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IIASA Interim Report
April 2011

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Interim Report **IR-11-037**

Agricultural production intensification in Ukraine: Decision support of agricultural policies based on the assessment of ecological and social impacts in rural areas

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April 23, 2012

Contents:

Foreword

The Current unstable situation of food markets in Ukraine is caused by imbalanced agricultural production activities induced by recent agricultural reforms. Instability of food production not only undermines food security, but also creates depression to the economy as a whole. Every reform in Ukrainian agriculture extended far beyond the agricultural sector affecting all sectors of national economy.

Current land reform removes land moratorium and is expected to have positive effects on agricultural and rural area developments. However, the reform carries a number of uncertainties and threats both for agricultural enterprises and for rural areas. For rural areas development, the reform may cause further land concentration and reduction of job opportunities. For agricultural enterprises introduction of new regulations may result in decreasing profits and increasing production costs comprised of increased land lease rates, costs for improved fertilization and land management. This will inevitably lead to further escalation of profitable cash crop production.

In this paper, I briefly summarize main socio-economic and environmental aspects and indicators which motivate the analysis of sustainable agriculture intensification pathways in Ukraine emphasizing the need to address emerging systemic risks which may affect security of food, water, energy, environment, as well as social security and health provision to rural population.

In order to avoid escalation of cash crops production, it is necessary to introduce regulations as to what crops and where to produce them. This may be done through governmental interventions which may provide financial support to restructure production in order to avoid monocropping. To ensure that the reform leads to rational and sustainable land use, transition of large enterprises to new norms and criteria of agricultural production and land management requires adequate planning tools for the analysis of financial and resource capacities to increase profits of enterprises by improved resource management increasing crop yields to their potentials.

In these studies, the analysis of optimal production allocation and expansion is carried out in a spatial and dynamic context consistently with local bio-physical production potential. The model incorporates diverse inherent uncertainties and risks. It proved to be a valuable tool for actual use by decision-makers. The proposed advanced methodology integrates stochastic optimization methods with multi-criteria analysis for supporting policy decision-making. It allows incorporating massive socio-economic and agricultural data base to be used for advising and negotiating decisions with policy-makers.

Abstract

Agriculture is one of the major economic sectors of Ukraine. Therefore, improving agricultural practices is of critical importance for economy, environment, and society in Ukraine. Rapidly increasing intensification of agricultural production promotes large agrarian enterprises. These processes lead to certain consequences. An export-oriented business has a raw character, doesn't fulfill its social role and carries environmental risks. The main goal of these studies is to investigate flexible crop production portfolios/practices at the regional and district level in Ukraine to meet local agro-ecological norms, consumers demand, financial resources, availability of infrastructure and help to improve local strategies for food security and robust land resource utilization. The proposed stochastic model calculates in accordance with available database at regional (25 regions) and district (496 districts) levels the results, which are visualized using GIS software. This paper analyzes current land use processes and develops proper policy recommendations to mitigate the negative consequences (socio, ecology, economic) of unsustainable agricultural intensification in the future.

Acknowledgments

The research has been conducted during YSSP 2011 Ecosystems services and management Project. I am grateful to my YSSP supervisors Tatiana Ermolieva, Yuri Ermoliev, H. van Velthuizen, Guenther Fischer for their guidance and advising during the work. I thank Ukrainian NMO for financial support of my participation in YSSP 2011. Special thanks go to the Director of Institute of Economics and Forecasting National Academy of Science of Ukraine Academician Valerij M. Heyets and Department Head of Economy and Policy of Agrarian Transformation Elena N. Borodina for their help during this summer. Also I thank, YSSP 2009, Oleksandra Borodina and, YSSP 2010, Sergiy Kyryzyuk for assistance in this research.

About the author

Oleksiy Frayer was a participant of the Young Summer Scientist Program (YSSP) in 2011 with the ESM program at the International Institute for Applied Systems Analysis. He graduated from the Agrarian University (Vinnitsa, Ukraine) with specialization in agricultural economy. He is currently a junior researcher at the Department for Economy and Policy of Agrarian Transformations of the State Organization, Institute for Economics and Forecasting (IEF) of the Ukrainian National Academy of Sciences.

His main research interests focus on identifying and estimating socio-economic and ecological impacts of agricultural production intensification. At present Oleksiy is developing a methodology concerning agro-ecological impacts in conditions of large scale enterprise activity.

Introduction

Ukraine possesses rich natural resources and can play an essential role in the world's food market, which in the recent years has experienced major production gaps because of expanded food demand, persistent weather problems, food-to-biofuel transition of agricultural lands, etc. According to international experts, with proper management and investments, Ukraine can make a major enhancement to food security [25]. However, agricultural GDP in Ukraine declined by 51% between 1991 and 1999, recovered by 10 % per year in both 2000 and 2001, slightly increased by 1.2% in 2002 and declined again by 18% in 2003. Currently, the share of agricultural products for the total GDP is about 8.2%. Before 1991, the agricultural sector provided employment to about 31.5% of workers, now only 15.6% of active population is employed in agriculture. This decrease of economic efficiency and stability in agriculture has been one of the most prolonged in the former Soviet Union republics [20]. Some of these trends resulted from a collapse in the general economy, but this recession was made deeper and longer by policy reforms which led to substantial restructuring of agricultural sector in Ukraine.

Currently, agricultural enterprises in Ukraine are being actively integrated forming large agriholdings [1]. During 2005 and 2006 the number of enterprises, which operate more than 10 thousand hectares of land, has increased by 27%; the average size of the total area in these enterprises has risen by 7% to more than 20 thousand hectares. Large agriholdings will considerably represent agrarian sector of Ukraine in the nearest 5–7 years. This trend was intensified in 2008-2009, what was generated by Ukraine's WTO accession.

Large agriholdings are as a rule efficient business projects with easy access to capital, markets, policy facilitation. They may rather freely choose among the commodities to produce and in what amounts. This freedom induces specialization in more profitable products, mostly production of cash crops, to satisfy increasing foreign demands. For the sake of increasing profits, large agriholding expand arable lands minimizing other expenditures, e.g. especially expenditures for adequate fertilization, which leads to soil quality degradation.

Production specialization, land concentration, and arable land expansion are among the main reasons for increasing socio-economic and environmental risks in rural areas of Ukraine. The risks can be shortly classified as follows: depopulation of rural areas; increasing unemployment and worsening rural livelihood; expansion of agricultural territories and overuse of natural resources; degradation of environment; decrease of food and water security.

To slow down the negative trends, simultaneous implementation of the agricultural sustainable intensification strategy and the rural-areas development strategy is important [8]. The sustainable agricultural intensification[1] should be based on improving the land use efficiency leading to yield increase through improved management. It is also important to mitigate the effects of reduced rural employment opportunities resulting from increased efficiency. This can be done through governmental legislation and programs providing

[1] Here sustainable intensification is defined as sustainable crop production aimed to increase crop yields taking into account such factors as biophysical land potentials, availability of infrastructure and financial resources, and all other relevant factors affecting productivity and sustainability, including social, political, economic and environmental impacts.

financial support to different forms of agribusinesses as well as creating off-farm employment and public services in rural areas [3-4].

Although the goals of increasing resource use efficiency are clear, the implementation of the goals in concrete development strategies is difficult because of the complexity and numerous interaction, in space and time, in natural and anthropogenic systems, especially if accounting for inherent systemic risks and uncertainties.

There exist many approaches to agrifood production planning. Many traditional approaches to evaluation of agrifood strategies ignore possible uncertainties and variability in production conditions, weather, market state, fluctuations of demand, etc., simply by averaging them, which is equivalent to dealing with only one possible pathway (scenario) of future developments. In this study, we further develop a two-stage stochastic optimization model, which has been developed and applied in [3-4], [16], [29] for the analyses of food security and socioeconomic aspects of sustainable rural development in Ukraine. The planning of optimal production allocation and expansion is carried out in a spatial and dynamic context consistently with local bio-physical production potential [14]. The model incorporates diverse inherent uncertainties and risks. It proved to be a valuable tool for actual use by decision-makers [3-4], [16]. The proposed advanced methodology integrates stochastic optimization methods with multi-criteria analysis for supporting policy decision-making. It allows incorporating massive socio-economic and agricultural data base to be used for advising and negotiating decisions with policy-makers. In Section 2 and 3, current agricultural developments in Ukraine are described with a help of main demographic, socio-economic, and environmental indicators. Section 3 summarizes past agricultural reforms in Ukraine that induced strong priority for producing highly demanded on international markets "bioenergy" crops with further adverse effects on environment and socio-economic conditions. Section 4 discusses the model enabling analysis of optimal agricultural production allocation and intensification through better use of resources - natural, human, and financial. We discuss alternative scenarios and strategies to support rural community developments in Ukraine aiming at ensuring food security, socioeconomic and environmental safety and stability. Main results are summarized in section 4 and section 5.

2. Motivations for sustainable production intensification in Ukraine

Large agriholdings focus on production of profitable crops such as raw-materials for biofuels, avoiding production of less profitable products for direct consumption. Decreasing production diversity and diversion of land and water resources from direct food production undermines food security. It worsens environmental quality through imbalanced fertilization rates and absence of necessary crop rotations. Imbalanced and unstable grains production affects also the livestock sector, foremost, large animals and cows [3-4]. Livestock production decreased three times from 1991 to 2010. Apart from monocropping which disturbs the supply of grains for direct consumption, food security problem has been exacerbated by inadequate import-export quotas [16] and weather uncertainties.

