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LAND USE AND CROP DYNAMICS RELATED TO CLIMATE CHANGE SIGNALS DURING THE POST-COMMUNIST PERIOD IN THE SOUTH OLTENIA, ROMANIA

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Climate change strongly influences the environment having consequent impacts on natural resources in general and particularly on land use/land cover dynamics. The paper is aiming to relate socio-economic changes over the post-communist period and climate change signals in southern Oltenia (mainly represented by increased temperature, decreased precipitation and extreme events phenomena such as aridity and drought) to land use dynamics and agricultural production. The authors used and processed a wide range of statistical socio-economic data (land use/land cover pattern, cultivated areas, crop production, fertilizers), meteorological data (daily, monthly and annual from the most representative meteorological stations in the study-area), as well as spatial data (Corine Land Cover 1990, 2000, and 2006). Defining and explaining the complex causal interactions between climate change signals and land use dynamics were depicted by means of some relevant climatic indicators (Standardized Precipitation Index as well as Climatic Water Deficit and Thornthwaite Aridity Index for the main crops), land use data processing using GIS techniques (change, conversion, relocation) and multiple causal correlations between the acquired climatic and land use parameters with crop production.

Key words: land use dynamics, crop production, climate change signals, climatic indexes, South Oltenia.

INTRODUCTION

Land use dynamics and climate change and variability, soil degradation, as well as other environmental transformations interact to affect natural resources through their effects on ecosystem structure and functioning. Understanding ecosystems' response to climate and land use changes is compulsory for human beings to protect the environment and their components (CCSP, 2003; Gao *et al.*, 2004). Therefore, environmental challenges such as deforestation, urban sprawl, agriculture, and other related socio-economic issues with global dynamics have substantially altered and fragmented land. Climate variability and change can affect and can also be affected in various manners land use/land cover usually having local impacts but with global consequences. As a result, reconstruction of past land-cover changes and projection of possible future land-cover changes are needed to understand past climate changes and to project possible future climate alteration, thus land-cover characteristics could become important inputs to climate models. In addition, changes in land use and land cover, especially when coupled with climate variability and change, are likely to affect ecosystems and the many important goods and services that they provide to society (Entwisle and Stern, 2005).

Based on observational data on a global scale and mostly on various scenarios of possible future changes, the Fourth IPCC Assessment Report (AR4) on the key climatic parameters puts forward an increasing rate of warming characterized by significant regional differences and many situations with extreme temperatures and frequent heat waves,

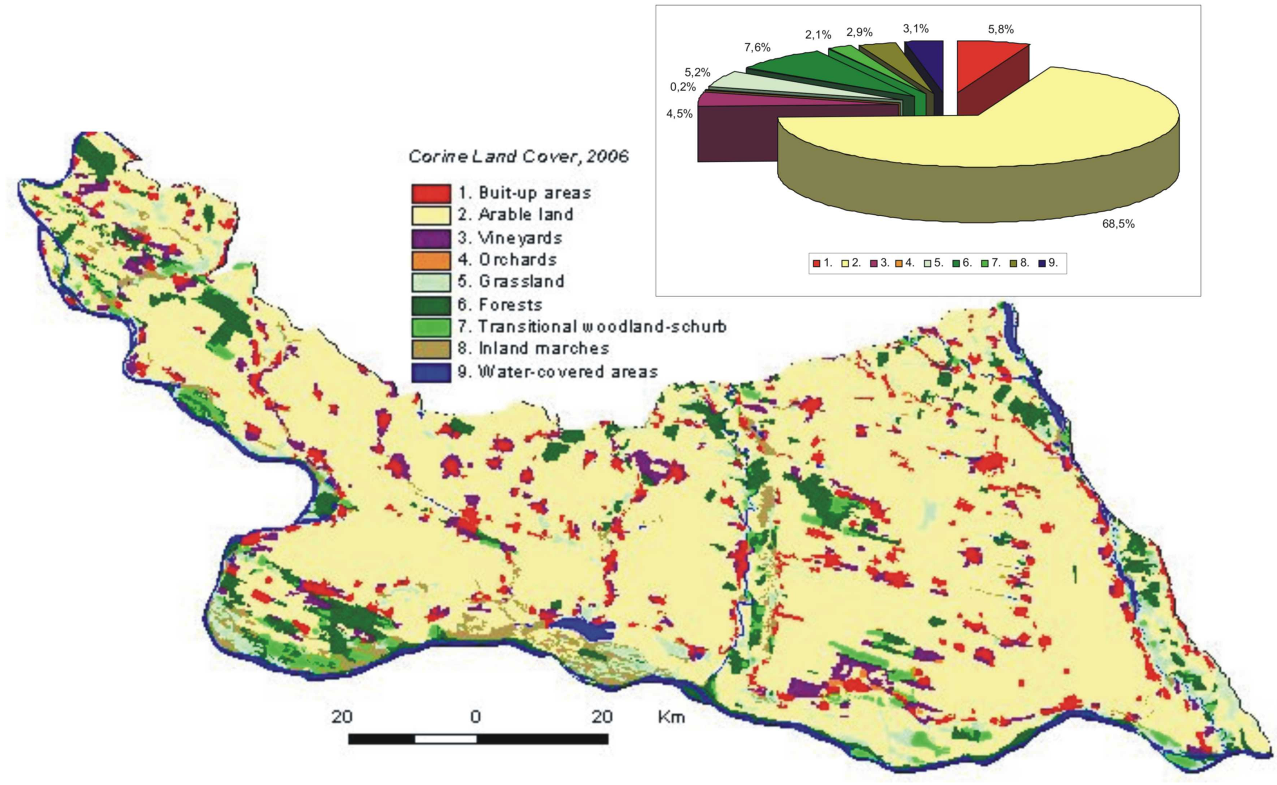

Fig. 1. Land use map of Southern Oltenia (Corine Land Cover, 2006).

