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# PAST AND FUTURE LAND USE/COVER FLOWS RELATED TO AGRICULTURAL LANDS IN ROMANIA. AN ASSESSMENT USING CLUE-S MODEL AND CORINE LAND COVER DATABASE

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**Abstract:** The current paper aims to provide a regional-level (Development Regions) assessment of the past changes in the agricultural land use pattern during the 1990–2006 period and to simulate future changes (2007–2050) in order to detect the main potential agricultural flows and their regional differences. The simulation was carried out through the CLUE-S model (the Conversion of Land Use and its Effects at Small regional extent) using CORINE Land Cover (CLC) database and several biophysical and socio-economic explanatory variables associated with the current land use/cover pattern. Because of the political and socio-economic changes that took place after 1990 and their relevance for the resulted spatial transformations in land use/cover pattern, two scenarios based on the annual change rate of the 1990-2000 and 2000-2006 were used in order to explore potential future land use/cover changes. Thus, the predicted maps indicate significant changes in the agricultural land use pattern mainly in relation to the local-level conversion processes. Two change flows stand out, i.e. intensification and extensification of agriculture. The first flow is more likely to occur in the Banat and Crișana Plains and Hills, the Transylvanian Tableland and west of the Romanian Plain, while the second will mainly occur in the Moldavian Plateau, the Dobrogea Plateau, the central part of the Romanian Plain and the Subcarpathians. Furthermore, a significant increase in the agricultural lands related to forest losses and decrease related to forest gains are expected in the plain regions, Transylvanian Tableland, Getic Piedmont, Moldavian Plateau and Subcarpathians. The results of the current research provide important information on the future spatial distribution of the agricultural land use classes in order to improve the general understanding on the causes and consequences of change. Therewith, it can be utilized as reference study for further sustainable land use strategies and policy-making to ensure the effective management and use of agricultural land resources.

**Key-words**: past and future agricultural flows, CORINE Land Cover, CLUE-S model, Romania

## 1. INTRODUCTION

Land use and land cover change is a research topic within the global environmental context, having important consequences for environmental sustainability, as well as for food security. The conversion of cultivated land to non-farm uses, such as built-up areas, together with the even more growing population, is considered to be a serious threat to future food availability for some regions (Brown, 1995, Verburg at al., 1999). Also, the increasing agricultural land at the expense of natural areas (e.g. forests or grasslands) could have significant negative effects on environmental quality (e.g. biodiversity loss, habitat fragmentation, increased soil compaction, loss of nutrients) (Foley et al., 2005, Chhabra et al., 2006), thus enhancing the impacts of some extreme hydro-meteorological phenomena such as drought.

The pattern of agricultural lands is strongly influenced by a range of location factors, such as socio-economic development, environmental conditions (e.g. soil fertility, climate, topography), spatial planning (e.g. nature conservation), agricultural policies and the political context (Veldkamp et al., 2001). Also, under the current climate change context, large agricultural lands are affected by dryness and drought phenomena which call for special adaptation measures to limit the negative effects or avoid abandonment of these lands, especially in the most vulnerable areas. In effect, the European agriculture is strongly influenced by the Common Agricultural Policy (CAP) of the European Union implemented in 1960 with the aim at guaranteeing enough food for European citizens and providing the farmers with an adequate level of income (Stillwell & Scholten, 2001).

GIS and simulation models are important tools for monitoring land use/cover changes and development of future scenarios, as well as for understanding land use/cover patterns and complex driving mechanisms (Britz et al., 2011). Over the last decades, various spatially explicit models have been developed with the purpose of explaining and predicting the spatial dimension of land use/cover changes through empirical-statistical models (Irwin and Geoghegan, 2001; Lambin et al., 2000), rule-based simulation models, particularly cellular automata (Clarke et al., 1997; Kamusoko et al., 2009), agent-based models (Evans and Kelley, 2004; Parker et al., 2003), and hybrid models which combines estimation and simulation models (Veldkamp and Fresco, 1996). The CLUE-S (Conversion of Land Use/Land Cover and its Effects at Small regional extent) is one of the most frequently used models to predict land use/cover changes based on driving factors. This model is an example of advanced statistical empirical multi-scale land use/cover change model (Veldkamp & Fresco, 1996) developed for understanding and predicting the impact of biophysical and socio-economic forces that drive land use/cover change. Up to now, the model has been used and validated in a wide range of applications (e.g. Veldkamp et al., 2001; Verburg and Veldkamp 2004; Castella et al., 2007; Jinyan et al., 2007).

In the last three decades, agricultural lands in Romania underwent significant long-term changes, as a result of the socio-economic and political dynamics, as well as of biophysical and climatic drivers (Popovici et al., 2016). The most important changes of the post-communist period (after 1989) were reflected in the quality of agricultural lands, the new types of landed property, the land exploitation, as well as in the conversion of agricultural lands (inside the agricultural land use categories or between these categories and other land use/land cover classes, such as built-up areas or forest lands).

Generally, in Romania, studies on land use/cover changes and related landscape patterns have been conducted using various methods at different spatial scales. The methodology related to Land Cover flows was used in some studies at national (Popovici et al., 2013) and regional (Kucsicsa et al., 2015) level for analysing past land use/cover changes over two distinct periods 1990-2006, and 1912-2006, respectively. Several regional and local studies have used spatial and statistical analyses (e.g. logistic regression, proximity-based statistical analyses; change detection analyses based on satellite imagery or historical maps) in order to identify and assess the main land use/cover changes, driving forces and their impact on the environment or society. The main topics addressed in these studies have referred to cropland changes (Lakes et al., 2009; Kuemmerle at al., 2009), urban growth-related processes (Mihai et al., 2015; Grigorescu and Kucsicsa, 2017) and probability (Kucsicsa and Grigorescu, 2018), the reduction of fertile agricultural lands (Şandric et al., 2007; Ioja et al., 2011, Grădinaru at al., 2015), historical changes in forest and/or agricultural patterns and its drivers (Munteanu et al., 2014; Feurdean et al., 2017). Despite that, studies on the prediction of future land use/cover changes using modelling techniques have not been addressed so far in the Romanian literature. That being so, the aim of the current paper is to understand and assess the main past and possible future changes in the agricultural land use pattern in Romania using the CLUE-S simulation model and CORINE Land Cover database. The change analysis focused on different land use conversions taking place within the agricultural lands and in the resulted change flows. The concept of Land Cover Flows (LCF) applied in many studies i.e. Haines-Young and Weber (2006), Feranec et al., (2000, 2010). Such approaches are in order to understand and visualize the spatiotemporal dynamics of different land use/cover categories and patterns in relation to the explanatory driving forces in order to provide sustainable management solutions for the use of land resources.

## 2. MATERIALS AND METHODS

### 2.1. Description of the study-area

The biophysical and socio-economic conditions of Romania favor the great diversity of the land use/cover types with a significant extension of the agricultural lands and regional differences at the major landform units. According to the CLC 2012 datasets, *agricultural lands* represent almost 60% of the total country area. Due to the diversity of the natural conditions, the agricultural lands hold different shares in every major relief unit, with highest percentages of the total surface area in the plain regions (over 80%), between 60-80% in the Plateaus, 50-60 in the Banat and Crișana Hills and the Subcarpathians, and under 25% in the mountain regions and Danube Delta (Fig. 1). The analysed agricultural land use categories have a different distribution within the major relief units. Thus, *arable lands* represent the main agricultural land use class in the plain regions, Dobrogea Plateau and the Danube Delta with over 80% of the total agricultural area and in the Moldavian Plateau, Getic Piedmont and the Banat and Crișana Hills with 50-65% of the total agricultural area. *Permanent crops* (orchards and vineyards) cover the largest surfaces in the Subcarpathians and the Plateau regions. *Pastures* are present on significant surfaces in all the relief units, with the highest shares in the agricultural area of the mountains (30-40%) and the hilly (about 25%) regions. *The heterogeneous agricultural areas* are defined as areas occupied mainly by agriculture, interspersed with significant natural areas (e.g. grasslands, forests, moors, water bodies, bare rocks) around the villages, especially in mountain regions (the largest surfaces being registered in the Apuseni Mountains), but also in hilly and plateau regions. *The complex cultivation areas* include small parcels of arable lands, pastures and/or permanent crops, plus the gardens located around households. This class covers significant areas mainly in the mountain areas and the Getic Piedmont (10-15% of the total agricultural area).