Large agriholdings require fewer workers than traditional agricultural enterprises thus reducing employment opportunities for rural residents. With further intensification and concentration of agricultural production, the employment is expected to decline even further. With about 25% of Ukraine's labor force based in rural areas, financial support of small and medium enterprises as well as creation of off-farm jobs and improved public services in rural areas becomes a problem of the first priority. The following analysis in this section briefly summarizes main socio-economic and environmental aspects and indicators which motivate these studies of sustainable agriculture intensification pathways emphasizing the need to address emerging systemic risks which may affect security of food, water, energy, environment, as well as social security and health provision to rural population.

Depopulation: Increasing concentration and capitalization of agriculture, short-term market orientation with priority to large-scale enterprises resulted in significant distraction of rural settlements, income polarization, loss of welfare, depopulation, increase of unemployment and criminality [5-6], [19-20], [22], [24], [26]. The lack of employment, low incomes and insufficient social and health provision in rural areas in Ukraine induced high rate of outflow of rural population to cities and the accelerated rate of the population's ageing. For example, over 400 rural settlements disappeared from the map of Ukraine during 1991-2005 (for comparison, in some regions of Ukraine there are a total of 400-500 rural settlements).

Table 1. Changes in the rural population of Ukraine, 2002-2009.

	Years					Parity 2009 to 2002
	2002	2006	2007	2008	2009	
Total population, mln	48.6	46.9	46.7	46.4	46.1	-2.5
Rural population, mln	15.9	15.1	14.9	14.7	14.6	-1.3
Share of rural population, %	33.1	32.4	32.2	32	32	-1.1

Source: state committee of statistic of Ukraine, 2009.

Table 1 summarizes the changes in Ukrainian population during the last 10 years, indicating a decrease in both total and especially rural population. According to Ukrainian statistics, at the beginning of 2002 in about 90% of rural settlements there was a negative birth rate and in about 11% - no newborns were registered at all. Since then, the situation has not improved. If central and local governments do not address this problem soon, in the near future the level of depopulation in the certain districts (spots) central regions of Ukraine will reach 80-90%. [24].

Employment: Intensive large-scale enterprises and agriholdings are not interested in hiring many employees. They require much fewer workers than Soviet-type agribusinesses. They make use of qualified labor force (often from cities) thus neglecting the possibility of retraining the rural people and investing in local human capital. The number of workers employed in agriculture has significantly decreased since 1990, the decrease stipulated by agricultural reforms, concentration and capitalization of agricultural businesses. In the period from 1990 to 1999, the decrease had the lowest rate in the western rural regions of the country, where a larger share of traditional households and smallholders were still involved in agriculture. Figure 11 displays the changes of workloads from 2004 to 2009 by economic regions of Ukraine in terms of agricultural land per worker. It shows that before 2004, only two eastern regions had a rather high workload, i.e. 40-50 ha per worker. In the rest of Ukraine the workload was below 40 ha per worker. Between 2004 and 2007, the trend of decreasing agricultural employment propagated from western to eastern regions: one region (Lugansk) having a workload above 60 ha per worker, three regions (Kharkov, Dnepropetrovsk, Zaporozhe) 50-60, seven – 40-50 ha per worker, respectively. Eastern and southern regions show no significant changes. After 2007, largely due to opening of the market and then WTO accession, the eastern regions started to be more involved in intensification and capitalization processes thus catching up with the western and the central part of Ukraine.

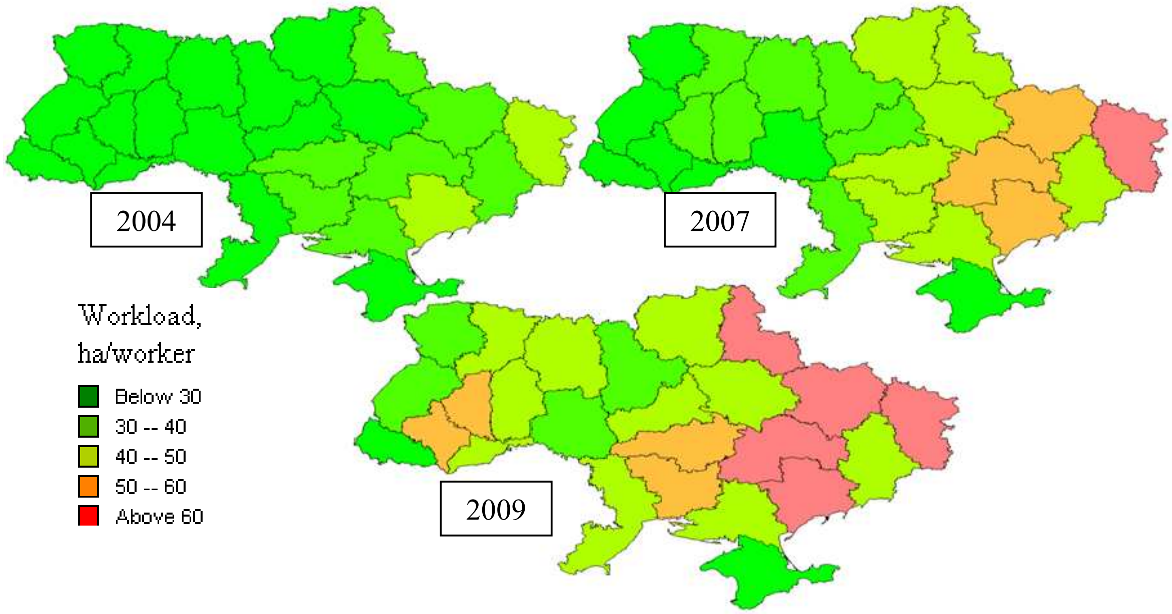


Figure 1. The dynamics of workloads by Ukrainian regions (ha per worker), 2004-2009. *Source:* database "Main Economic Indicators of Agricultural Enterprises", 2004-2009.

Currently, employees in agriculture receive extremely low salaries. In 2006 the average per-hour rate for employee in agriculture was ~ 0.72$, with the highest in the Kiev region (0.93$) and the lowest in the Khmelnicky region (0.53$). In comparison with other countries these figures look really dramatic. Increasing levels of workload per agriworker proves that there is a need to create off-farm jobs in rural areas to provide employment to rural inhabitants. As a summary, low living standard of rural population, deficit of jobs/employment, degradation and depopulation of settlements, low social benefits such as pensions and health provision, destruction of local food markets, etc. are the main factors aggravating the rural problem.

Land resources: One of the important ecological aspects of agricultural production in Ukraine is high land use utilization rate. Land has an invaluable wealth in Ukraine which is capable of ensuring food security to the population. Ukraine is among the leading countries in the world in agricultural land resources (Table 2). According to recent estimates (2010), the share of agricultural land in total land is about 68.9 %, of which 53% is arable land. Of all available agricultural land about 47.6% (44% of arable land) are used by large agricultural enterprises and 37.7% (26.6% arable land) by households. More than 17% of the total country's territory is covered by forests. Cities and other built-up areas occupy more than 6.9 mill ha (11.4%) of land resources.

Table 2. Availability of agricultural areas in comparison with other countries.

Country	Farmland		Arable land	
	Mln. ha	%	Mln. Ha	%
France	29.27	53.3	18.35	62.7
Germany	16.89	47.3	11.95	70.7
Hungary	5.78	62.2	45.85	79.3
Poland	16.12	51.6	12.54	77.8
Australia	409.03	52.8	47.16	11.5
Canada	67.6	6.8	45.1	66.7
Russia	215.56	12.6	121.75	56.5
Ukraine	41.28	68.4	32.48	78.7
USA	40.35	41.0	162.75	40.3

Source: Faostat, 2009

There are two main aspects distinguishing agricultural production intensification in Ukraine from intensification processes in other countries. Intensification in Ukraine is characterized by increasing profits at minimal costs without preserving agronomical norms, e.g. regarding crops rotation and adequate fertilization. Large agricultural enterprises increase production volume by expanding arable land. The profits are earned through uncontrolled exploitation of land by monocropping cash crops. Because of expansive agricultural production, in many regions of Ukraine the share of arable land used by all types of enterprises and land users (land operated by large scale, medium, and small enterprises, and individual plots) is now exceeding 80%, as displayed in Figure 2.

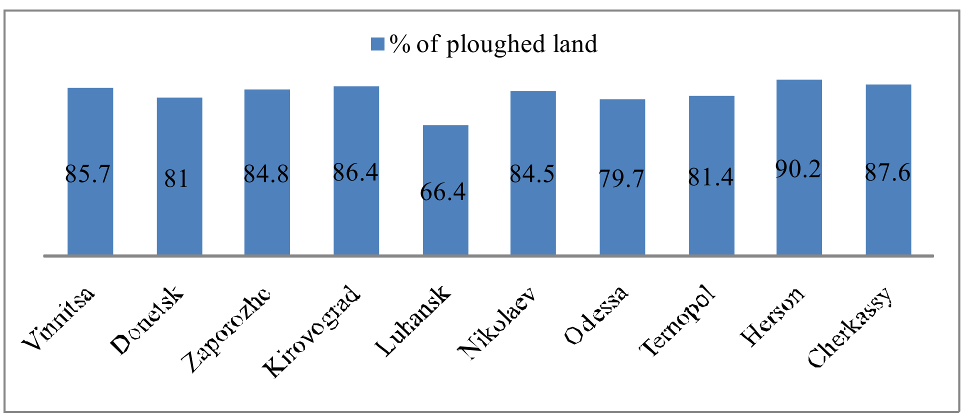


Figure 2. Regions of Ukraine with the highest share of arable land, %,
Source: State agency of land resources of Ukraine, 2009

The rate of agricultural land utilization is very different by region. According to the Ukrainian State Agency of land resources, the level of arable land in Zaporozhe, Kirovograd, and Nikolayev is above 81%, while in Transcarpathian region - 36%, Ivano-Frankovsk - 45.5%, Rovno - 46. 8%. Figure 2 shows regions with the share of arable land exceeding 80% of total land. These are Vinnitsa, Donetsk, Zaporozhe, Kirovograd, Nikolayev, Ternopol, Kherson, Cherkassy regions. In some of these regions the share reaches almost 90%, which exceeds the norms and may lead to irreversible changes.