excessive droughts and heavy rainfall, etc. (IPCC, 2007). Most of these scenarios estimate that the drought will persist and increase in intensity in critical agricultural regions of Europe (especially in the southern and south-eastern regions) regions that will suffer pronounced dryness, heat, water shortage and an increasingly reduced agricultural production (Păltineanu *et al.*, 2007a, Păltineanu *et al.*, 2009). Studies conducted in Romania underline as major drivers of global climate change: increased air temperature, decreased precipitation and ultimately the extended aridity and drought phenomena, especially during the crop growing season, thus having a great impact on agricultural production. Most of areas exposed to aridity and drought phenomena in Romania (considered on a global scale under the Köppen climate classification) are located in the south, southeast and east of the country (Marica and Busuioc, 2004; Păltineanu *et al.*, 2007a, 2007b, 2009; Busuioc *et al.* 2010a, Sandu *et al.*, 2010, Dragotă *et al.*, 2011).

Therefore, in south Oltenia, changes in temperature and precipitation regime over two future projected intervals (2021–2050, 2071–2100) under A1B emission scenario, were acquired from two sources (Busuioc *et al.*, 2010a; Busuioc *et al.*, 2011): a) through statistical downscaling models developed over the reference period 1961–1990 and applied to the changes of predictors derived from two RCM (regional climate models) simulations (CNRM and RegCM3) achieved in the framework of ENSEMBLES project (van der Linden and Mitchel, 2009); b) directly from 8 ENSEMBLES RCM outputs. Thus, the uncertainty given by the differences of the climate change signals derived through various models is reduced. Consequently, among the 9 ENSEMBLES RCMs analysed by Busuioc *et al.* (2010a), the two RCMs considered as input in the SDMs are the most accurate in simulating the annual temperature and precipitation values in South Oltenia (Busuioc *et al.*, 2010b).

According to the above mentioned climate change scenarios in south Oltenia the mean annual temperatures would rise by 1.1 in 2021–2050 and 2.6°C in 2071–2100 against the current climatic period (1961–1990). In terms of mean annual precipitations, a decrease of over 40 mm (2021–2050) and 124 mm (2071–2100) against the reference period is projected. Therefore, the outcomes of the climate change scenarios point towards significant seasonal changes in terms of both temperature and precipitation values (Table 1).

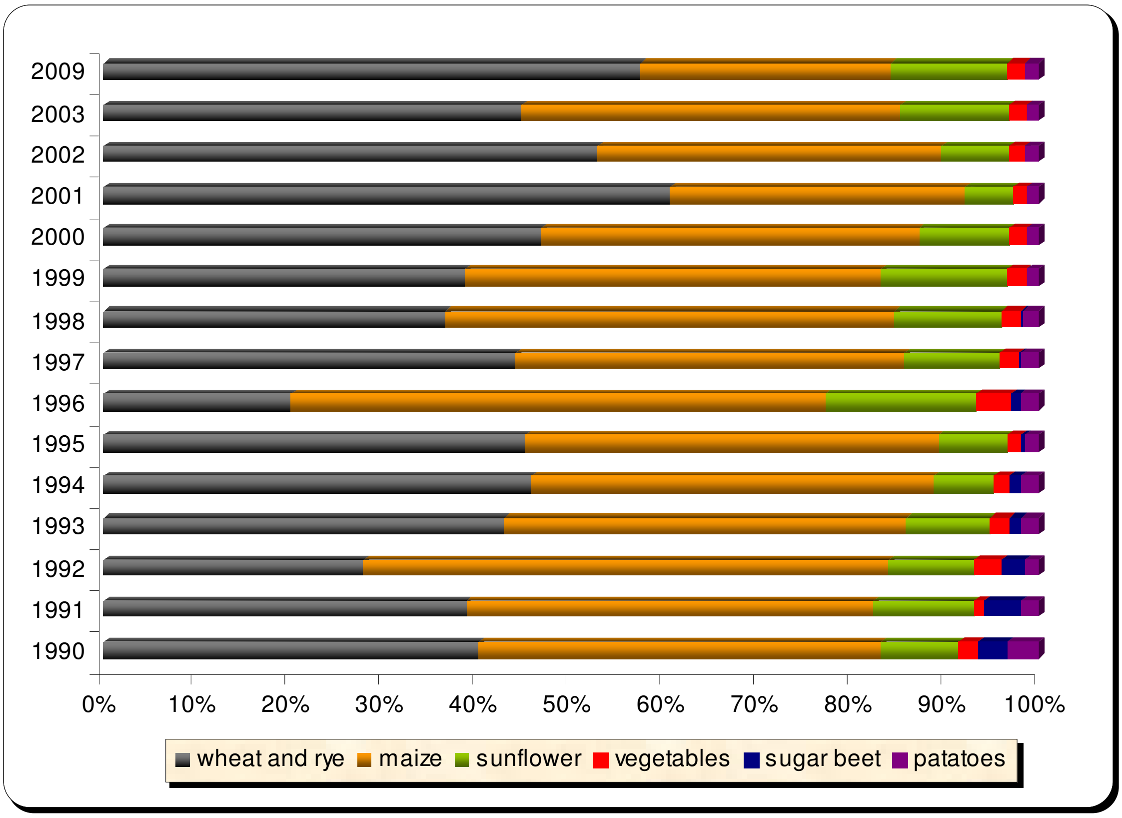

Fig. 2. Cultivated area in southern Oltenia.