## 2.2. Modelling future land use/cover dynamics

The current study aims at analysing the main future land use/cover change flows related to agricultural lands. The results rely on the CLUE-S model applied to predict the dynamics of land use/cover categories in Romania, assessed at regional level (Development Regions in Romania). The prediction is based on the CLC (available at the European Environment Agency) a database used as a basis for several studies carried out in Romania at the national and regional level (Kuemmerle et al., 2009; Feranec et al., 2000; Popovici et al., 2013; Hanganu & Constantinescu, 2015; Petrişor, 2015). This study used the CLC 1990 and 2000 (version 18.5) and 2006 (version 18.5.1) datasets (accessed 16.03.2017) to assess past changes over two periods (1990-2000 and 2000-2006) and to prepare the dependent and two independent variables (settlement density and distance to settlements) (Table 1). Furthermore, the CLC 2012 was considered as reference map in order to evaluate the spatial accuracy of the simulation. Based on CLC nomenclature classification, ten land use/cover categories were generalized and simulated: *built-up areas*, *arable lands*, *permanent crops*, *pastures*, *scrub and/or herbaceous vegetation association*, *forests*, *open spaces with little or no vegetation*, *heterogeneous agricultural areas*, *natural grasslands* and *agricultural complex cultivation patterns*. In Figure 2 is described synthetically the methodology used to calibrate, simulate, and validate the results.

### *2.2.1. Dependent variables: land use/cover categories*

The dependent variables have been prepared using the CLC 2006 datasets. Hence, for the simulation, a binary raster with the "presence" and "absence" for each category was created. Due to their complexity and rapid dynamics, few land use/cover categories (e.g. waters, inland marshes, mineral extraction sites) were not included in the simulation.

### *2.2.2. Explanatory factors*

In order to simulate land use/cover categories and, consequently, to analyse the future agricultural flows, 18 continuous biophysical and socio-economic driving factors were included in the model. The explanatory factors were selected according to the

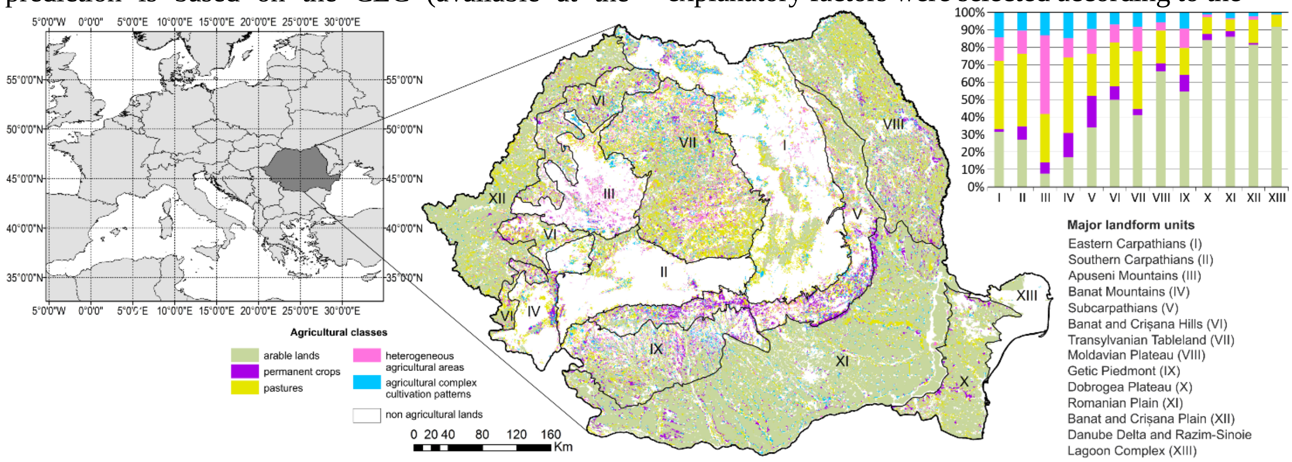

Figure 1. Study-area. The distribution of agricultural classes in the major relief units according to CLC 2012 datasets

knowledge of the study area, to the results provided by previous studies, the expert judgment, as well as to the availability of data. The data were adapted to spatially explicit layers of continuous data, in accordance with the geo-processing procedures described in Table 1.

Both, the dependent variables (land use/cover classes) and the driving factors for each raster cell were determined using ArcGis 10.4 and transformed into an ASCII text format (necessary for the simulation). Because of the large simulated areas and the different scale/resolutions of data used, a spatial resolution (pixel) of 500 m by 500 m was chosen for the simulation.

### *2.2.3. Modelling future land use/cover dynamics*

*The CLUE-S model*

The CLUE-S model was used to simulate the changes in land use/cover pattern and, consequently, to assess future dynamics of agricultural land use categories. The CLUE-S is a new version based on the early CLUE model (Veldkamp and Fresco, 1996). This is based on an empirical analysis of location suitability combined with the dynamic simulation of competition and interactions between the spatiotemporal dynamics of land use/cover systems and specifically developed for the spatially explicit simulation of the land use/cover change (Verburg et al., 2002). The model includes a spatial and a non-spatial module (Verburg et al., 2002), which combines statistical analyses and decision rules that determine the sequence of land use/cover types (Schaldach and Priess, 2008). The non-spatial module calculates the demands for land use/cover based on the analyses of the explanatory factors. The spatial module translates these demands into land use/cover changes according to the probabilities and rules of the different land use/cover types using a raster-based system. Furthermore, Verburg et al., (2002) provided a more detailed description of the model.

*The model calibration*

The current simulations of land use/cover conversion revealed the following aspects:

*Land use/cover requirements.* Because of the political and socio-economic changes that took place after 1990 in Romania and their relevance for the resulted spatial transformations in the land use/cover pattern, two scenarios were used in order to explore potential future land use/cover changes. In the first scenario ($S_1$), the land use/cover changes from 2007 to 2050 were predicted by interpolating the linear trends of the annual change rate occurred between 1990 and 2000 (Table 2). This interval covers the period subsequent to the fall of the communist regime