High land utilization rate is induced by increased foreign demand for cash crops, e.i. wheat, sunflower, rapeseed, etc. With rapid capitalization, large scale enterprises increase amount of arable land. For example, Figure 3 shows the expansion of arable land in operation by large scale enterprises from 2004 to 2009. In 2004, the share of arable land operated by large enterprises was above 50%in only three regions. Towards 2007, the number increased to four and by 2009 already eight regions had 50% of land in operation by large agriholdings. Regions with high land use rate are allocated primarily in central and eastern parts of Ukraine. In 2009, already in eight regions the share became 70% and in 10 – about 50%. Figure 3 also shows that during the last decade, production portfolio of large enterprises comprised primarily of three-four cash crops, i.e. wheat, corn, sunflower, rapeseed.

The land resource aspects of agricultural production intensification in Ukraine can be shortly characterized as having the following characteristics:

- profit maximization with minimization of expenditures during production process;
- short-term planning without preserving environmental norms;
- continuous expansion of cultivated areas;
- prevailing production of cash crops without further processing. Therefore the majority of enterprises have a raw nature of production and imbalanced fertilizer application.

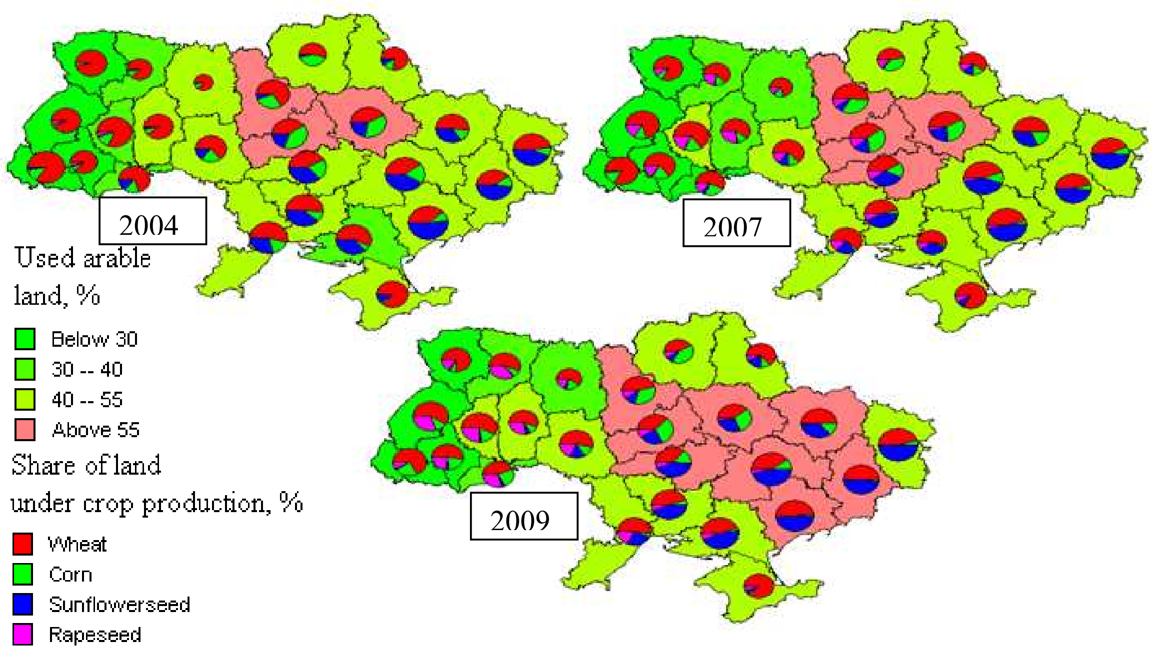


Figure 3. The dynamics of arable land expansion and main production commodities by Ukrainian regions, 2004-2009. *Source:* database "Main Economic Indicators of Agricultural Enterprises", 2004-2009.

Fertilizers application: Another ecological aspect of production intensification in Ukraine is imbalanced land fertilization. After the collapse of the Soviet Union, consumption of mineral fertilizers decreased by 78% because of removed subsidies for fertilizers. Further on, consumption of mineral fertilizers in Ukraine decreased 24 times and this trend continues. According to Figure 4, during the years characterized by production intensification, to speed up plant growth at minimal cost only one type of fertilizer, namely, nitrogen, has been applied with small proportion of potash and phosphate fertilizers, practically ignoring organic fertilization. Appendix A presents actual rates of fertilizer application at regional level in Ukraine and compares them to optimal rates.

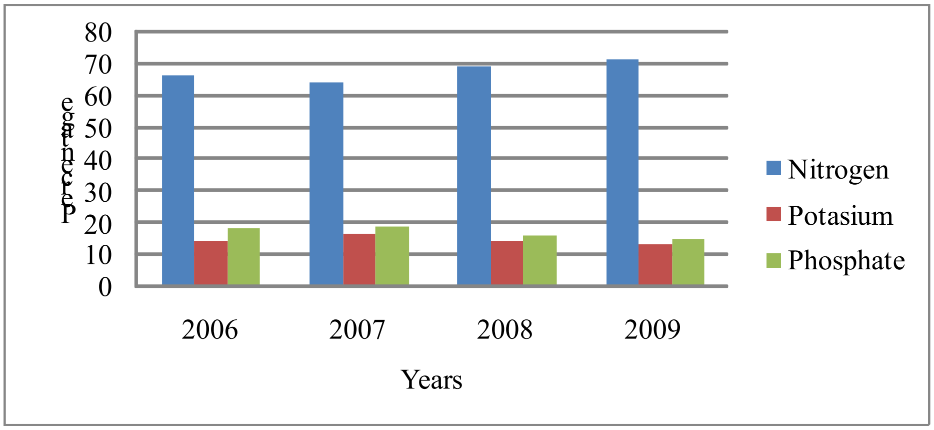


Figure 4. Mineral fertilizer consumption, in percentage terms. *Source:* State committee of statistic of Ukraine: introduction of mineral and organic fertilizers by agrarian enterprises under the crops 2006-2009.

Land degradation: With imbalanced fertilizer application, excessive ploughing, and prevailing monocropping soil quality deteriorates and its fertility decreases. One of the most diagnostic features of the soils' degradation is the reduction of organic substance in it and its component - humus. In Ukraine, average annual loss of humus due to water and wind erosion is about 15 tons/ha, which means about 740 million tons loss of fertile soil (which contains about 24 million tons of humus and many other essential microelements) at country level. In addition to unconstrained land exploitation, land damaged by natural water erosion is about 32% of the total area or 13.3 million ha. In the territory of 68 thousand ha the humus layer is completely lost. To slow this trend down, there is a need for the development of proper regulations restricting overuse of lands, ensuring proper fertilization, prohibiting intensive monocropping. Such regulations are expected to become a major topic of concern in the currently planned land reform (see section 3).

Economic aspects: Table 3 shows the structure of production costs in agrarian enterprises. With all other expenditures being low, the largest share of expenditures is for fertilizers. Large costs of fertilizers stimulate expansion of arable land to derive higher production volumes with minimal investments and no yield increases.

Table 3. Cost structure of agrienterprises with plant production specialization, 2009.

	Production costs	Seeds		Fertilizers		Fuel		Salaries		Another direct costs	
	Bln. hrn.	Bln. hrn.	%	Bln. hrn.	%	Bln. hrn.	%	Bln. hrn.	%	Bln. hrn.	%
Grain	10.09	1.04	10.3	2.16	21.4	1.4	13.9	0.83	8.2	2.51	24.9
Corn	4.57	0.75	16.3	0.8	17.6	0.54	11.8	0.31	6.8	1.04	22.8
Sunflower seed	5.11	0.71	13.8	0.65	12.2	0.82	16.0	0.44	8.5	1.42	27.8
Rape seed	2.59	0.26	9.9	0.71	27.4	0.3	11.4	0.15	5.9	0.55	21.3
Total, th. hrn.	22.36	2.75	-	4.29	-	3.06	-	1.73	-	5.53	-
Total, th. usd.	2.8	0.34	-	0.54	-	0.38	-	0.22	-	0.69	-

Source: database "Main Economic Indicators of Agricultural Enterprises", 2004-2009

3. Land reform and its possible implications for agricultural and rural area developments

Land is among the main factors of agricultural production determining also the quality of outputs. Land includes not only the location of production but also natural resources above and below the soil surface. Current land overexploitation calls for reforms leading to planning sustainable agricultural production intensification and land use. Sustainable use of land resources as defined by FAO [8], is "....the management and conservation of the natural resource base, and the orientation of technological and institutional change in such a manner as to ensure the attainment and continued satisfaction of human needs for present and future generations. Such sustainable development (in agriculture, forestry and fisheries sectors) conserves land, water, plant and animal genetic resources, is environmentally non-degrading, technically appropriate, economically viable, and socially acceptable".