Table 1

The mean seasonal deviation of temperature and precipitation amounts for the two climate change periods against the reference interval (1961–1990)

	Period	Winter	Spring	Summer	Autumn
Temperature (ºC)	2021–2050	+ 0.8	+ 0.9	+ 1.7	+ 1.0
	2071–2100	+ 1.9	+ 2.0	+ 3.7	+ 2.7
Precipitation (mm)	2021–2050	– 5	– 8	– 6	+ 19
	2071–2100	+ 6	– 11	– 35	+ 3

Subsequently, in southern Oltenia aridity and drought phenomena are the most important trends of global climate changes, especially over the last decades, having the greatest impact on the agricultural sector in terms of decreasing agricultural productivity, increasing land degradation and livestock heat stress. Concurrently, in the post-communist period, these outcomes are the result of a range of complex interactions with other political, social, economic and environmental factors. Understanding the key drivers of land use and their interrelationship with land management decisions and policies one may be able to project future land uses under certain economic, environmental, and social scenarios in order to minimize negative impacts, especially as related to climate change (Entwisle and Stern, 2005). Under these conditions, in addition to the development of several climate change scenarios, various international projects had tackled the impact of climate change signals on different economic sectors such as: tourism, agriculture, energy supply and public in order to estimate economic vulnerability and impacts on the national economies (*e.g.* EU FP6-CLAVIER project).

STUDY AREA

The study-area is situated in the south-western part of Romania, between Danube and Olt rivers covering about 8,350 sq.km (17% of the Romanian Plain area). It has a relatively low relief with piedmont plains, river terraces, which are extensively covered by Aeolian sands, and floodplains. The propitious natural conditions made the region inhabited from the earliest times, settlements developing and becoming traditionally agricultural. It is dominantly rural, with 73.35% of its population living in the country-side.

Current land use. The South Oltenia is one of the most important agricultural regions in Romania. The natural conditions (relief, soils, climate, etc.) were propitious for expansion of *agricultural land* to over 79% of total surface area. Agricultural terrains include *arable land* (68.53% of total plain area), *pastures and hayfields* (4.46%), *vineyards and orchards* (4.7%) (Fig. 1).

In terms of structure, most of the arable area (over 80%) is cultivated with grain cereals (maize, wheat and rye) which are suggestive of a cereal-growing agriculture, followed by oleaginous plants (mainly sun-flower) over 14% and other crops (potatoes, vegetables, sugar beet, etc.) 6% (Fig. 2).

Natural and semi-natural vegetation cover relatively small surfaces - 14.5%, of which *forests* represent 7.6%, *transitional woodland-shrubs* 2.1%, and *grassland* 5.2% because favorable natural conditions have in time led to the extension of farmland (Fig. 2). These categories of lands are more extended along the Valley of the Danube and of the main rivers (the Olt and the Jiu) that run across the plain from north to south. *Wetlands* have the largest spread along the floodplains of large rivers (the Danube, the Olt and the Jiu) and together with *water-covered areas* hold near 6% of the study-area.

During the communist period, wetlands had shrunk significantly as a result of the ample drainage and embankment works in the Danube Floodplain in view of expanding the agricultural areas.

Built-up areas cover 5.81% of the terrains and include urban and rural settlements, different buildings for agricultural and industrial activities (greenhouses, silos, industrial sites, etc.), commercial units, sport and leisure facilities, road and rail networks, mineral extraction sites, lands covered with domestic and industrial waste, etc.

The Oltenia Plain is dominantly rural, with 148 settlements, of which 9 small towns with under 20,000 inhabitants each and with a population density of 76 inh./km^2 (below the country average of 90 inh./km^2).

Current climatic conditions. According to the climatic regionalization, Southern Oltenia falls in the transitional temperate-continental climate with Mediterranean influences.

It develops thermal characteristics of more then 10 ^{o}C (exceeding 11 ^{o}C in the Danube Floodplain), precipitation between 500–600 mm/year, air humidity amid 78–80% and mean annual potential evapotranspiration of over 700 mm/year (Sandu *et al.*, 2008; Dragotă *et al.*, 2011), specific for the plain areas in the south of the country.

Its climatic individuality, mainly supported by the coupling of air temperature and precipitations, is given by the aridity and drought phenomena. In the framework of the actual climate changes, these restrictive climatic phenomena represent the main natural hazards which are affecting the study-area.

METHODS AND DATA

In order to identify and analyze the main land use changes during the post-communist period the Corine Land Cover database; *EEA*, 1990, 2000 and 2006, and the 1989–2009 statistical figures supplied by the National Institute of Statistics (Romanian Statistics Yearbooks, Tempo On-line database, etc.) have been used. The statistical data (cultivated area, crop production, fertilizers) were available at commune level (NUTS 5). The irrigation data were provided by the National Administration of Land Improvement (Danube-Olt branch), and also a lot of additional data have been obtained from field surveys.

The original 23 classes of the Corine Land Cover characteristic for southern Oltenia were grouped into 9 major land use/land cover categories, which include the following classes: built-up areas, arable land, vineyards, orchards, grassland, forest, transitional woodland-shrub, inland marches and water-covered areas (Table 2).

Additionally, by using GIS-based methods, the CLC 1990, 2000 and 2006 shape files were converted to raster files. These were reclassified and each land use category was assigned with a 1 to 9 code.