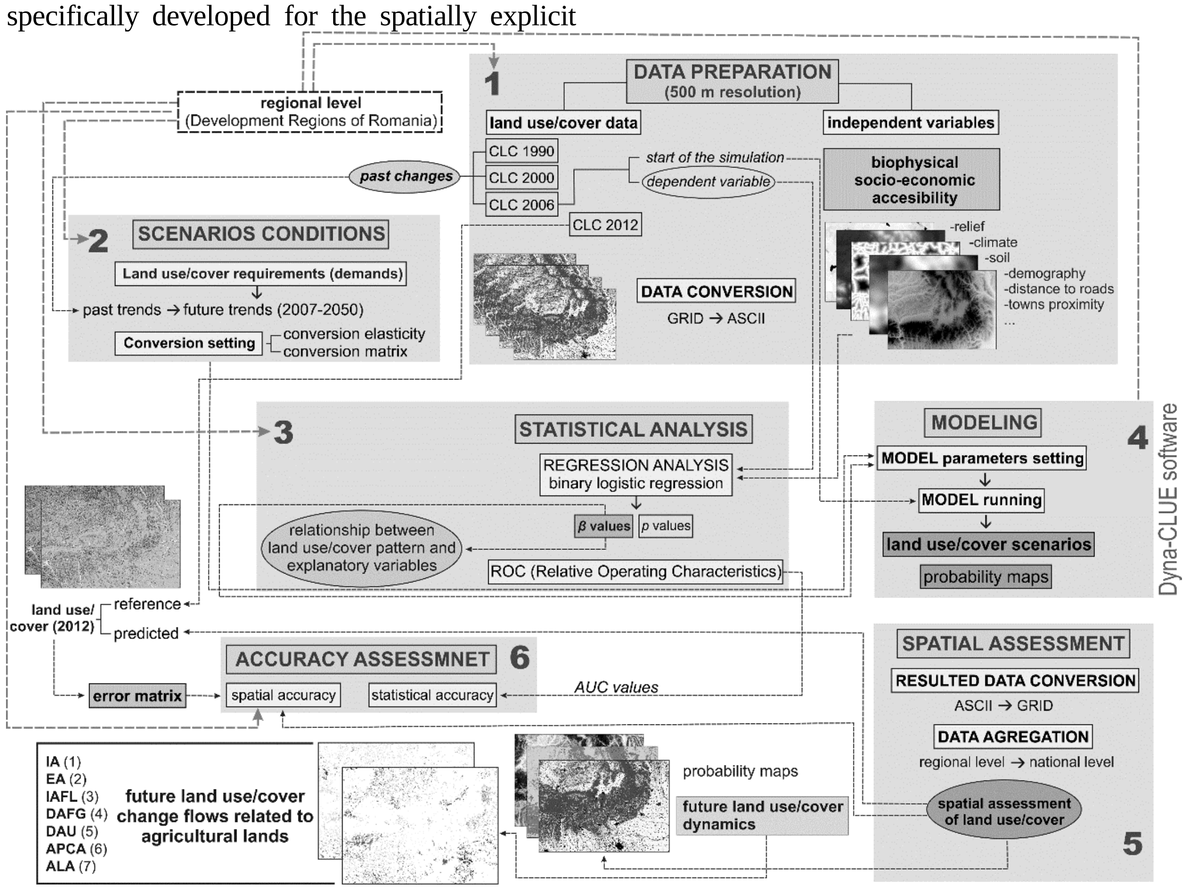


Figure 2. Flowchart of the methodology used to predict the future land use/cover pattern and to analyse the main change flows related to agricultural lands.

Table 1. Independent variables included in the logistic regression model.

| Explanatory variable | Derived by | Data preparation procedure |
|---|---|---|
| *Elevation* | Digital Elevation Model (DEM–30 m resolution) | Merging datasets into elevation raster (m) |
| *Slope declivity* | Digital Elevation Model (DEM–30 m resolution) | Calculating slope raster layer (º) |
| *Precipitation* | National Meteorological Administration (1 km resolution) | Merging datasets into annual average precipitation (1961-2015) raster (mm) |
| *Temperature* | National Meteorological Administration (1 km resolution) | Merging datasets into annual average temperature (1961-2015) raster (°C) |
| *Horizontal relief fragmentation* | EU-Hydro River Network, accessed in 07.04.2017 (20 m resolution) | Calculating line density (in km/km$^2$) |
| *Total organic matter content in topsoil* | Romania – Soil quality and electricity transmission grid. Geographical atlas (16 km resolution) | Categorical to continuous raster, ranging from extremely low to excessive (8 categories) |
| *Population density* | Population census (2006)* | Calculating population density (inh/km$^2$) |
| *Population growth* | Population census (1992, 2006)* | Calculating population growth in the 1992-2006 period (‰) |
| *Employees* | Population census (2006)* | Merging datasets into employees raster (no) |
| *Unemployment rate* | Population census (2006)* | Merging datasets into unemployment rate raster (%) |
| *Employments in the tertiary sector* | Population census (2006)* | Number of employees in the tertiary sector |
| *Large Livestock Units (LLU)* | Population census (2006)* | Calculating the LLU number |
| *Built/non-agricultural ratio* | Population census (2006)* | Calculating the ratio between built-up and non-agricultural land (in %) |
| *Settlement density* | CLC datasets 2006 (accessed 16.03.2017)** | Calculating point density (no/km$^2$) |
| *Distance to nearest main towns(county-seat)* | National Institute of Statistics | Calculating Euclidean distance to nearest main towns*** |
| *Distance to nearest main roads (motorway, European, national and county roads)* | ESRI Romania database (scale 1:5000) | Calculating Euclidean distance to nearest main roads*** |
| *Secondary roads density (communal, forestry and agricultural roads)* | ESRI Romania database (scale 1:5000) | Calculating line density (km/km$^2$) |
| *Distance to settlements* | CLC datasets 2006 (accessed 16.03.2017)** | Calculating Euclidean distance to nearest settlements*** |

* available at LAU2 (Local Administrative Units — the low-level administrative divisions in Romania)

** CLC minimum mapping unit = 25 ha

*** due to the large study area and the chosen resolutions of the simulation, the distance was calculated using a buffer ring equal to 1 km

(1989), largely overlapping the so-called transition period which led to a series of radical political and socio-economic transformations with influences on excessive fragmentation and degradation of the productive quality of agricultural lands, the abandonment of arable lands and permanent crops which gives place to conversion into other urban sprawl-related land use categories (Popovici et al., 2013; Grigorescu et al., 2015; Popovici et al., 2016). In this period, the main land use/cover changes which have characterised Romania were: important increase in the agricultural complex cultivation patterns (1.76%), heterogeneous agricultural areas (0.6%), built-up areas (0.6%) and forest cover (0.4%) related to decrease in scrub and/or herbaceous vegetation association (3.7%) and permanent crops (3.0%). In relation to these changes, significant dynamics in the agricultural lands are expected until 2050 at the regional level. Overall, an important increase in heterogeneous agricultural areas and agricultural complex cultivation patterns are expected, while permanent crops and pastures will considerably decrease. Furthermore, according to this scenario, almost similar surfaces of arable lands are expected in 2050 (Table 2). The second scenario ($S_2$) assumes that land use/cover will change based on the interpolated linear trends of the annual change rate occurred between 2000 and 2006 (Table 2). This interval overlaps the so-called post-transition period which gave rise to changes mainly related to the country's accession to the European Union and the adoption and implementation of the Common Agricultural Policy (CAP). As a consequence, important land use changes associated with the conversion of agricultural, forest or pasture lands to residential, commercial and industrial (logistic) through deforestation and urban sprawl (suburbanisation) processes took place (Popovici et al., 2013; Grigorescu et al., 2015; Grigorescu and Kucsicsa, 2017). In this period, increase of the pastures (2.2%), arable lands (1.7%), built-up areas (0.2%) and forests (0.2%) in relation to the decrease of the natural grasslands (9.7%),

Table 2. Annual rate of change (ha) of agricultural land classes calculated for $S_1$ and $S_2$ according to the past changes occurred in the 1990-2000 and 2000-2006 periods. Differences at the level of Development Regions in Romania

| | Development Regions | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | North–East | | North–West | | Centre | | South–East | | South Muntenia | | South–West Oltenia | | West | |
| agricultural classes | $S_1$ | $S_2$ | $S_1$ | $S_2$ | $S_1$ | $S_2$ | $S_1$ | $S_2$ | $S_1$ | $S_2$ | $S_1$ | $S_2$ | $S_1$ | $S_2$ |
| *arable lands* | +790 | –1054 | +125 | +3020 | –830 | +5691 | +98 | –7075 | +213 | –5841 | –263 | +4558 | –135 | +7934 |
| *permanent crops* | –460 | –1046 | –178 | +496 | +9 | –1033 | –1175 | –150 | –430 | +583 | –218 | –754 | –165 | –1541 |
| *pastures* | –1078 | +1313 | –295 | +796 | +443 | –1279 | –163 | +9271 | +83 | +5170 | +58 | –1090 | –118 | –3924 |
| *heterogeneous agricultural areas* | +90 | –1833 | +28 | +813 | +508 | –2858 | +13 | –1191 | –65 | +71 | +83 | –592 | +103 | –1655 |
| *agricultural complex cultivation patterns* | +442 | +2954 | +205 | –2004 | +220 | –1200 | +408 | +760 | +18 | –329 | +160 | +188 | +80 | –831 |

permanent crops (5.1%) and heterogeneous agricultural areas (7.8%) have been identified. According to these past changes, until 2050 significant increase in pastures and arable lands are expected, while heterogeneous agricultural areas, permanent crops and agricultural complex cultivation patterns will considerably decrease (Table 2).