It is expected that current land reform which removes land moratorium will positively effect agricultural and rural area developments in Ukraine. Generally, reforms introduce a whole complex set of institutional, economical, social, juristic, and ecological, as well as other, measures enabling new production, land use regulations and formation of new social relationships. Every reform in Ukrainian agriculture extended far beyond agricultural sector affecting all sectors of national economy. It is difficult to make a complete review of past reforms. It is also difficult to foresee future emerging implications of the reforms. In the following, we make a brief overview of past agricultural reforms in Ukraine starting from the first reform in 1990.

On December 18, 1990, the Supreme council of Ukraine approved the resolution № 563-XII on land reform. In this resolution, for the first time the land was defined as the object of the reform. It became possible to distribute the land among population and farmers. This reform envisaged rational land use and environmental protection.

Concept of "land" as private property was formalized in the Land Code and the Resolution 2200-XII "On land reform acceleration and land privatization" in March 1992. Among the main tasks of this reform were the following:

- Introduction of different kinds of land ownership and land management, providing their equal development and increasing efficiency;
- Renovation and improvement of all land categories (farmlands: tillage, hayfields, etc; forests and so on);
- Creating an effective state mechanism and economic management for rational use of land resources and their protection;
- Development and adoption of regulations to guide the land reform and post-reform relations implementing principles of efficiency, equity, and usability.

Since then proclaimed land reform, the land relations and ownership structure in agriculture radically changed. Before January 1, 1992, all farmland of Ukraine was under state ownership. Because of the reform, already in 1996 the share of agricultural land in use by farms became about 36.6% and 3.2% – under private use. The main owners of the land became collective farms. In 2000, the farmland was withdrawn from the state ownership and distributed between private landowners and within collective farms.

Resolution of President of Ukraine L. Kuchma "On urgent measures of accelerating the agricultural reform" became the next phase of land reform. It accelerated the privatization process in rural areas. Individuals were granted the right to leave collective farms and organize individual enterprises or create other economic entities on the available land plots. At this stage, lease contracts with a minimal lease rate were introduced.

In accordance with State Agency of Land Resources, on October 1, 2010, over 6.9 million individuals gained rights to own land plots (83.4% of the total agricultural area) with average plot size of about 4.2 ha. According to certificates or/and public acts available for the period 2000-2010, land owners signed about 4 584 400 leasing contracts (17 million hectares or 62% of distributed land). Most of the contracts were signed for up to 5 years with average lease rate of about 300 hrn per hectare per year.

The removal of land moratorium is the third stage of the land reform. On June 20, 2011, the law "On land market development" was approved. It is expected that this reform would lead to increasing market value of agricultural land, i.e. increasing lease rates up to 3% of determined land value. Currently, as Figure 5 shows, average land lease rates vary from 150 to 300 hrivna (hrv, 1 hrv ~ 0.12 USD) per hectar land by regions in Ukraine.

To guarantee land quality, land passports will be introduced containing land quality and land use type indicators (soil characteristics, types of agricultural specialization). It is expected that land lease periods will increase up to 50 years.

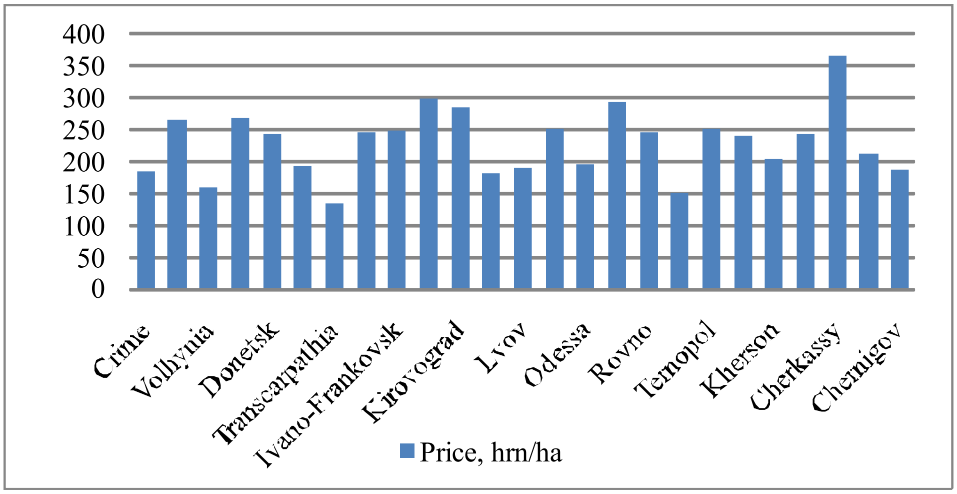


Figure 5. Average lease rates for 1 ha of land in 2009 by Ukrainian regions. *Source:* database "Main Economic Indicators of Agricultural Enterprises", 2004-2009.

The new reform may introduce the following positive changes:

1. Realization of constitutional rights of Ukrainian population for land ownership;
2. Development of the efficient land market (market operations are conducted on legal basis at proper economic value);
3. Sustainable, effective and rational land use (in accordance with socio-economic and agro-ecological criteria);
4. Increasing credit base with land as a pledge (additional financing);
5. Increasing level of investments in agriculture
6. Optimization of land use by consolidation land plots.

However, the new legislation carries a number of uncertainties and threats both for agricultural enterprise and for rural areas. For rural area development, the reform may cause further land concentration, reducing number of enterprises, decreasing job opportunities. For agricultural enterprises introduction of new regulations for sustainable land use may result in decreasing profits and increasing production costs comprised of increased land lease rates, costs for adequate fertilization and land management to keep up with the agro-ecological norms.

These studies carry out geographically explicit analysis of crops profitability by comparing actual yields with break-even yields i.e. ensuring that production costs equal to profits from sales. Appendix B shows that the most profitable is production of oil (technical) crops (sunflower seed, rape seed, etc). Their actual yields exceed the break-even point. For corn and wheat, both yields are almost equal, which means that a small increase of production costs e.g. due to increasing fertilizer application or increased lease rate may divert farmers from production of these products. Thus, Appendix C compares actual and break-even yields if lease rates will become twice higher then now, as it is expected that in the open market the lease rates will be not less than 600 hrn per ha, i.e. increase at least twice. In almost all regions under these conditions the grain production becomes unprofitable and it is likely that the increase of lease rate will stimulate agrarian companies to produce even more profitable cash crops (in this case, technical). Therefore, the new law will further stimulate farmers towards export of technical crops ignoring the basic principles of sustainable development and thus the country food security.

In order to avoid escalation of cash crops production, it is necessary to introduce regulations as to what crops, where and how to produce. This may be done through governmental interventions. To ensure that the reform leads to rational and sustainable land use, transition of large enterprises to new norms and criteria of agricultural production and land management requires adequate planning tools for the analysis of financial and resource capacities to increase profits of enterprises by improved resource management increasing crop yields to their potentials.

4. Production planning and allocation model

The implementation of efficient resource use and food security goals in concrete development strategies is difficult because of the complexity and numerous interactions, in space and time, in natural and anthropogenic systems, especially if accounting for inherent systems risks and uncertainties. The main challenges of planning agricultural production associate with multiple goals and constraints of involved agents. Planning tools need to include anthropogenic factors and complex interactions of behavioral, socio-economic, cultural and technological factors. Technological considerations comprise of e.g. production costs, availability of technologies, potential for environment (soil) improvements. Socio-economic factors include land tenure system, farming objectives, crop composition/portfolio, and structure of livestock. The planning of production allocation and intensification must be carried out in a spatial and dynamic context consistently with local bio-physical production potential [14].

Uncertainties and risks are inherent in agricultural practices. Land performance has always been affected by weather and climate, and sophisticated adaptive strategies to cope with climatic vulnerability have evolved in many agricultural communities. Currently new kinds of risks in agrifood system emerge which are highly interdependent and endogenous on policies' implementation. These risks affect environmental conditions, rural livelihood, and often misuse and redistribute utilization of common natural resources compromising intergenerational fairness, thus having relation to every aspect of sustainability development. Experimenting with endogenous socio-economic and environmental processes may be very expensive and dangerous. Therefore, the credibility of models and methods is subject to explicit treatment of uncertainties. The model introduced in this section permit**s** different specifications of uncertainties to be incorporated in the analysis. Uncertainties within a time step and spatial unit may be represented by a number of scenarios, e.g. dry, wet, or normal weather conditions, or high, normal and low yields. In fact, in many cases uncertainty of, e.g., weather characteristics, is considered as the driving variable attributing to various risks of agricultural production, including yield failure and market situation.

4.1. Description of the data

The reliability of data determines the model outcomes. In these studies the data came from different sources. The data on the demographic situation of the country, balances and consumption of the main food commodities by population of Ukraine, crop statistics of Ukraine for 2004-2009, mineral and organic fertilizers by agrarian enterprises for 2004-2009, and volumes of sales and prices of basic agricultural products in the markets was derived from State Statistical Committee of Ukraine. Economic and social indicators came from the Ukrainian database "Main Economic Indicators of Agricultural Enterprises", 2004-2009. Data on land resources and land use were assembled using information from

State Agency of Land Resources of Ukraine. Other data were harmonized from available GIS data sets, data of Ministry of Agrarian Policies of Ukraine, Ministry of Finance of Ukraine, FAO, USDA, World Bank, OECD and HEIFER. Table 4 summarizes the variables used in the model and divides them into three broad groups of indicators:

Table 4. Model indicators, 2004-2009.

Type	Indicators
General	Income, profitability, number and activity regions of enterprises according to land size in use, state support
Social	Population size and its changes in rural territories, demographic employment structure, labor, payment and income level for rural population, domestic consumption rates
Ecological	Chemical fertilizers (within regions), expenditures on fertilizer purchasing, crop rotation, soil quality

Estimation of model indicators (consumption, lease rates, profitability levels, yields' variability, etc.) at required spatio-temporal resolutions is rather time consuming. It requires the development of auxiliary models and data harmonization and downscaling procedures [10].