Using Map Calculator tool to compute a subtraction between grids, several values revealing the level of land use changes were identified as follows: 0 values pixels representing no change in land use structure (*0 = no change)* and values lower or higher than 0, indicating changes in land use pattern *(< 0 > = change)*.

The authors made use of valuable analogue and digital data (climatic, demographic etc.) with the aim of correlating land use dynamics with climate change in southern Oltenia. Therefore, the authors used and processed annual, monthly and daily climatic values (temperature, precipitations, wind, potential evapotranspiration etc.) from the most significant meteorological stations inside the study-area (Craiova, Caracal, Băileşti, Calafat), as well as from Turnu Măgurele and Drobeta Turnu Severin, situated in the adjacent region and considered as support stations for the 1961…2007 time frame. For defining and characterizing the relationship between the dynamics of the climatic elements and climate change on one hand and land use dynamics on the other, some relevant climatic indexes and indicators were used.

Table 2

Corine Land Cover for southern Oltenia

Corine Land Cover Classes	
111 Continuous urban fabric	1. Built-up areas
112 Discontinuous urban fabric	
121 Industrial areas	
123 Port areas	
124 Airports	
131 Mineral sites	
133 Construction sites	
141 Green urban areas	
211 Non-irrigated arable land	2. Arable land
213 Rice fields	
242 Annual crops assoc. with permanent crops	
243 Complex cultivation patterns	
221 Vineyards	3. Vineyards
222 Orchards	4. Orchards
231 Pastures	5. Grassland
321 Natural grasslands	
331 Beaches-dune-sand	
311 Broad-leaved forests	6. Forest
313 Mixed forests	
324 Transitional woodland-shrub	7. Transitional woodland-shrub
411 Inland marches	8. Inland marches
511 Water courses	9. Water-covered areas
512 Water bodies	

Firstly, in an attempt to quantify the precipitation anomalies, versus the average for multiple time scales (3, 6, 9, 12 months) (Hayes, 2002, 2003), out of which the present paper has concentrated on the last one, the **Standardized Precipitation Index (SPI)** was calculated. On the basis of the resulted values the South Oltenia region frames into the ***deficit domain*** (SPI $\leq$ -2 = extremely dry), placing the study-area amongst the most affected regions of Romania by aridity and drought (Dobrogea and Southern Moldova). According to the hierarchy of natural hazards conducted by Bryant, 1991 at global scale and yet adapted by Croitoru and Moldovan, 2005 for the Romanian territory, dryness and drought phenomena are ranked first.

Secondly, in order to emphasize once more the aridity and drought characteristics of the study-area, which conditions the **Climatic Water Deficit (WD)**, the **Thornthwaite Aridity Index** (**1948) (Iar-TH)** for the growing season (April-October) was calculated.

The complex assessment of aridity and drought characteristics have taken into account the following parameters: air and soil temperature, relative humidity, saturation deficit, rainfall (annual amounts of precipitation, semestrial, seasonal, monthly, the maximum amount fallen in 24 hours, liquid and solid precipitation frequency), direction and wind speed etc. The spatial distribution of the extreme classes of the analyzed parameters and indexes overlaps mostly with the agricultural fields in southern Oltenia.

RESULTS AND DISCUSSIONS

Impact of political, socio-economic and climatic drivers on land use pattern

Over the last 20 years, land use/land cover in Romania underwent significant changes being the result of the dynamics of political, socio-economic, technological, as well as, biophysical and climatic drivers.

As from 1989, the fall of the communist regime marked the beginning of a new, transitional period towards the market economy, a new stage in the evolution of agriculture and implicitly in land use. The most important changes of that period were seen in the space dynamics of the main land use/land cover categories and their quality, a new type of landed property and land exploitation (Popovici, 2008).

In the transition period (1990–2003), the permanent expansion of private property is the direct outcome of the decollectivisation and privatisation of agriculture, a process that begun in 1990, by the enactment of Land Law 18/1991, completed and modified by Law 169/1997 and Law 1/2000 (Popescu, 2001; Bălteanu *et al.*, 2004, 2005). This set of laws stipulated the retrocession of agricultural and forest land to their former owners or their heirs; initially it was to be 10 ha equivalent arable land/family, eventually Law 247/2005 providing for *restitution in integrum*.

In the post-transition period (2003-to-date) corresponding to Romania's pre- and post-accession to the European Union, the main land use changes being connected with the adoption and implementation of the Common Agricultural Policies (CAP).

Some of the negative effects of the post-communist land reform were the excessive fragmentation of farming land, the emergence of large numbers of individual farms practicing

