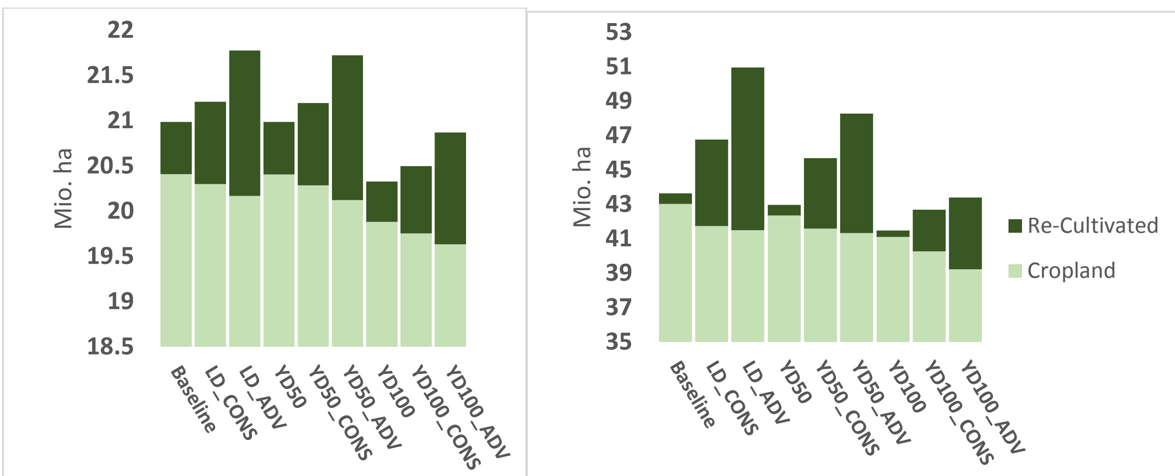

Figure 4: *Cropland use in Ukraine and Russia in 2030.* ***Note****: bars are cut at 18.5 Mio. ha in Ukraine and 35 Mio. ha in Russia for better visualization of re-cultivation effects in the single scenarios.*

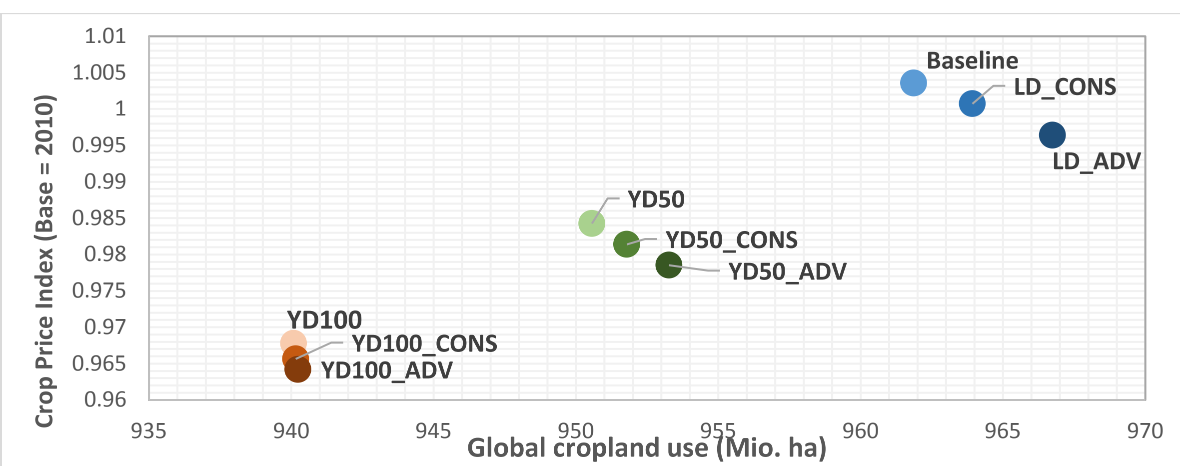

Figure 5: *Global price and land use effects in 2030. Figures refer to crops integrated in GLOBIOM.*