4.2. Model formulation

The goal of the proposed model is to investigate in a systemic way robust pathways increasing resource use efficiency in Ukrainian agriculture by planning agrifood system to fulfill food security goals and to reduce stress on natural non-renewable resources (e.g., water, soil), which may also significantly depend on the climatic conditions and weather variability. The model involves three main types of criteria and constraints: food security, production costs minimization, and environmental (resource) constraints. The problem of agrifood systems planning is very practical as many governmental policies relate to utilization of environmental and land resources, but these policies are frequently implemented under a high degree of irreversibility without accounting for inherent uncertainties and risks [3-4], [16] as previous agricultural reforms show. Many traditional approaches to evaluation of agrifood strategies ignore possible uncertainties and variability in production conditions, weather, market state, fluctuations of demand, etc., simply by averaging them, which is equivalent to dealing with only one possible pathway (scenario) of future developments. Below are typical examples from agrifood systems planning illustrating the pitfalls of deterministic approaches:

Example 1: Suppose there are two farms with the same crop structure and average yields, but with different variances of the yield, e.g., due to weather conditions. It is clear that the farm with a larger variance in yields is more vulnerable and may be less profitable but it is impossible to distinguish them on the basis of average data.

Example 2: Suppose there is only one type of soil and two crops, A and B. Crop A performs better in dry seasons and crop B outperforms crop A in wet seasons. On average, the weather conditions may only be dry or wet, implying monocropping structure as an optimal solution, i.e., cultivation of only crop A or only crop B. By taking into account probabilities for both weather conditions, dry or wet, the structure of the optimal solution changes to a multicropping structure: crop A and crop B must be included in the optimal solution in proportion related to frequencies of wet and dry seasons, prices on the market, etc. In general, the portfolio of crops may include crop C which underperforms crop A in dry and crop B in wet seasons, however under weather uncertainties has higher yields than both of the crops.

The proposed model can be used for planning production of different agricultural commodities. In these studies, we include the main agricultural commodities essential for national food security. In Ukraine among the products which ensure food security are cereals (wheat, rye, barley, corn), meat (beef, pork, poultry), milk, fish, sunflower oil crops (sunflower, rape), eggs, vegetables, fruits. The model is geographically explicit, it operates at the level of Ukrainian districts (496) and regions (25). In [16] the model was implemented on Ukraine-EU level. Here we describe the results of modeling for 7 major crops (wheat, rye, barley, corn, sunflower seed, soy bean and rape seed) and investigate optimal and robust allocation of their production minimizing the gap between the actual yield and the potential yields (derived from AEZ methodology [14]). The model analyses possibilities of yield gap reduction at minimal costs provided food security goals, resource constraints, and agricultural norms (e.g. balanced fertilization) are satisfied.

The model includes environmental constraints restricting the use of land and other natural resources (water, air) within ambient norms. Production costs include lease rates, costs for seeds, fertilizers, fuel, and other expenditures. We develop several scenarios of plausible lease rates and analyze farmers' behavior with respect to these scenarios. Land expansion constraints include alternative scenarios of land expansion by type of a farmer (e.g. small, medium and large). We assume that production functions of farmers depend on crop portfolios and financial support (credits, bonds, insurance and subsidies). Financial support may be provided by central/local governments, private or public financial institutions to maintain a profitable level for farmers during their transition to sustainable intensification. We assume that financial support is provided only to those farmers who agree to pay taxes locally and implement sustainable agricultural practices e.g. adequate crop portfolio, crop rotation, fertilization, etc. Food security constraints include direct demand for food and feeds and indirect demand, e.g., international export obligations and inter- regional trades.

Following [3-4], [16], [29], the structure of the model is presented below. Production of major agricultural commodities is allocated by districts or regions. By $x_{ij} \geq 0$ we denote area for production of commodity i in region j to meet demand d_{ij} in product i. Performance of farmers in location j is characterized by the following aggregate production function:

$$\begin{aligned} I_j = & \sum_{i=1}^{n} P_{ij} a_{ij}(\omega) x_{ij} - \sum_{i=1}^{n} c_{ij} x_{ij} - \sum_{i=1}^{n} \pi_{ij} + \\ & \sum_{i=1}^{n} \varphi_{ij} x_{ij} \max\{0, a_{ij}^{*} - a_{ij}(\omega)\} P_{ij} + \\ & \sum_{k} P_{ki} z(\omega)_{kij} - \sum_{k} P_j z(\omega)_{ijk}, \end{aligned} \tag{1}$$

where k denotes import or export between regions, $j = \overline{1:n}$ ($n = 496$ or $n = 497$ (if foreign region is included). In (1), farmers' profits are defined as a difference between total incomes (revenues) and total expenditures. The incomes consist of revenues from crop sales $\sum_{i=1}^{n} P_{ij} a_{ij}(\omega) x_{ij}$ and financial aid (compensations) $\sum_{i=1}^{n} \varphi_{ij} x_{ij} \max\{0, a_{ij}^{*} - a_{ij}(\omega)\} P_{ij}$.

Financial aid may include credits, insurance, environmental bonds and governmental subsidies for improving land management, e.g., increasing yields through adequate fertilization. The expenditures comprise of production costs $\sum_{i=1}^{n} c_{ij} x_{ij}$ and payments for financial aid $\sum_{i=1}^{n} q_{ij}$, e.g. lending rate, insurance premium. The structure of production costs is summarized in Tables 4. Having rather low labor and land costs, large share of total expenditure goes to fertilizers. Therefore, increased fertilization may substantially increase production costs.

Net inter-regional trade flows are defined as a difference between the value of imports $\sum_{k} P_{ki} z_{kij}$ purchased by region j and the value of exports $\sum_{k} P_{ki} z_{kij}$ from region j. Trades redistribute the products between producers and consumers to satisfy the required regional and national food security targets at minimal costs.

In the model, it is assumed that only those farmers (locations) who pay taxes locally and agree to improve land use by proper crop combination are supported financially, i.e. based on bio-physical production potentials and adequate crop rotation. Financing of farmers may be arranged through local or central, private or governmental financial institutions or funds. Performance of such a fund is described by means of its financial reserve. The fund accumulates its reserve receiving payments from farmers for financial support (i.e. premiums, lending rates, etc.). Stable performance of such a fund depends on the balance (2), which is the balance between total payments from farmers to the reserve fund and financial support paid out:

$$R = \sum_{i,j} q_{ij} - \sum_{i,j} l_{ij} x_{ij} \max\{0, a_{ij}^{*} - a_{ij}(\omega)\} P_{ij}(\omega), \qquad (2)$$

Condition (3) imposes a "collective risk" or a safety constraint on financial funds performance requiring that the total level of aid paid out to farmers should be less then the total payments to the fund from farmers with defined probability (safety) level γ :

$$\Pr ob\left[\sum_{i,j} q_{ij} - \sum_{i,j} l_{ij} x_{ij} \max\{0, a_{ij}^{*} - a_{ij}(\omega)\} P_{ij}(\omega) \geq 0\right] \geq \gamma \qquad (3)$$

In the model, a condition regulating the demand for financial aid (credits, insurance and bonds) is introduced by a fairness condition on the level of farmer's payment to local funds. :

$$\Pr ob\left[\sum_{i,j} q_{ij} - \sum_{i,j} l_{ij} x_{ij} \max\{0, a_{ij}^{*} - a_{ij}(\omega)\} P_{ij}(\omega) \geq 0\right] \geq \gamma, \; j = \overline{1:m}, \qquad (4)$$

where $P_{ij}(\omega)$ is price for crop i and $\sum_{i} q_{ij}$ are total payments paid by farmers j to local funds for crops i,. Equation (4) guarantees also sufficient level of financial supply.

Food security constraint is necessary to maintain a certain level of agricultural product supply that is termed as food security level. Food security in location j can be fulfilled through actual agricultural production $a_{ij}(\omega)x_{ij}$ of crop i in location j or/and through trade balance between regions $\sum_k z_{kji}(\omega) - \sum_k z_{jik}(\omega)$. If production level is too low or production costs are too high, the farmer receives financial aid as a compensation for insufficient production, e.g. if actual yield of crop $a_{ij}(\omega)$ is lower than expected or potential is low a_{ij}^*, i.e. when $\max\{0, a_{ij}^* - a_{ij}(\omega)\} > 0$ Therefore, food security constraint is introduced in the model as follows:

$$a_{ij}(\omega)x_{ij} + l_{ij}x_{ij}\max\{0, a_{ij}^* - a_{ij}(\omega)\} + \sum_k z_{kji}(\omega) - \sum_k z_{jik}(\omega) \geq d_{ij} \quad (5)$$

for all scenarios ω, where l_{ij} defines the agreed level of compensation.

The overall goal of the model is to maximize expected farmers profits under constraints (2), (4), and (5):

$$\max \sum_j EI_j \quad (6)$$

s.t. (3), (4), (5).