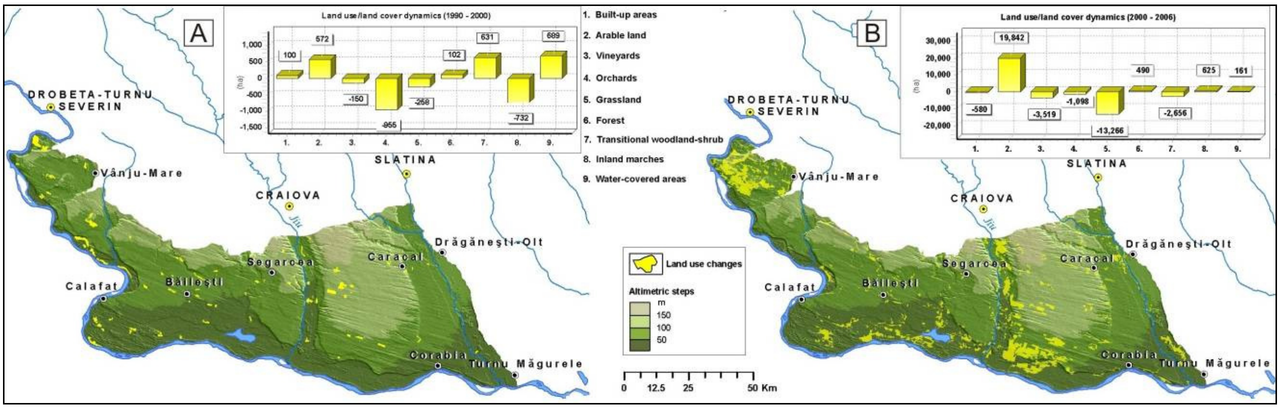

Fig. 3. Land use /land cover changes in southern Oltenia (1990-2000; 2000-2006).

subsistence agriculture, poor services for agriculture (irrigation, fertilization, mechanization, etc.). All of these have contributed to the severe degradation of the agricultural land quality, with direct impact on crop production and rural welfare. The political and socio-economic changes that marked the transition period have created a land use system far more vulnerable to climate changes, also depleting adjusting capacity and resilience (Fraser et al., 2009). At the same time, the absence of irrigation and other land improvement systems has led to yearly crop output variations, largely dependent on climate conditions.

Over the last 20 years, climate changes were some of the most important driving forces of land use changes in the south Oltenia, especially by intensification of extreme climatic events (droughts, desertification, hail storms and floods).

One of the aims of this paper is highlighting the changes in the land use/land cover pattern, the main phenomena of conversion, of substitution of one type of land cover for another. It is a GIS based study of Corine Land Cover data from 1990, 2000 and 2006, the main land use/land cover changes being identified and analyzed over two time spans: 1990–2000 and 2000–2006 periods (Table 3; Fig. 3).

Over the 1990–2000 period, structural land use changes affected some 0.87% of the overall surface, while in 2000–2006 over 6.62% of it underwent these changes. Conversion occurred either inside land use agricultural categories, or between these categories and other land use/land cover classes, such as forest or wetlands.

Arable lands registered most significant evolutions over the 2000–2006 period (more than 19.8 thou ha), extending to the detriment of grassland, vineyards and orchards, in that, within the same interval, over 60% of Sadova-Corabia vineyard were cleared and replaced by arable terrain. Even if the arable area increased, their productive potential was largely degraded, with negative effects on the quantity and quality of agricultural production. A major problem of southern Oltenia's agriculture is the abandonment of arable terrains, particularly in low-productive regions (sand-covered areas).

Table 3

Land cover/Land use changes in the South Oltenia (1990–2006)

CLC classes	area 1990 ha	area 2000 ha	area 2006 ha	changes 1990-2000	changes 2000-2006
1. Artificial surfaces	47,451.2	47,696.2	47,116.7	245.0	-579.5
2. Arable land	535,198.6	535,772.9	555,615.2	574.3	19,842.3
3. Vineyards	40,368.7	40,219.1	36,699.8	-149.6	-3,519.3
4. Orchards	2,772.9	2,514.5	1,416.1	-258.5	-1,098.3
5. Grassland	55,672.5	55,774.2	42,508.2	101.7	-13,266.0
6. Forest	60,810.7	61,441.5	61,931.9	630.8	490.3
7. Transitional woodland-shrub	20,061.3	19,329.7	16,674.0	-731.6	-2,655.7
8. Inland marches	22,131.7	22,822.6	23,447.4	690.9	624.7
9. Water-covered areas	26,179.6	25,224.5	25,385.7	-955.1	161.2

If arable land stays fallow for several years, they get covered with vegetation; since identifying them on satellite images is sometimes difficult, they are listed under grassland. Several other causes for abandoning arable lands is their high fragmentation (parcels under 2 ha), money shortage with the small farmers, the absence of markets to sell the products, few if any irrigation systems, etc. (Bălteanu and Popovici, 2010).

Over the 1990–2006 period orchards and vineyards areas shrank by some 5,000 ha. Large areas of ***orchards*** and ***vineyards*** were abandoned or cleared after being restituted to their former owners or to their heirs under Land Law 18/1991, new fruit-trees and vineyards being planted usually on small, dispersed plots.

Pastures and ***hayfields*** would expand to the detriment of vineyards and orchards; lose in favour of arable land, especially in the post-transition period.

Forest and Transitional woodland-shrubs. Forested areas extend in either internal, while the surface of the latter class shrank by up to 2.6 thou ha, the tree-covered surface kept growing due both to the conversion of more than 1,960 hectares of class 7 into class 6 over 1990–2000, basically 607 ha after 2000, and the reforestation of some sandy soils. Significant class 7 areas were turned into arable (2), vineyards (3), orchards (4) and inland marshes (8).

Over the 1990–2007 period, in the southern Oltenia, land use/land cover conversion mostly took place within the following classes: grassland to arable; pastures to arable; arable, grassland and forest to build-up areas; vineyards and orchards to arable or to pastures, forest to transitional woodland-shrub, arable to inland marches etc.

The climate change impact on land-use structural changes is seen, particularly in sandy soil areas (Sadova, Bechet, Corabia, Apele Vii, etc.) through intense aridization phenomena liable to enhancing future desertification over larger surfaces.

The absence of irrigation and the uncontrolled deforestation of protection belts accelerated the northward extension of desertification-affected surfaces, conducive to depleted arable-land productivity and, in time, abandonment of these lands.