*Conversion settings.* The conversion settings for specific land use/cover types determine the temporal dynamics of the simulations (Verburg, 2010). In this direction, two sets of parameters were configured based on past changes and the authors' understanding of the land use/cover system in the study area: conversion elasticity (ELAS) and land use/cover transition sequences (TS). ELAS is related to the reversibility of land use/cover changes, the values ranging from 0 (easy conversion) to 1 (irreversible change). For the current simulation, the following values were established: built-up areas = 1.0; arable lands = 0.3; permanent crops = 0.6; pastures = 0.2; scrub and/or herbaceous vegetation association = 0.6; forests = 0.7; open spaces with little or no vegetation = 0.9; heterogeneous agricultural areas = 0.4; natural grasslands = 0.3; agricultural complex cultivation patterns = 0.5. According to the TS, all land use types could be converted into any land use category (TS = 1), except for the built-up areas which could not be converted into other categories (TS = 0). Moreover, scrub and/or herbaceous vegetation association and forests were not allowed to change to built-up areas and permanent crops.

*Logistic regression analysis.*

For the location characteristics, the relations between land use/cover pattern and the explanatory factors were quantified through logistic regression (using the forward stepwise method) in order to determine the location suitability of each analysed land use/cover types (Verburg et al., 2002). The corresponding coefficients of the best fitted predictor sets were subsequently used to calculate suitability maps for each land use/cover type. The results of the logistic regression analysis were tested using ROC (Relative Operating Characteristics), a measure of the goodness of fit of the logistic regression model (Pontius & Schneider, 2001). In the standard ROC approach, the predictive probability map is compared with the map of the true binary event in order to assess the spatial coincidence between the event and the probability values (Mas et al., 2013). A completely random model gives a ROC value of 0.5, while a perfect fit results in a ROC value of 1.0.

Finally, the simulation was carried out with the Dyna-CLUE software (v 2.0), based on the probability maps, the decision rules and the actual land use/cover map (CLC 2006) conducted by an iterative procedure (Verburg et al., 2002). In order to assess the spatial accuracy of the simulations, a cross-classification map was created by overlaying the predicted results (2012) and the real data (CLC 2012). As a result, the spatial fit was calculated based on the confusion matrix, a common method applied to test the accuracy in land use modelling (Verburg et al., 2002; Ahmed et al., 2013). Depending on the error matrix, different statistical accuracy measures were calculated: Overall Accuracy (OA), Producer's Accuracy (PA), User's Accuracy (UA), and Kappa index (Cohen, 1960).

### 2.3. Establishing the major change flows related to agricultural lands

Past changes (1990–2006) in the agricultural land use pattern and predicted future changes (2007–2050) have facilitated the establishment of the main change flows in agricultural lands. The method used to assess land use/cover change flows was developed by Stott & Haynes-Young (1998), Haines-Young & Weber (2006), Weber (2007), Feranec et al. (2000, 2007, 2010) who grouped the changes by major land use processes. According to their methodology, Popovici et al. (2013) and Kucsicsa et al. (2015) identified eight main land cover flows to assess past changes in the land use/cover pattern in Romania at national and regional scale using the CLC database.

Based on the previous methodology and its adaptation to the land use/cover simulated categories, in the present study the authors identified and analysed seven change flows related to agricultural lands, depending on the transition matrix (Fig. 3) between the land use/cover categories of the current and the predicted year (in this study 2006 and 2050, respectively): (1) *intensification of agriculture* – IA (internal conversion of agriculture from lower-to-higher intensity of use, and also conversion from scrub and/or herbaceous vegetation association and natural grassland classes to agriculture classes); (2) *extensification of agriculture* – EA (internal conversion of agriculture from higher-to-lower intensity of use); (3) *increasing agricultural lands related to forests losses* – IAFL (conversion of forest to agricultural areas); (4) *decreasing agricultural lands related to forest gains* – DAFG (conversion of agricultural areas to forests and scrub and/herbaceous vegetation association); (5) *decreasing agricultural lands related to urbanisation* – DAU (conversion of agricultural classes to built-up areas); (6) *arable and permanent crops abandonment* – APCA (replacement of arable and permanent crops with grasslands and open spaces) and (7) *other agricultural land abandonment*, others than arable and permanent crops – ALA (conversion of heterogeneous agricultural areas and agricultural complex cultivation patterns to natural grasslands and open spaces). Because in calibrating the CLUE-S model the built-up areas were assumed not be allowed to convert to other land use/cover categories, the transition between this category and agricultural lands was not identified.

## 3. RESULTS

### 3.1. Explanatory variables of the land use/cover pattern. The regression results

The explanatory factors of agricultural lands are different across the development regions in Romania. Regression results suggest that the spatial relations between the explanatory factors and the characteristics of the agricultural land use classes vary in terms of the ecological potential and the socio-economic characteristics of each development region. According to the *Nagelkerke* $R^2$, the higher values (0.41–0.61) were obtained for arable lands, indicating that the explanatory factors included in the model together explain between 41% and 61% the occurrence of this land use class. For the remaining agricultural classes, the obtained *Nagelkerke* $R^2$ values were: 0.11–0.34 for permanent crops; 0.08–0.11 for pastures; 0.09–0.17 for heterogeneous agricultural areas and 0.09–0.14 for agricultural complex cultivation patterns. The predictor sets attained good statistical accuracy. Ergo, the AUC values indicate a good fit between the predicted and the real agricultural land classes. The greatest prediction ability was found for arable lands in the West (AUC = 0.91), South Muntenia and Centre (AUC = 0.90) Development Regions, permanent crops in the North-East (AUC = 0.82) and South–East (AUC = 0.80) Development Regions and for heterogeneous agricultural areas in the South-East (AUC = 0.79), Centre and South Muntenia (AUC = 0.77) Development Regions. Except for pastures in the North-West Development Region with an AUC value of 0.6, the AUC is equal or greater than 0.75, which in most cases suggests a good correlation and good capacity to explain the agricultural pattern by the explanatory factors included in the model.

*Model interpretation*

The relative contribution of the explanatory factors was evaluated using the corresponding coefficients in the logistic regression. According to the spatial resolution and data used, the $\beta$ coefficients show that biophysical factors and variables related to accessibility make the most important contribution to explaining the current spatial pattern of agricultural lands in Romania (Fig. 4).

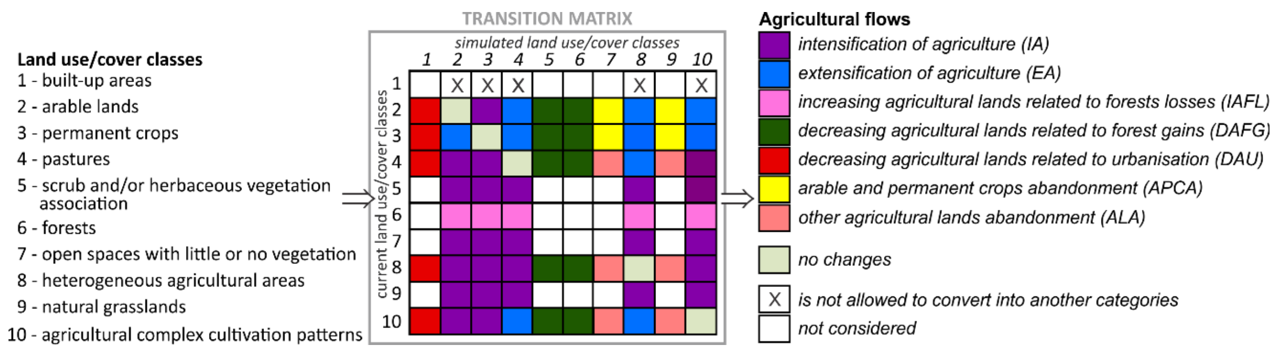


Figure 3. Matrix of future land use/cover change flows related to agricultural lands.