The problem may be reformulated as:

$$\max \sum_j \left[w_j EI_j + \alpha_j E \min\{0, \sum_i P_{ij} l_{ij} \max\{0, a_{ij}^* - a_{ij}(\omega)\} - \sum_i q_{ij}\} \right] + \lambda E \min\{0, \sum_{ij} q_{ij} - \sum_{ij} l_{ij}x_{ij} \max\{0, a_{ij}^* - a_{ij}(\omega)\}\} \quad (7)$$

s.t. to food security constraint (5), where

$$E \min\left\{0, \sum P_{ij} l_{ij} \max\{0, a_{ij}^* - a_{ij}(\omega)\} - \sum_i q_{ij}\right\} \quad (8)$$

and

$$E \min\left\{0, \sum_{ij} q_{ij} - \sum_{ij} P_{ij} l_{ij} \max\{0, a_{ij}^* - a_{ij}(\omega)\}\right\} \quad (9)$$

define expected overpayments by farmers and expected deficit of funds reserve, respectively. Function (7) is a stochastic version of the scalarization function used in multicriteria analysis. Formally, the scalarized function (7) corresponds to a multicriteria stochastic minimization model with criterion function (7) and the criteria functions (8)-(9). Coefficients α_j define import prices and λ stand for the price of a contingent credit which the fund (investor) will buy if their reserve drops below acceptable level.

In the model we assume that for each location j we have N scenarios (observations) of random variable ω (weather conditions), i.e., ω_j^k, $k = \overline{1:N}$, which induces random yields $a_{ij}(\omega_j^k)$ of crops i (e.g. in different years). The distribution of $a_{ij}(\omega_j^k)$ is derived by combining information on historical variability of yields by locations with expert opinions. Using N scenarios (or historical observations), expressions (8) and (9) may be replaced by empirical expectations

$$\frac{1}{N}\sum_{k=1}^{N}\min\left\{0, \sum P_{ij} l_{ij} \max\left\{0, a_{ij}^{*} - a_{ij}(\omega_j^k)\right\} - \sum_i q_{ij}\right\} \tag{10}$$

and

$$\frac{1}{N}\sum_{k=1}^{N}\min\left\{0, \sum_{ij} q_{ij} - \sum_{ij} P_{ij} l_{ij} \max\left\{0, a_{ij}^{*} - a_{ij}\right\}\right\}. \tag{11}$$

Linearization of (7)-(11) derives the following problem:

$$\max \sum_{j=1}^{m} w_j \left[y_j + \beta_j \frac{1}{N}\sum_{k=1}^{N} v_k^j \right] + \sum_{j=1}^{m} \alpha_j \left(\frac{1}{N}\sum_{k=1}^{N} t_k^j \right) + \lambda \left(\frac{1}{N}\sum_{k=1}^{N} \varphi_k \right)$$

s.t.

$$v_k^j \le 0,$$

$$v_k^j \le I_j(\omega_k^j, x, z, q) - y_j,$$

$$t_k^j \le 0,$$

$$t_k^j \le \sum_{i=1}^{n} P_{ij} l_{ij} \xi_{ij}(\omega_k) - \sum_{i=1}^{n} q_{ij},$$

$$\varphi_k \le 0,$$

$$\varphi_k \le \sum_{ij=1}^{n,m} q_{ij} - \sum_{ij=1}^{n,m} P_{ij} l_{ij} x_{ij} \xi(\omega_{ij}).$$

$$a_{ij}(\omega) x_{ij} + l_{ij} x_{ij} \max\{0, a_{ij}^{*} - a_{ij}(\omega)\} + \sum_k z_{kji}(\omega) - \sum_k z_{jik}(\omega) \ge d_j,$$

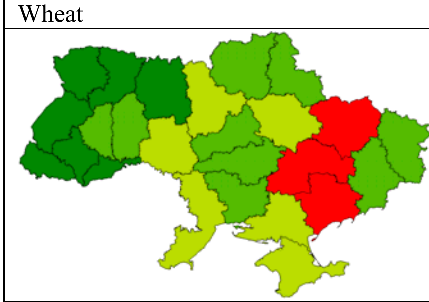
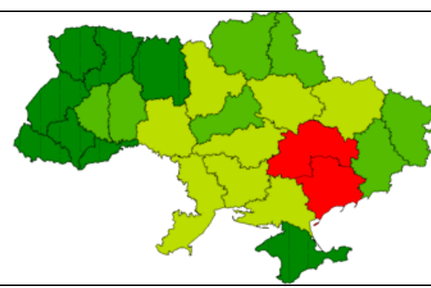
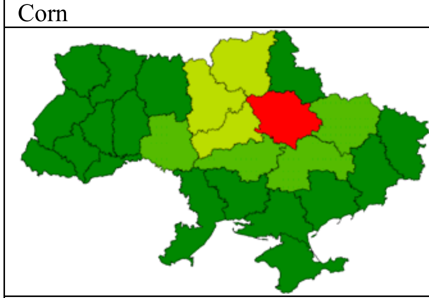
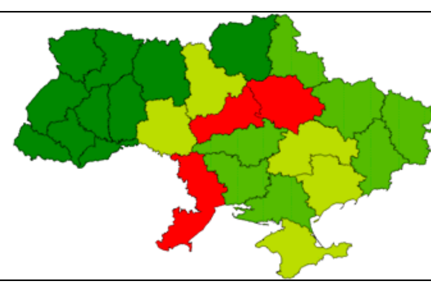
for all scenarios of $\omega_k \in \Omega$, $j = \overline{1:m}$, $i = \overline{1:n}$, where i indexes crops and j - producers (districts/counties).

4.3. Numerical results

Appendix D shows historical variability of wheat yields by selected Ukrainian regions. Similar histograms for all regions, districts, and major crops were used in the model to characterize weather related eventualities. The distribution of actual production may not be optimal and robust (Appendix B) against e.g. weather uncertainties. Actual production allocation does not always coincide with the best conditions for crops productivity. I.e., if variability of yields is due to climatic conditions, then in many regions it may be more rational from food security considerations to produce other crops.

The model derives optimal cost minimizing crop composition by locations and shows those crops that are robust against uncertainties which we compare to actual in Figure 6. The model can estimate additional financial support necessary to ensure transition of farmers from current primarily cash crops production to the optimal combination of crops derived by the model. The results fulfill food security goals and natural resource constraints.

The model allows analyzing alternative criteria to minimize yield gaps (between the actual and the potential production) at minimal costs, as shown in Appendixes E, F. To simplify visualization, the results are aggregated to regional level (25 regions). In Figure 6 we compare the current and the derived crops production allocation. Appendixes E, F summarize the result in the form of tables.

Current distribution	Model decision	Legend
Wheat		
		Land, ha Below 100 000 100 000 -- 200 000 200 000 -- 300 000 Above 300 000
Corn		
		Land, ha Below 50 000 50 000 -- 100 000 100 000 -- 150 000 Above 150 000
Sunflower seed		

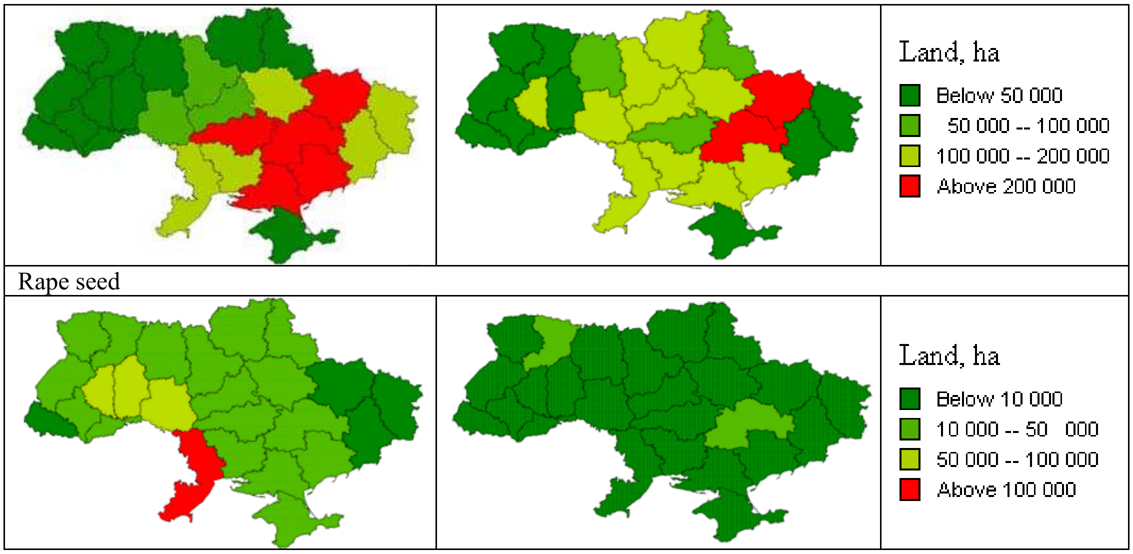


Figure 6. Comparison of current and model designed distributions.

As Figure 6 shows, the model proposes increasing rye and corn production. Production of other crops, especially, sunflowers and rape, may be reduced and allocated differently.

5. Conclusions and discussions

These studies analyze agricultural development trends in Ukraine in the last two decades. Major attention is given to characterize implications of agriculture production intensification on food and environmental security and rural livelihood. Agribusiness activities in Ukraine have the following main characteristics:

1. Short-term planning goals: maximization of immediate profits, cash crops export; low quality agripractices, etc.;
2. Monopolism and lobbying caused by fast growth of large agriholdings ;
3. Rapid deterioration of soils, environmental degradation;
4. Absence of social responsibility;
5. Non-market (shadow) system of crediting and financial support;
6. Unfair access to resources, markets, etc.