Much of the arable area in Apele Vii, Mârşani, Daneţi, Celaru, Castranova, etc. communes, which falls into the high drought-affected sandy soils of the Leu-Rotunda Plain, were left fallow every year. Irrigation systems in the region were not operational, crops being irrigated here and there by individual owners of wells dug in the fields.

Climate changes impact on crop production

Climate changes and variability and land use/land cover dynamics are connected and interrelated in complex ways at different spatial and temporal scales (Entwisle and Stern, 2005).

One of the methods to connect the two domains is applying climatic indexes and indicators able to explain and quantify the causal relationships between them. One of the most relevant climatic indicators is the **Standardized Precipitation Index (SPI)**. This index was conceived with the aim at defining and monitoring drought evolution and quantifying deficit and excess of precipitation in different periods, thus providing it a certain temporal flexibility (Dubrovsky et al., 2008; Svoboda, 2009). Even though it attempts at characterizing a complex phenomenon (drought), one of the main restraining aspects of SPI is related to the fact that is considering only precipitations as input data. According to the values of extreme classes for SPI, southern Oltenia region frames into the ***deficit domain*** (SPI ≤ –2 = extremely dry) (table. 4 and 5).

The spatial distribution of this extreme class reveals that approximately 50% of the study-area is characterized by SPI values indicating a *maximum intensity (1–1.5* and *1.5–2)* for the deficit periods (the north and center of the Desnăţui Plain, as well as the Leu-Rotunda Field). The rest of the South Oltenia fits within the interval *0–0.5* and *0.5–1* which points to a *slightly diminished intensity* of this precipitation deficit character (Fig. 4).

Table 4

Criteria used for the framing the intensity of droughts and the excessive rainfall by means of SPI index

SPI Values	Attribute	Risk Type
2.0 or more	Extremely humid	High
1.5 … 1.99	Very Humid	Medium
1.0 … 1.49	Moderately humid	Low
-0.99 … 0.99	Almost normal	No risk
-1.0 … -1.49	Moderately dry	Low
-1.5 …-1.99	Very dry	Medium
-2.0 or less	Extremely dry	High

Table 5

The rank and variation domain of the (SPI %) subclasses for selecting the extreme classes for the 12-month consecutively period in Romania

Variation Domain for the SPI	SPI > 2 (%) Class			SPI < -2 (%) Class			Total Class SPI > 2 (%)	Total Class SPI < -2 (%)
	> 3	2.5 - 3	2 – 2.5	-2.5 …-2	-2.5…-3	< -3		
Maximum	1.5	1,7	7.5	5.0	1.9	3.0		
Minimum	0.0	0,0	0.0	0.0	0.0	0.0		
Average	0.0	0,3	1.4	1.5	0.3	0.1	1.7	1.9
Standard Deviation	0.2	0,4	1.0	0.9	0.5	0.3		
CV (%)	460.1	170.7	74.8	59.3	140.7	356.9		

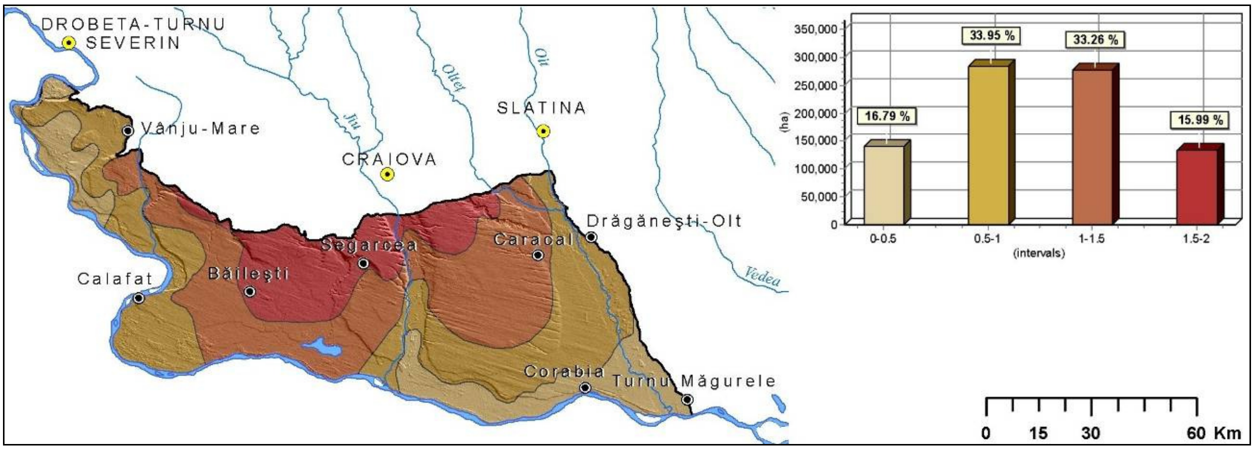

Fig. 4. Spatial distribution of the SPI < -2 (%) calculated for 12 months in South Oltenia.

With the aim of completing the aridity and drought components in the South Oltenia, the second climatic index used is **Thornthwaite Humidity Index** (**Iar-TH**), which takes into consideration, besides precipitation amounts, other climatic parameters. Initially, on a global scale, it was defined by the humidity classes (*description*) segmented by units (*criterion*) (tab. 6).