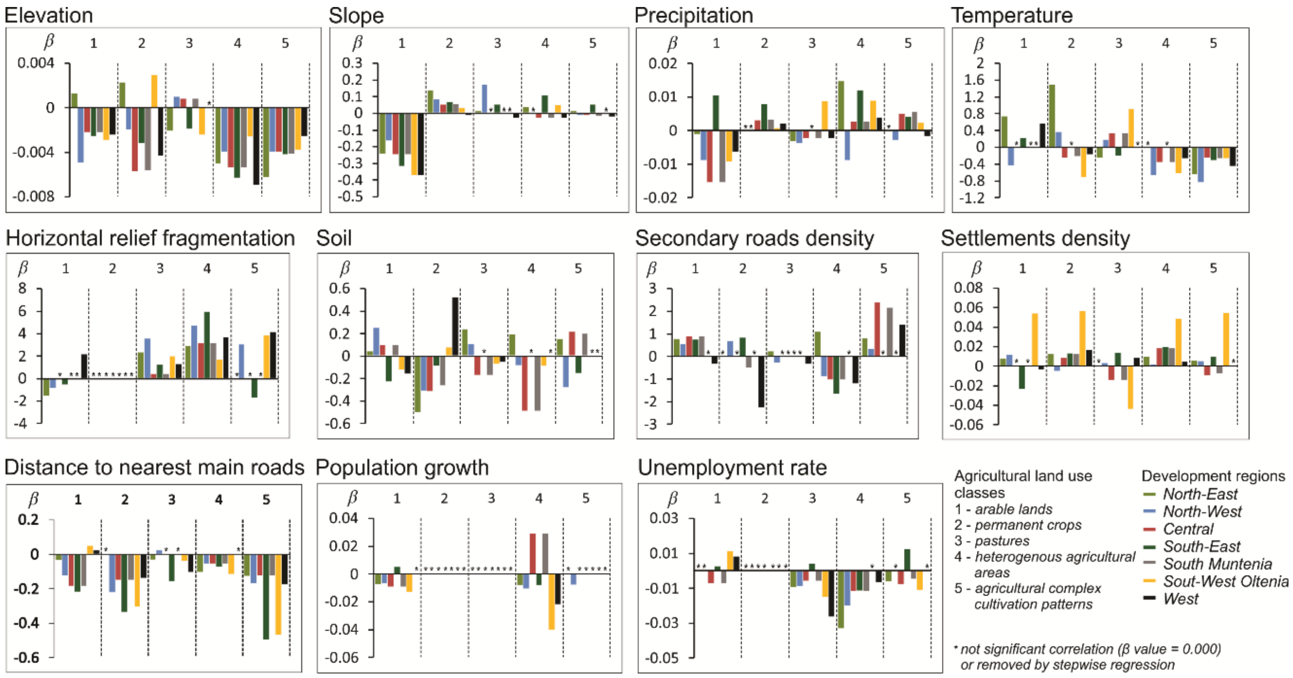


Figure 4. The graphical representation of the $\beta$ values of the most important factors determined by logistic regression

Among all analysed variables, the horizontal relief fragmentation was found to be the most significant predictor with a positive contribution mainly to pastures and heterogeneous agricultural areas, and a negative one to arable lands in most Development Regions. The model also reveals that as the slope increases, the arable land area decreases. In terms of climatic features, the temperature is positively related to the occurrence of arable lands, permanent crops, and pastures, having a negative relation with heterogeneous agricultural areas and agricultural complex cultivation patterns because of their large extension mainly in the Subcarpathians and the mountainous regions. The influence of secondary road density on the agricultural land use pattern is also evident. The regression model makes a positive contribution to arable lands and agricultural complex cultivation patterns, indicating the great occurrence of this category mainly inaccessible areas. Furthermore, the proximity of main roads has a significant influence on all agricultural land use classes, negative $\beta$ values showing that the transportation network affects mostly arable lands, permanent crops and agricultural complex cultivation occurrence. The models demonstrate that the remaining explanatory factors related to biophysical and socio-economic indicators are little significant for the current spatial pattern of agricultural lands. However, agricultural land use classes are more likely to occur in the lowlands and generally when the precipitation amounts increase. Furthermore, agricultural land classes tend to occur in areas where population growth and the unemployment rate are low.

### 3.2. Past and future changes in agricultural land use pattern

The post-communist period experienced profound socio-economic and political changes that have had a significant impact on agricultural land use categories, both in terms of spatial distribution and productive potential. According to CLC datasets, permanent crops were the land use category with a negative record in both study periods, their surface decreasing by over 64,175 ha (Table 3). While in the first period (1990-2000) permanent crops, complex cultivation areas, and pastures registered major spatial changes, the last two categories having a positive trend; in the second period (2000-2006) it was arable lands and pastures with a significant increase, while heterogeneous areas, permanent crops, and complex cultivation areas had the highest area losses.

Over the 2007-2050 period, except for arable lands, the model indicates that the agricultural land use will continue the historical trend registered in the 1990-2000 and 2000-2006 periods. In consequence, the simulations show a decrease in permanent crops by almost 14% in $S_1$ and 23% in $S_2$, respectively. Heterogeneous agricultural areas are expected to have the most significant spatial changes, an increase by 10.7% under $S_1$ and a decrease of 32.3% under $S_2$. $S_1$ predicts an area reduction by 4.3% for pastures and 1.7% for arable lands, in opposition with $S_2$ that estimates increases for both classes (15.2% for pastures and 2.7% for arable lands). Furthermore, the model indicates an increase in complex cultivation areas under $S_1$ (6.6%) and a decrease under $S_2$ (4.9%).

Table 3. Agricultural land use in Romania over the 1990-2006 period (according to CLC datasets) and predicted under $S_1$ and $S_2$ scenarios.

| | Past changes | | | | | Future changes | | | |
|---|---|---|---|---|---|---|---|---|---|
| *class* | ha | | | gains and losses (%) | | ha | | gains and losses (%) | |
| | *1990* | *2000* | *2006* | *1990–2000* | *2000–2006* | *2050 ($S_1$)* | *2050 ($S_2$)* | *2006–2050 ($S_1$)* | *2006–2050 ($S_2$)* |
| *1* | 8,148,250 | 8,150,225 | 8,290,875 | +0.02 | +1.7 | 8,153,225 | 8,524,725 | –1.7 | +2.7 |
| *2* | 805,775 | 781550 | 741,600 | –3.1 | –5.4 | 652,725 | 604,850 | –13.6 | –22.6 |
| *3* | 2,533,275 | 2,521,775 | 2,576,125 | –0.5 | +2.1 | 2,469,350 | 3,039,375 | –4.3 | +15.2 |
| *4* | 1,180,075 | 1,187,650 | 1,094,600 | +0.6 | –8.5 | 1,225,850 | 827,075 | +10.7 | –32.3 |
| *5* | 834,450 | 849,075 | 840,250 | +1.7 | –1.1 | 899,750 | 800,800 | +6.6 | –4.9 |

1 – arable lands; 2 – permanent crops; 3 – pastures; 4 – heterogeneous agricultural areas; 5 – complex cultivation areas

### 3.3. Past and future agricultural flows

Seven main flows were analysed based on the past dynamic of agricultural land use categories, as well as on the simulation of their future evolution under the two development scenarios.