It is becoming increasingly difficult to regulate agricultural intensification because of the absence of proper institutional regulations by government. Among the important regulatory constraints the following should be selected: firstly, satisfaction of local demand; introducing the institute of social responsibility; increasing the level of rural employment; enforcement of the control for the use of natural resources (especially important in context of new land law); state interventions review. The studies use the model being developed jointly by IIASA and Institute of Economic and Forecasting, National Academy of Ukraine, for planning agricultural production in accordance with sustainable goals. With the new model introduction (especially at the district level) the farmer's activity is expected to be oriented on satisfying the country demand at local level and as result will provide:

- Sustainable rural development
- Food security with minimal pressure on ecology
- Avoidance of significant production costs (fertilizers, lease rates, transport, etc.)

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Appendix A. Fertilizer application in Ukraine, 2009, kg/t crop yield.

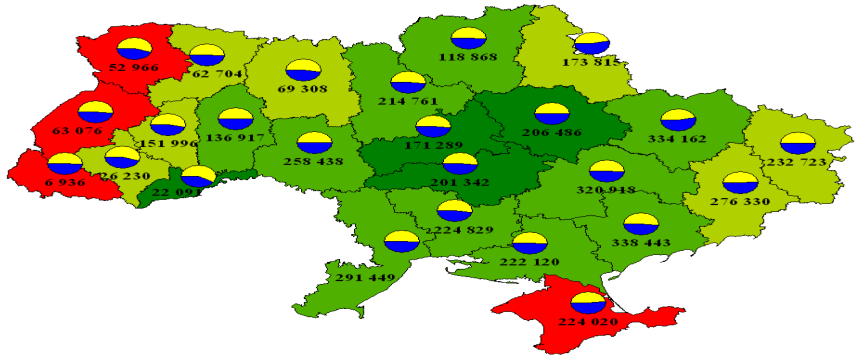
	Wheat			Corn			Sunflower seed			Rape seed		
	N	P2O5	K2O	N	P2O5	K2O	N	P2O5	K2O	N	P2O5	K2O
Optimal	32	14.7	36	26	11.6	30	90	25.2	20.4	90	25.2	20.4
Average	15.0	2.7	2.4	11.6	2.3	2.2	12.7	4.3	3.4	36.6	8.4	7.7
Crime	14.7	5.3	0.6	7.0	0.6	0.4	9.0	3.8	0.0	45.9	15.2	2.1
Vinnitsa	15.0	2.4	2.3	10.9	1.1	1.0	15.5	3.9	4.3	33.6	4.8	5.6
Volhynia	19.5	3.4	3.7	13.0	2.6	5.2	3.3	0.0	0.0	52.1	10.1	11.5
Dnepropetrovsk	14.4	2.1	1.0	8.9	2.1	1.3	8.3	3.8	2.1	37.0	7.8	2.9
Donetsk	13.0	3.0	0.9	5.4	1.5	0.8	6.2	3.9	1.7	32.0	10.1	1.7
Zhitomir	14.5	2.9	3.3	15.8	2.7	3.1	10.5	5.7	3.8	33.6	8.0	11.1
Transcarpathia	17.1	6.2	4.3	14.7	3.3	3.3	17.0	9.7	11.4	41.4	11.5	15.2
Zaporozhe	12.9	1.3	0.7	10.7	2.9	1.7	5.6	3.3	1.6	38.7	5.2	3.2
Ivano-Frankovsk	17.8	4.3	4.5	12.8	4.5	4.0	12.1	8.7	9.4	33.5	7.0	16.0
Kiev	12.2	2.1	2.2	10.3	1.8	1.8	11.0	3.0	3.3	37.4	5.3	6.1
Kirovograd	12.4	1.8	1.4	7.5	1.8	1.6	5.8	2.6	1.9	40.3	7.3	6.0
Lugansk	19.8	1.3	0.8	19.1	1.6	1.4	11.7	2.2	1.0	37.8	11.2	3.1
Lvov	22.4	5.0	6.5	12.1	3.1	3.2	0.0	0.0	0.0	31.1	8.8	10.6
Nikolayev	12.3	1.6	0.9	4.8	1.9	0.9	5.8	2.8	1.7	37.9	8.2	5.0
Odessa	13.6	1.8	1.2	9.2	3.1	1.0	8.9	3.5	2.2	33.8	6.3	2.9
Poltava	12.5	2.5	1.4	10.7	1.0	0.8	8.9	3.2	2.5	31.3	9.8	4.1
Rovno	19.4	2.1	3.9	16.8	1.8	4.0	16.4	5.5	4.6	36.9	6.7	13.4
Sumy	15.4	3.6	3.8	11.1	2.6	4.1	9.3	5.4	4.5	38.8	8.4	8.6
Ternopol	12.5	3.0	3.1	9.8	1.9	2.6	14.6	2.9	3.9	35.8	11.2	12.2
Kharkov	15.1	2.5	2.3	13.7	5.5	5.1	8.1	4.1	3.7	41.8	17.9	18.6
Kherson	15.1	1.1	0.4	11.4	2.5	1.6	17.9	9.3	3.2	27.5	3.0	1.1
Khmelnitsky	15.1	2.9	2.7	13.8	3.5	3.0	18.7	7.2	7.6	39.1	12.4	11.4
Cherkassy	13.5	1.9	1.7	8.0	1.6	1.7	9.9	5.1	5.1	46.1	7.0	6.9
Chernovtsy	10.3	1.9	3.2	17.4	1.3	1.1	17.1	2.8	2.8	18.7	3.5	4.2
Chernigov	15.8	2.8	2.6	14.5	1.6	1.8	16.1	7.9	8.4	32.0	10.0	11.1

Source: State committee of statistic of Ukraine: introduction of mineral and organic fertilizers by agrarian enterprises under the crops 2004-2009*;* FAO (1995).

Appendix B. Comparison of actual and critical (revenue=costs) crop yield in regions according to share of sowed area, 2009.