Table 6

Thornthwaite aridity index classes and units on a global scale

Type	Description	Criterion
A	Perhumid	$I_{Th} > 100$
B_4	Very humid	$80 < I_{Th} \leq 100$
B_3	Highly humid	$60 < I_{Th} \leq 80$
B_2	Moderate humid	$40 < I_{Th} \leq 60$
B_1	Low humid	$20 < I_{Th} \leq 40$
C_2	Moist subhumid	$0 < I_{Th} \leq 20$
C_1	Dry subhumid	$-20 < I_{Th} \leq 0$
D	Semiarid	$-40 < I_{Th} \leq -20$
E	Arid	$-60 < I_{Th} \leq -40$

Compared to temperate latitudes and climatic conditions specific for Romania in terms of vegetation period (April-October) Iar-TH registers reformulated and adapted aridity classes (Monteith, 1965, Allen 1986, Allen et al., 1989, 1997, 1998, Jensen *at al.*, 1990, Hargreaves, 1989, 1994, Hargreaves *et al.*, 1985; Hattfield and Allen, 1996; Păltineanu *et al.*, 1999, 2007b), as follows (Păltineanu *et al.*, 2007a.) (Tab. 7):

Table 7

Thornthwaite aridity index classes and units on a regional scale

Description	Criterion
Semitemperate	0-10
Semiarid	20-40
Arid	> 40

In the study-area, the ***maximum intensity of the Iar-TH*** ranges between 50–55 units covering most of Blahniţa, Desnăţui and Romanaţi Plains (Dăbuleni Field) extending to the floodplains and terraces of the Danube, Olt and Jiu Rivers (approx. 550,000 ha, making up 67.57% of the South Oltenia).

Over 27% of the analyzed area displays an Iar-TH of 45–50 units describing an intermediary step of vulnerability to dryness, covering about 230,000 ha in the northern Romanian Plain (Caracal and Leu-Rotunda Plains), North of Segarcea, Blahniţa and Băileşti Plains. The lowest values of Iar-TH (40–45 units) are found at the contact area between the Getic and Mehedinţi Plateaus, only 5.27% of the studied area (Fig. 5) (Dragotă *et al*., 2011).

Among the most used indirect methods for assessing aridity and drought and the induced effects in agriculture, the Thornthwaite method defines the correction factors for different crops according to spatially differentiated soil, groundwater and climate conditions. Depending on each plant's phenophase specific for the vegetation period, these factors are essential in the irrigation process for estimating the actual water consumption. Thus, the **maximum real evapotranspiration** (ETC-east) value of major crops in South Oltenia (wheat, maize and sunflower) was assessed.

For ***wheat*** crops, during the growing season (May-June), ETC-est registers decreasing values from the South, South-West to north, north-east, where in the northern area of Caracal and Desnăţui Plains they reach the lowest level (340–350 mm). Maximum water consumption values for the entire growing season reaches the highest point in the Danube Plain and in the southern Romanaţi (Dăbuleni Field) and Desnăţui Plains (Segarcea and Băileştiului Plains), reaching 360–370 mm. (Fig. 6. A).

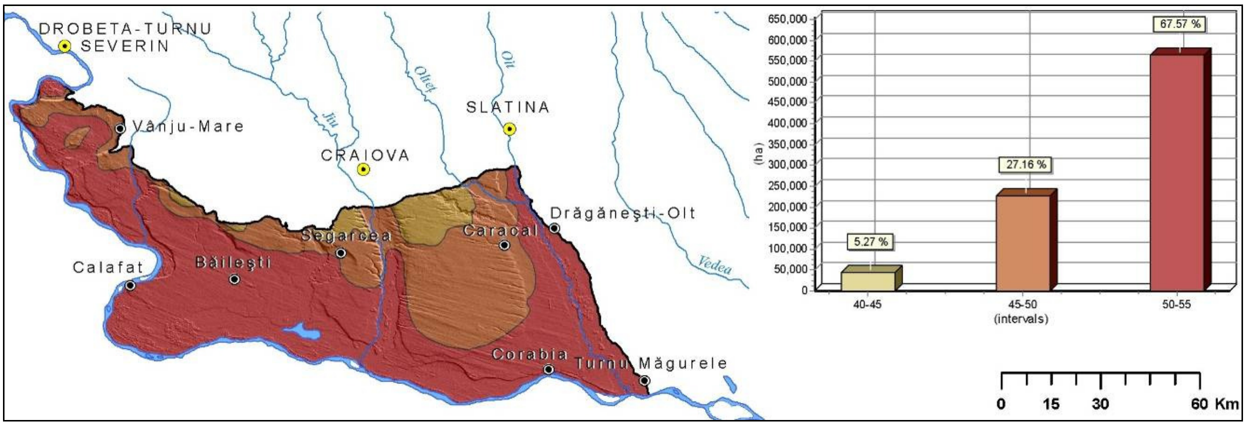

Fig. 5. Spatial distribution of the Thornthwaite (Iar – TH, % mm/mm) aridity index during the vegetation period (April – October) for the main crops in South Oltenia.