Over the 1990-2000 period, a total of 3,956,600 ha (17% of the country's surface-area) underwent changes, of which 39% represents the internal conversion of agricultural lands (intensification and extensification) and 61% changes between these categories and other land use classes, such as built-up areas, forest lands, grasslands, etc. In the second period (2000-2006) the changed area covered over 4,900,000 ha, while the internal conversion of agricultural lands represents 48% of all changes. According to the change detection matrix (Fig. 4), the most frequent land use/cover flows related to agricultural lands over the 1990–2000 interval were DAFG (21.8% of the total changed area), IA (20.8%), IAFL (18.5%) and EA (18.0%). Over the 2000–2006 period, the same flows had the highest percentages, but the most significant ones were IA and EA, by 27.3%, and 20.7%, respectively, of the total changed area (Table 4).

Concerning the spatial distribution of the past agricultural lands dynamics (Fig. 5a) one may notice significant disparities within the major relief units. The highest frequency of DAFG and IAFL flows is found in the mountain and hilly units, while IA and EA are characteristic of lowlands and Plateaus. Steepest shrinking of agricultural land to the benefit of forestland occurred between 1990 and 2000, mainly in the Apuseni Mountains (42% of the total changed area), the Banat Mountains (36%), the Southern Carpathians (35.3%) and the Eastern Carpathians (34.9%). At the same time, these were the regions in which the forest area was reduced mainly in favor of pastures or heterogeneous agricultural land. The expansion of built-up area to the detriment of agricultural land occurred in all relief units and in both periods, particularly in the Romanian Plain, the Subcarpathians, the Banat and Crișana Plain, the Moldavian Plateau and the Dobrogea Plateau. Between 1990 and 2006, the share of DAU/total changed-affected area ranged from 3.5% (the Apuseni Mountains) and 17.6% (the Romanian Plain). Agricultural land abandonment flows (APCA and ALA) affected rather small areas, being almost evenly distributed on the territory of the major relief units, except for ALA which affected larger areas at a rate of 8.3%/total change-affected area over 1990-2000 and of 7.3% over 2000-2006. The IA and EA occurred especially in the lowlands and the Plateaus, yet IA and EA held a relatively equal share in almost all the relief units except for the mountain regions and the Danube Delta, where IA than rather EA held by far higher shades in all the major relief units, less so in the Romanian Plain, the Moldavian Plateau and the Danube Delta.

Table 4. Past and future agricultural flows

| Flows | 1990-2000 | | 2000-2006 | | 2007-2050 ($S_1$) | | 2007-2050 ($S_2$) | |
|---|---|---|---|---|---|---|---|---|
| | ha | % | ha | % | ha | % | ha | % |
| Intensification of agriculture (IA) | 821,550 | *20.8* | 1,365,275 | *27.3* | 435,800 | *29.7* | 1,449,725 | *42.3* |
| Extensification of agriculture (EA) | 710,650 | *18.0* | 1,034,050 | *20.7* | 569,100 | *38.7* | 1,269,150 | *37.0* |
| Increasing agricultural lands related to forests losses (IAFL) | 732,975 | *18.5* | 774,200 | *15.5* | 146,075 | *9.9* | 368,125 | *10.7* |
| Decreasing agricultural lands related to forest gains (DAFG) | 862,475 | *21.8* | 919,300 | *18.4* | 184,575 | *12.6* | 179,350 | *5.2* |
| Decreasing agricultural lands related to urbanization (DAU) | 402,675 | *10.2* | 438,775 | *8.8* | 56,550 | *3.8* | 96,600 | *2.8* |
| Arable and permanent crops abandonment (APCA) | 16,050 | *0.4* | 12,650 | *0.3* | 66,275 | *4.5* | 45,700 | *1.3* |
| Other agricultural land abandonment (ALA) | 5,250 | *0.1* | 20,125 | *0.4* | 11,200 | *0.8* | 15,225 | *0.4* |
| Total changes | 3,956,600 | *100.0* | 4,992,375 | *100.0* | 1,469,600 | *100.0* | 3,425,650 | *100.0* |

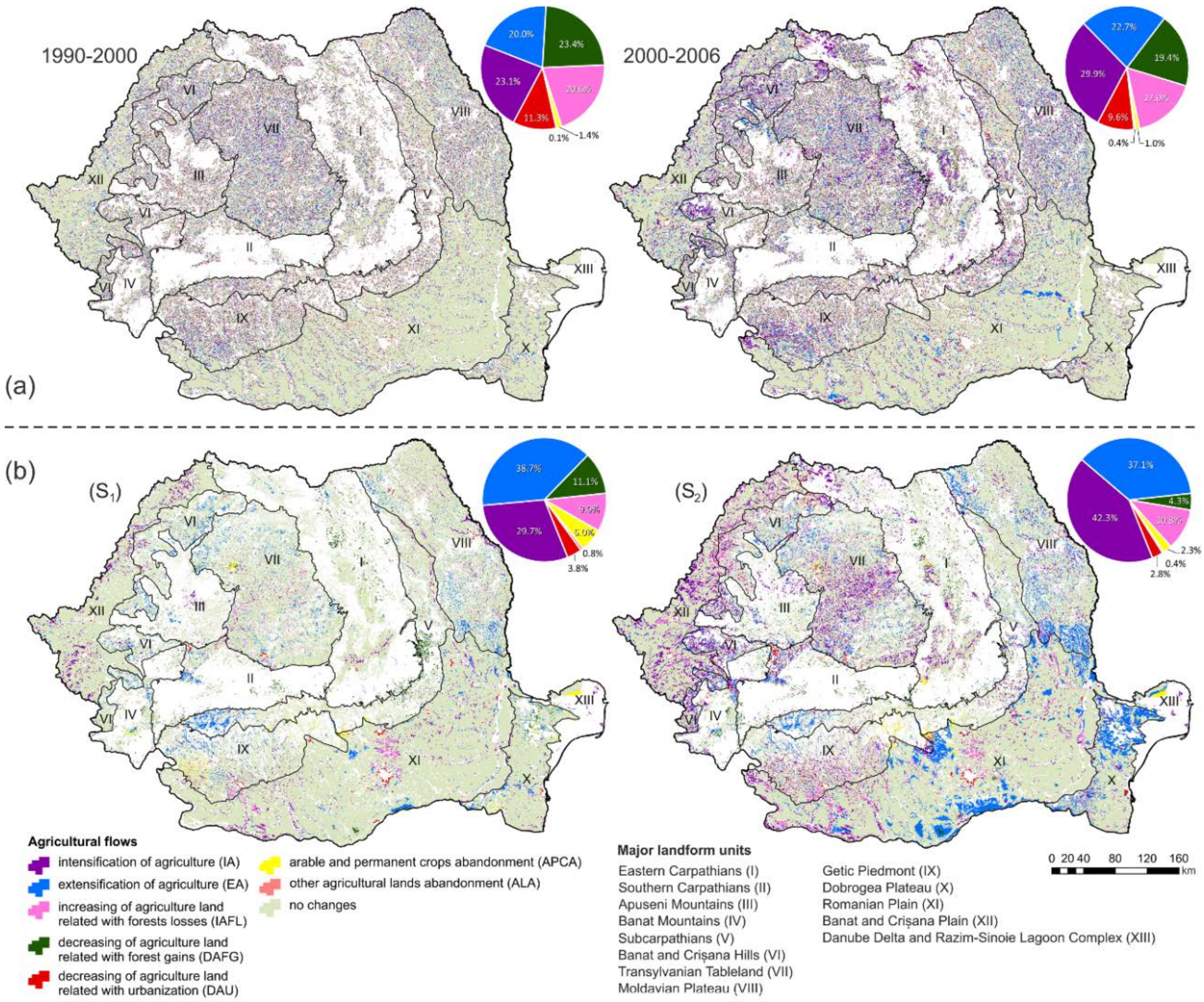


Figure 5. Past (a) and predicted (b) agricultural flows over 2007-2050 according to $S_1$ and $S_2$ scenarios.