Crop	Legend

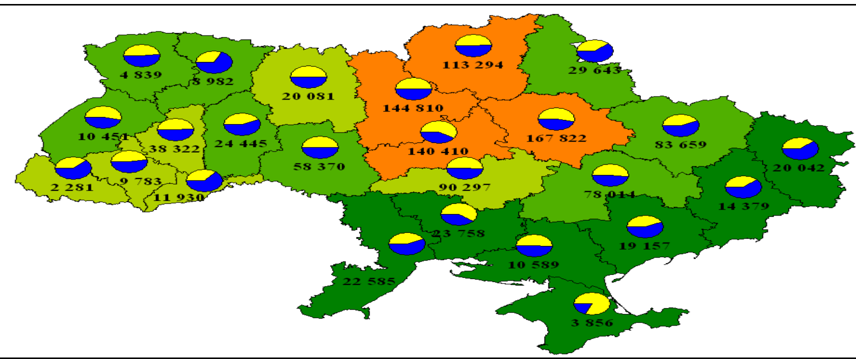
Wheat



Area under wheat, %

- Below 30
- 30 -- 40
- 40 -- 50
- Above 50

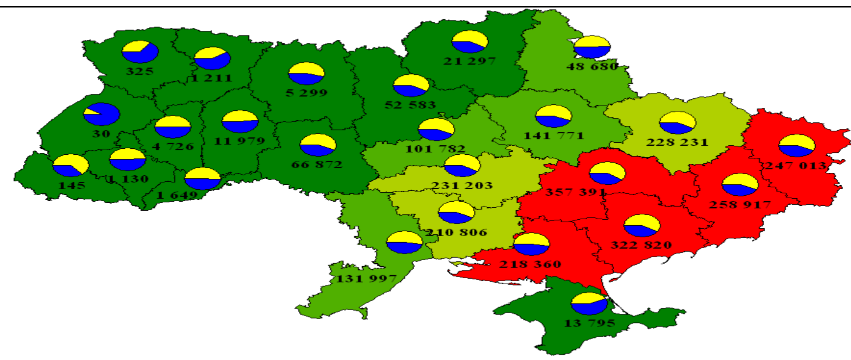
Corn



Area under corn, %

- Below 5
- 5 -- 10
- 10 -- 20
- Above 20

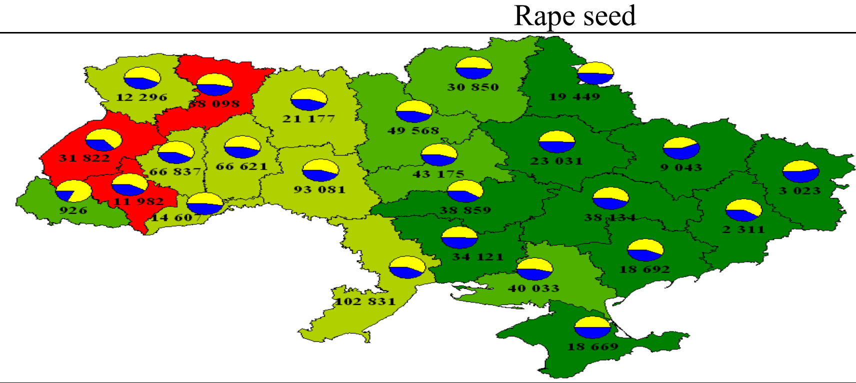
Sunflower seed



Area under SF, %

- Below 10
- 10 -- 20
- 20 -- 30
- Above 30

Rape seed



Area under rape, %

- Below 5
- 5 -- 10
- 10 -- 20
- Above 20

Yield: Actual Critical

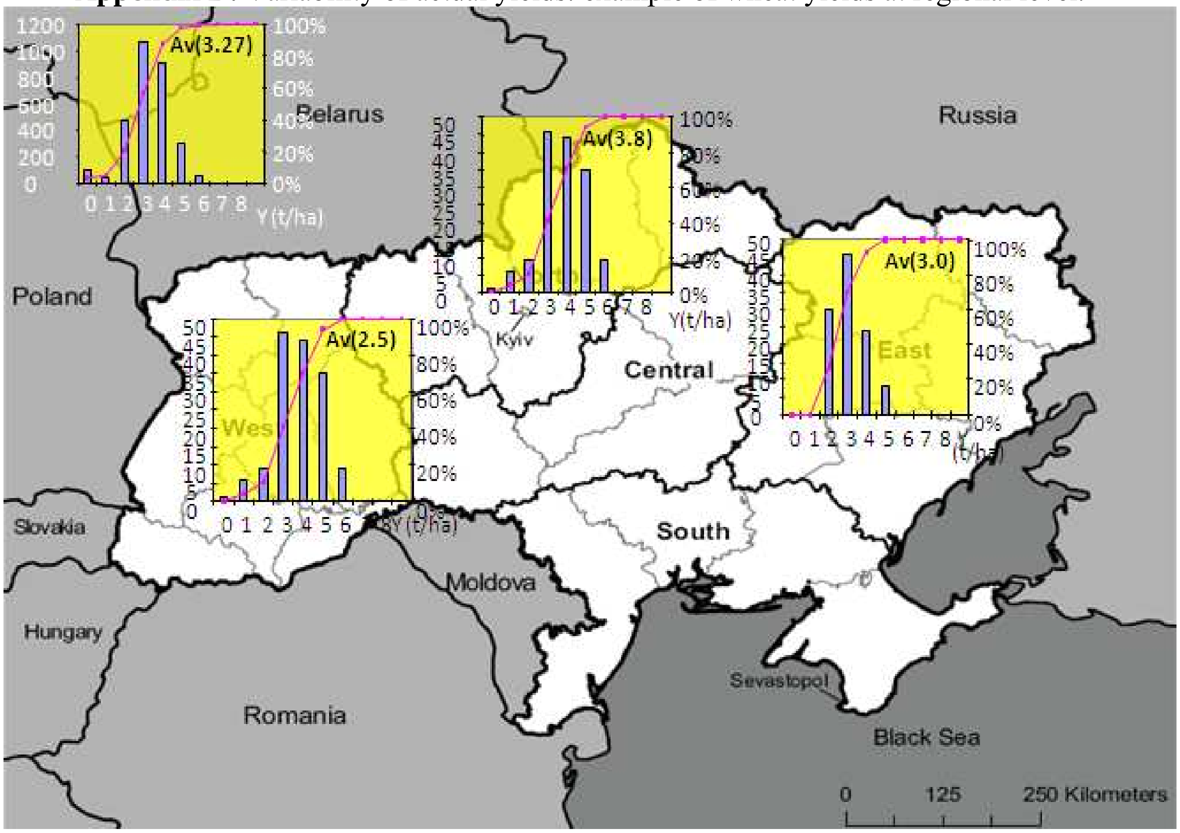
Indexes: sowed area

Appendix C. Actual vs critical yields: main crops (lease rates higher for 2 times)

	Wheat		Corn		SF		Rape seed	
	Actual	Critical	Actual	Critical	Actual	Critical	Actual	Critical
Crime	2.3	2.8	9.0	2.6	0.9	1.4	1.1	1.3
Vinnitsa	4.2	4.8	6.1	7.2	2.0	1.8	2.0	1.9
Volhynia	2.9	2.7	6.8	8.3	0.9	2.0	2.3	2.0
Dnepropetrovsk	3.2	3.8	3.6	4.1	1.6	1.4	1.5	1.5
Donetsk	2.9	3.7	2.9	5.5	1.7	1.6	2.3	1.9
Zhitomir	3.2	3.4	6.1	7.3	1.6	1.6	2.0	1.8
Transcarpathia	2.9	3.0	4.0	6.7	1.0	0.6	1.4	0.3
Zaporozhe	3.0	3.5	2.6	4.3	1.5	1.4	1.7	1.7
Ivano-Frankovsk	3.1	3.0	5.4	7.1	1.7	2.2	2.0	1.7
Kiev	4.0	4.4	6.5	7.8	2.5	2.1	2.2	2.0
Kirovograd	3.2	3.7	5.2	6.1	1.9	1.7	1.7	1.4
Lugansk	2.6	3.2	2.0	4.1	1.3	1.2	1.0	1.6
Lvov	3.3	3.3	7.0	6.5	1.1	12.2	3.3	1.9
Nikolayev	3.0	3.3	4.6	3.8	1.6	1.4	1.3	1.5
Odessa	2.8	3.2	2.5	4.0	1.1	1.2	1.5	1.3
Poltava	3.8	4.6	6.0	6.2	2.3	2.2	2.0	2.3
Rovno	3.4	3.7	4.8	11.7	1.5	2.6	2.5	2.4
Sumy	3.4	4.6	5.4	9.8	1.8	2.2	1.8	1.9
Ternopol	3.9	3.8	6.0	7.1	1.9	2.2	2.2	1.8
Kharkov	3.2	4.4	3.4	5.5	1.9	1.7	1.5	2.5
Kherson	2.5	2.9	6.0	7.0	0.5	0.6	1.2	1.2
Khmelnitsky	3.8	4.5	6.0	9.4	1.6	2.1	1.8	1.7
Cherkassy	4.8	5.5	7.5	6.3	2.4	2.2	2.1	2.1
Chernovtsy	3.7	2.9	4.8	9.7	1.6	1.7	2.6	2.5
Chernigov	3.4	3.8	5.4	6.5	1.8	1.5	2.0	2.1

[shaded box] - profitable production.

Appendix D. Variability of actual yields: example of wheat yields at regional level.



Appendix E. Distribution of land under crops according to the model (aggregated from the districts), ha.

	Wheat		Rye		Corn		Barley		Sunflower seeds		Soybeen		Rape seeds	
	ha	%	ha	%	ha	%	ha	%	ha	%	ha	%	ha	%
Crime	84.7	21.9	59.6	15.4	105.4	27.3	100.1	25.9	0	0.0	36.6	9.5	0	0.0
Vinnitsa	261.5	38.3	20.7	3.0	143.9	21.1	135.1	19.8	106.3	15.6	13.4	2.0	2.1	0.3
Volhynia	25.7	26.6	13.2	13.6	11.6	12.0	15.4	15.9	30.9	31.9	0	0.0	0	0.0
Dnepropetrovsk	310.2	32.4	19	2.0	127.2	13.3	185.7	19.4	242.2	25.3	47.9	5.0	26.2	2.7
Donetsk	181.1	37.1	19.5	4.0	64.1	13.1	27.9	5.7	48.7	10.0	141.9	29.0	5.5	1.1
Zhitomir	54.6	26.0	22.2	10.6	21.5	10.2	13.2	6.3	98.5	46.9	0	0.0	0	0.0
Transcarpathia	4.2	36.8	1.7	14.8	0	0.0	0	0.0	0	0.0	3.2	27.6	2.4	20.7
Zaporozhe	302	36.7	37.8	4.6	102.9	12.5	185	22.5	167.5	20.4	24.7	3.0	2.2	0.3
Ivano-Frankovsk	15.7	27.0	4.9	8.4	5.1	8.7	4.3	7.4	28.1	48.4	0	0.0	0	0.0
Kiev	272.6	40.8	20.3	3.0	120.5	18.0	97.3	14.6	155.7	23.3	0	0.0	1.7	0.3
Kirovograd	240.4	30.6	217.6	27.7	74.6	9.5	173	22.0	65.4	8.3	14.8	1.9	0.7	0.1
Lugansk	155.9	37.3	13	3.1	73.2	17.5	117.3	28.0	0	0.0	54	12.9	4.9	1.2
Lvov	55	42.9	12.7	9.9	0.9	0.1	25.91	20.2	32.1	25.0	0	0.0	2.4	1.9
Nikolayev	204.4	32.8	79.4	12.8	83.8	13.5	103.9	16.7	127.2	20.4	22.6	3.6	0.9	0.2
Odessa	277.7	33.7	28.9	3.5	164.8	20.0	188.4	22.8	128.6	15.6	36.7	4.5	0	0.0
Poltava	236.1	30.7	21.8	2.8	235.6	30.6	141.7	18.4	119.1	15.5	14.2	1.8	1.2	0.2
Rovno	43.4	29.1	7.4	5.0	0	0.0	47.6	31.9	31.1	20.8	0	0.0	19.8	13.3
Sumy	103.5	25.9	17.6	4.4	76.3	19.1	96.2	24.1	95	23.8	8.9	2.2	1.9	0.5
Ternopol	103.7	30.2	14.5	4.2	34.6	10.1	58.1	17.0	102.5	29.9	28.9	8.4	0.5	0.2
Kharkov	276	34.4	30.6	3.8	83.3	10.4	148.9	18.5	246.2	30.7	17.2	2.1	1.1	0.1
Kherson	200.3	33.7	19.7	3.3	98.3	16.5	112.2	18.9	147.2	24.8	14.9	2.5	1.7	0.3
Khmelnitsky	157	41.4	10.9	2.9	35.3	9.3	131.5	34.7	43.9	11.6	0	0.0	0.7	0.2
Cherkassy	147.5	23.9	9.1	1.5	235.5	38.2	64.5	10.5	131.5	21.3	27.3	4.4	0.6	0.1
Chernovtsy	0.4	0.5	4.3	5.5	18.4	23.6	25.8	33.0	27.7	35.4	0	0.0	1.7	2.2
Chernigov	120.9	28.7	10.9	2.6	44.3	10.5	106	25.2	125.3	29.8	12.1	2.9	1.4	0.3

Appendix F. Spatial distribution of robust crop portfolios suggested by the model.