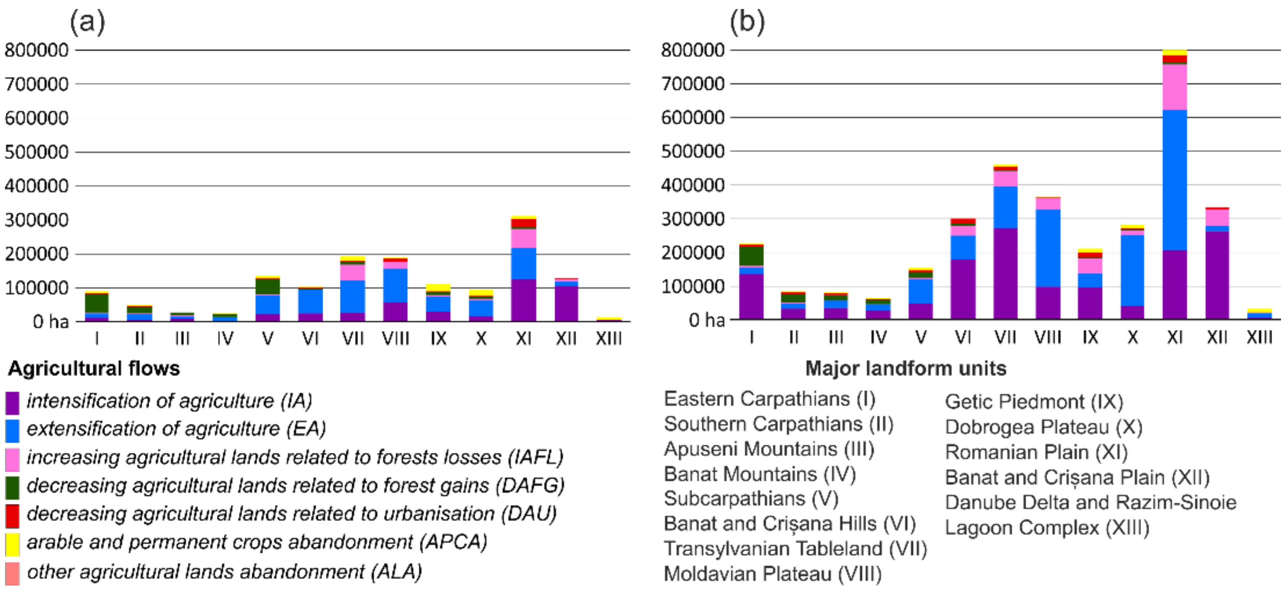


Figure 6. Comparative graphics representing the area of predicted agricultural flows according to $S_1$ (a) and $S_2$ (b) in the major landform units of Romania.

The predicted future dynamics of the agricultural flows (Fig. 5b) is different in both simulated scenarios and in the main relief units. The analysis of the predicted data reveals that the changes in agricultural land use classes will cover about 1,469,600 ha (6.4%) in $S_1$ and 3,425,650 ha (14.9%) in $S_2$ of the country's surface area. From the total land use/cover changes related to agricultural lands, the internal agricultural changes (IA and EA) are expected to have the highest percentages under both scenarios (Table 4).

*Intensification of agriculture* (IA) represents 29.7% ($S_1$) and 42.3% ($S_2$) of the total agricultural flows (Table 4). The highest intensification values are predicted to occur in the plain, plateau and hilly regions (the Banat and Crișana Plain and Hills, the Transylvanian Tableland, the western part of the Romanian Plain) where the expansion of arable lands and permanent crops to the detriment of pastures is expected (Fig. 6). Substantial agricultural area growth is also estimated for all mountain regions, with most significant increases under the $S_2$. Within these regions, the development of agricultural lands will occur mainly to the detriment of natural areas (scrub and/or herbaceous vegetation association).

*Extensification of agriculture* (EA) is the main predicted flow according to $S_1$ (38.7%) and the second flow according to $S_2$ (37% of the total agricultural flows). The transition of arable lands and permanent crops to pastures will occur mostly in the plain and plateau regions (e.g. the Romanian Plain, the Moldavian Plateau). Decreasing arable land mainly in favor of heterogeneous agricultural areas will take place in the Subcarpathians, the Transylvania Plateau and the northern part of the Dobrogea Plateau (Fig. 6).

*Increasing agricultural land related to forest losses* (IAFL) will hold approximately equal percentages under the $S_1$ and $S_3$, 9.9% and 10.7%, respectively, of the total agricultural flows (Fig. 6) and is likely to cover large areas in the plain and plateau regions (the Romanian and Banat and Crișana Plains, the Transylvanian Tableland, the Moldavian Plateau and the Getic Piedmont), involving mainly the conversion of forest into arable lands and pastures. In the Transylvanian Tableland, the most common conversion process is expected to be a transition of the forest into heterogeneous agricultural areas.

*Decreasing agricultural land related to forest gains* (DAFG) represents 12.6% ($S_1$) and 5.2% ($S_2$) of the total agricultural flows. This flow will occur in the Eastern and Southern Carpathians and Supcarpathians (Fig. 6), where forest areas and scrub and/or herbaceous vegetation association would largely develop mainly in the expense of pastures and heterogeneous agricultural areas.

*Decreasing agricultural lands related to urbanization* (DAU) is a most common flow in the vicinity of large cities, especially in the Romanian Plain and the Transylvanian Tableland. Over the 2007–2050 period, the conversion of agricultural lands into built-up areas is expected to have a positive trend, covering 56,550 ha (3.8%) according to $S_1$, and 96,600 ha (2.8% of the total agricultural flows) according to $S_2$. This process will be more obvious around of the main towns in the Romanian Plain, the Transylvanian Tableland, the Getic Piedmont and the Banat and Crișana Hills (Fig. 6).

*Agricultural land abandonment* represents the conversion of agricultural classes into grasslands and open spaces with little or no vegetation and was divided into two flows in order to emphasize the territorial disparities of the major relief units: *arable and permanent crop abandonment* (APCA) and *other agricultural land abandonment* (ALA), the second flow including pastures, heterogeneous agricultural areas and complex cultivation areas. APCA is expected to hold a higher percentage according to $S_1$ (4.5% of the total changed area) than under $S_2$ (1.3% of the total agricultural flows). The most affected regions will be the Getic Piedmont, the Dobrogea Plateau, the Banat Mountains, the Danube Delta and depressionary areas of the Eastern Carpathians (Fig. 6). The flow will be mainly related to the transition of the arable lands into grasslands or into open spaces with little or no vegetation. Abandonment of pastures, heterogeneous agricultural areas, and complex cultivation areas will cover relatively small surfaces that is 11,200 ha (0.8%) under $S_1$ and 15,225 ha (0.4% of the total agricultural flows) under $S_2$, predominantly in the mountain regions and in the west of the Getic Piedmont (Fig. 6).

### 3.4. Spatial accuracy

The values obtained for the spatial accuracy assessment (OA = 85.7% and Kappa = 0.8 for $S_1$; OA = 86.1% and Kappa = 0.82 for $S_2$) suggest that the model captures the trends in land use/cover changes, mainly according to the $S_2$. On this account, the simulated arable lands (UA = 93.3%; PA = 96.51%), heterogeneous agricultural areas (UA = 93.5%; PA = 76.5%) and pastures (UA = 76.8%; PA = 73.3%) had the greatest accuracy. By contrast, the permanent crops (UA = 54.2%; PA = 54.6%) and agricultural complex cultivation patterns (UA = 71.4%; PA = 58.6%) were the least accurate. As for the major landform units, best results were obtained in the Romanian Plain and the Banat and Crișana Plain, where correct prediction percentages of the simulated agricultural lands vary between 77-81%.

Good agreement results were registered mainly for arable lands and permanent crops. Therefore, in the Moldavian Plateau and in the Dobrogea Plateau percentage of correct prediction that is about 69%. In these regions, arable lands, permanent crops, and pastures were accurately predicted. Notable disagreements were found in the mountain units, mainly for the heterogeneous agricultural areas, agricultural complex cultivation patterns, and arable lands.

## 4. DISCUSSIONS

In the present study, the past trend after 1990 was assumed for future land use/cover dynamics and, consequently, for future agricultural flows tendency. These past changes took place during the transition period from a centralized to market economy, the most unstable period in terms of land property and marked dynamics generating significant agricultural changes, most of them with negative consequences on land quality (e.g. excessive fragmentation of farmlands, the emergence of numerous individual farms practicing subsistence agriculture, poor services for agriculture). Due to the political and socio-economic transformations, the studied period was divided into two distinct intervals implemented as scenarios in order to explore potential future land use/cover changes: 1990-2000, marked by the fundamental changes in agriculture when collective and state property were being replaced by the private property, and 2000-2006, corresponding to Romania's pre-accession to the European Union. Both scenarios reflect more or less the actual trend in the area, but for the future longer period (until 2050) we assume that it only provides a hypothetical comparison. However, the post-accession period (after 2007) should be considered as associated with several land use changes connected to the adoption and implementation of the Common Agricultural Policies and availability of structural funds. Given that the CLC dataset from the year 2012 was used only for the spatial validation of the model, the land use/cover dynamics after 2006 was not analysed and, consequently, the changes related to the post-accession period were not taken into consideration. Hence, the resulted predicted maps should be used as a preliminary data on the future potential land use/cover pattern and, therefore, on the future land use change flows related to agricultural lands.

Our results showed a different evolution of the seven agricultural flows in each of the two developed scenarios and in the landform units. The future dynamics of agricultural flows is directly influenced by the past changes in land use/cover pattern and by biophysical and socio-economic drivers. Two flows stand out under both scenarios – intensification, and extensification of agriculture. According to $S_2$, IA represents 42% of the total agricultural flows, compared to 29% under $S_1$. Also, IA has a smaller expansion than EA in $S_1$ and higher in $S_2$. This situation can be attributed to different political and socio-economic changes during the transition and post-transition periods. After 2000, the availability of European non-reimbursable funds, plus the legislative framework favourable to the foreign citizens to invest in the Romanian agriculture, large arable areas left fallow in the period of transition, started being re-cropped. On the other hand, possible enlargement of the EA under $S_2$ in the central part of the Romanian Plain, the Dobrogea Plateau and the south of the Moldavian Plateau could be attributed to the intensification of drought and dryness phenomena, but also to the lack of functional irrigation systems.

The continuous expansion of built-up areas inside and outside city boundaries is expected to be one of the mainland consumers. Decreasing agricultural lands in the favor of built-up areas (e.g. urban fabric, industrial, commercial and transport units) will be mainly related to the urban sprawl phenomenon. In the past, this process had been taking place in the vicinity of main cities at the expense of fertile arable land in the plain areas; vineyards, orchards, pastures and agricultural complex cultivation areas in the hills; pastures and heterogeneous agricultural areas in the mountains (Grigorescu et al., 2012, 2015, 2017; Ioja et al., 2011, Grădinaru et al., 2014), as follows they are being expected to have the same trend in the future.

During the post-communist period, especially in the second analysed interval (2000-2006), the expansion of the forest area is due primarily to natural regeneration (particularly in the mountain and Subcarpathian regions) and took place on abandoned arable lands, pastures and on deforested terrains (Popovici et al., 2013). The predicted results on the future decreasing agricultural lands related to forest gains show a tendency of pastures and heterogeneous agricultural areas to be abandonment and invaded by the transition vegetation. On the other hand, forest losses will be mainly in relation to the extension of arable lands, pastures and complex cultivation areas in the most important agricultural regions of Romania or in the accessible mountain units, where the heterogeneous agricultural areas cover large surfaces or where intensive logging occurs.

The current study has certain limitations and assumptions in the calibration of the model and generating the simulated maps that must be considered. The first refers to the unavailable datasets for the independent variables. For that reason, the resulted from pseudo $R^2$ suggest that the analysed explanatory factors included in the model together better explain only the arable lands. Within this context, in order to allow a better and realistic modelling, more predictor data (e.g. other data about the demographic and economic situation, land management and reclamation, land tenure, land price) must be integrated. Also, it is acknowledged that agricultural lands are very sensitive to climate change, socio-economic development, policies and market dynamics and any unexpected changes in these driving factors could influence the future pattern. Therefore, the current results only display the spatial changes (2007-2050) in agricultural lands pattern depending on the analysed explanatory factors, without considering the dynamic factors or political changes (e.g. climatic and demographic scenarios, Land Laws, land use planning). On the other hand, important limitations related to the spatial data resolution and accuracy of used data must be also considered. Due to minimum mapping area (25 ha), as well as the uncertainties in the visual interpretation of the satellite images, uncertainties related to vectorising of certain land use/cover type as well as related to locations affected by changes provided by the CLC database must be considered. Furthermore, the availability of socio-economic statistical data, only at the LAU2, and the coarse resolution of some of the spatial data (e.g. total organic matter content in topsoil, climatic data) also had restricted the accuracy of the model. Under these circumstances, it can be appreciated that, in the future, agricultural flows might affect more or less other areas indicated by the current research.

The values obtained for the spatial validation of the simulation suggest that the model captures most significant trends of land use/cover changes, mainly in the Romanian Plain and the Banat and Crișana Plain and in the Moldavian and the Dobrogea Plateau. In addition, it can be assumed that agricultural land changes based on the historical trends in the 2000-2006 period ($S_2$) related to pre-accession to the European Union better explain the current spatial distribution and future tendency in agricultural land use pattern.

Such insight on the land use/cover changes can provide valuable information for the decision-making process in agriculture. On that account, to foresee the negative impacts, to identify potential conflicts between competing for land functions, and to develop sustainable land use strategies to mitigate them (Fürst et al. 2013; Seppelt et al. 2013; Stürck et al., 2015) might be some of the expected achievements of such study.

## 5. CONCLUSIONS

The present study could be considered as preliminary work in explaining the spatial relationships between agricultural lands pattern and its explanatory factors in order to model the spatial changes in agricultural flows until 2050 at a regional scale (Development Regions), simulated by CLUE-S model. The results suggest that the explanatory factors vary under the ecological potential and socio-economic conditions of each development region. Overall, the regression models demonstrate that agricultural lands are mainly triggered by the biophysical characteristics (relief and climatic features, total organic matter content in topsoil) and accessibility. The results did not indicate a significant relationship with the population density, employees, employment in the tertiary sector, large livestock units or built/non-agricultural ratio. In addition, the predicted maps indicate significant changes in land use/cover classes related to agricultural lands to occur over the 2007-2050 period, with important disparities at the major relief units. As a consequence, the model predicts that the internal agricultural changes (intensification and extensification of agriculture) are expected to be the most important agricultural flows under both scenarios, mainly in the most important agricultural regions in Romania (Romanian Plain, Banat and Crișana Plain, Transylvanian Tableland). Significant increases in agricultural lands related to forest losses are expected also in the plain regions and Transylvanian Tableland, as well as in the Getic Piedmont and Moldavian Plateau. Furthermore, decreasing in agricultural lands related to forest gains is predicted to occur in the mountain regions and Subcarpathians in relation to forests and transitional vegetation expansion.

Because of the uncertainty linked to the input data and model calibration, the results of the current research should be considered as a preliminary work in order to identify areas with potential land use/cover change flows related to agricultural lands. This could help improve our understanding of the causes, locations, and consequences of land use changes, and be a reference for sustainable land use and policy-making to ensure sustainable management and use of agricultural land resources. In addition, the predicted map generated in this study can provide the basis for other scenarios where explanatory factors sets could be improved according to the specific biophysical and anthropogenic changes of an area.

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