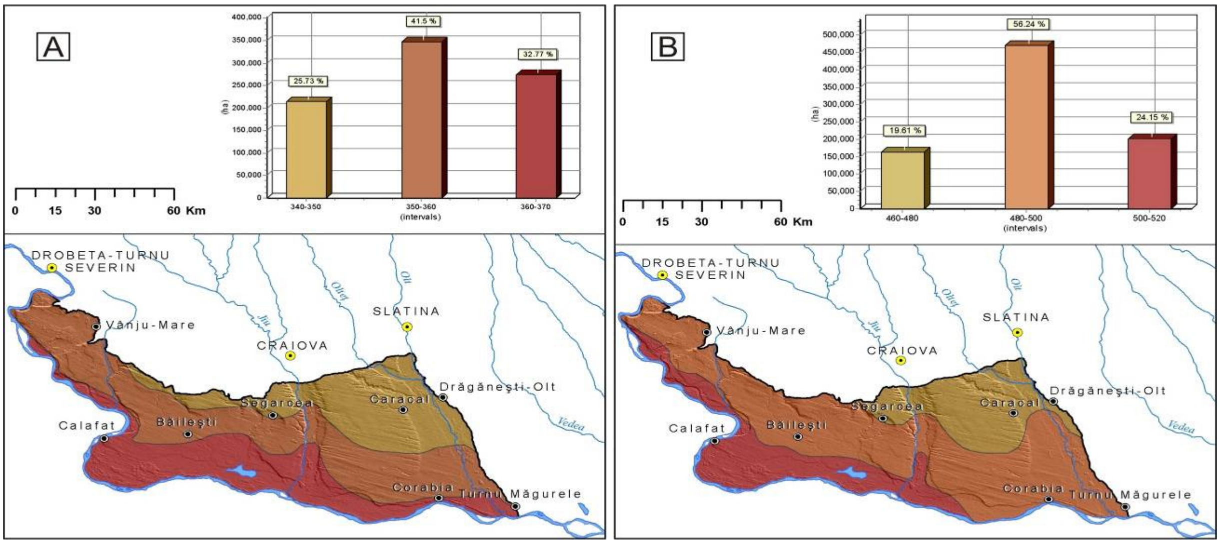

Fig. 6. ETc-est (mm) distribution for wheat (A), maize (B) during the growing season in South Oltenia.

In southern Oltenia, the highest values of ETC-east (500–520 mm) for ***corn*** were registered in the South-Western part of the area largely overlapping the southern Desnăţui Plain and the Danube Floodplain. These values decrease to the north and north-east, where they reach 460–480 mm (northern part of Caracal and Desnăţui Plains) (Fig. 6. B).

For ***sunflower*** crops, the largest area of southern Oltenia illustrates ETC-east values of 480–490 mm (40.17%) and 490-500 mm (39.39%) covering the widest part of Romanaţi and Desnăţui Plains as well as the Danube Floodplain situated between Jiu and Olt Rivers. The south-western extremity of Desnăţui Plain, expanding over Danube Floodplain displays ETC-east values of about 500–510 (the highest in Southern Oltenia, but not exceeding 8%).

The northern part of Caracal and Segarcea Plains shows values of 470–480 mm (10.65%), even 460–470 mm on a smaller area in the north-eastern extremity of Caracal Plain (1.87%) (Fig. 7).

The assessment of the aridity and drought related phenomena was achieved by the **climatic water deficit (WD)** in order to frame the study-area into a region with different degrees of aridity**.** The index is based on the relationship between precipitation (P) and potential evapotranspiration Thornthwaite (PET) under a formula agreed by the United Nations Environment Programme (UNEP).

This aims at completing other drought indicators, such as SPI and Iar-TH, in order to have a more accurate quantification and applicability of the water supply needed for a reference crop (Păltineanu *et al*., 2009; Dragotă *et al.*, 2011).

The spatial distribution of the climatic water deficit versus ET_0 – TH on an annual basis, covers the largest area of southern Oltenia: between -150 ... -200 mm (approx. 60%), the most part of the Romanaţi and Desnăţui Plains.

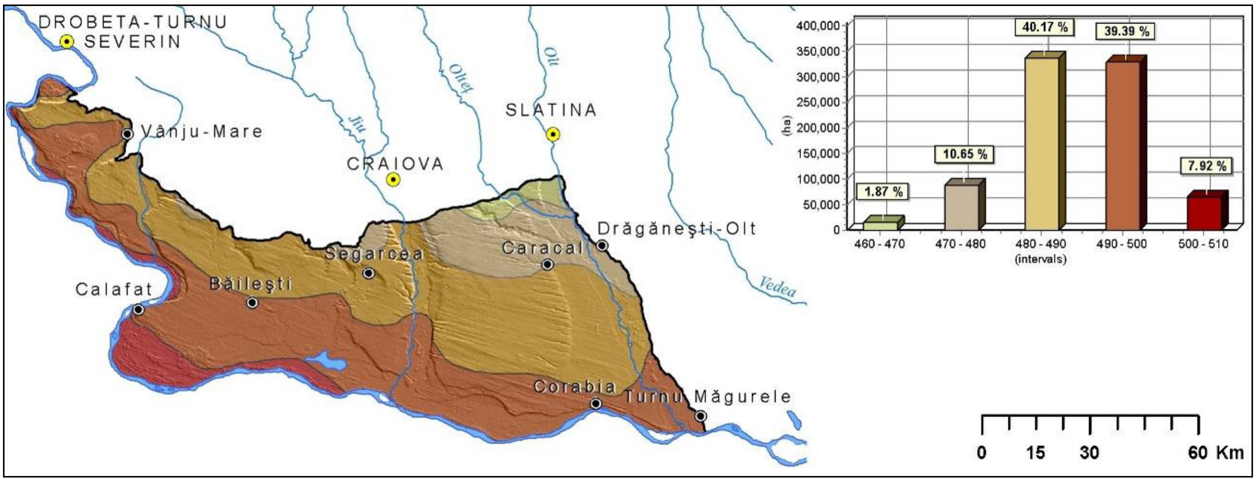

Fig. 7. ETc-est (mm) distribution for sunflower during the growing season in South Oltenia.

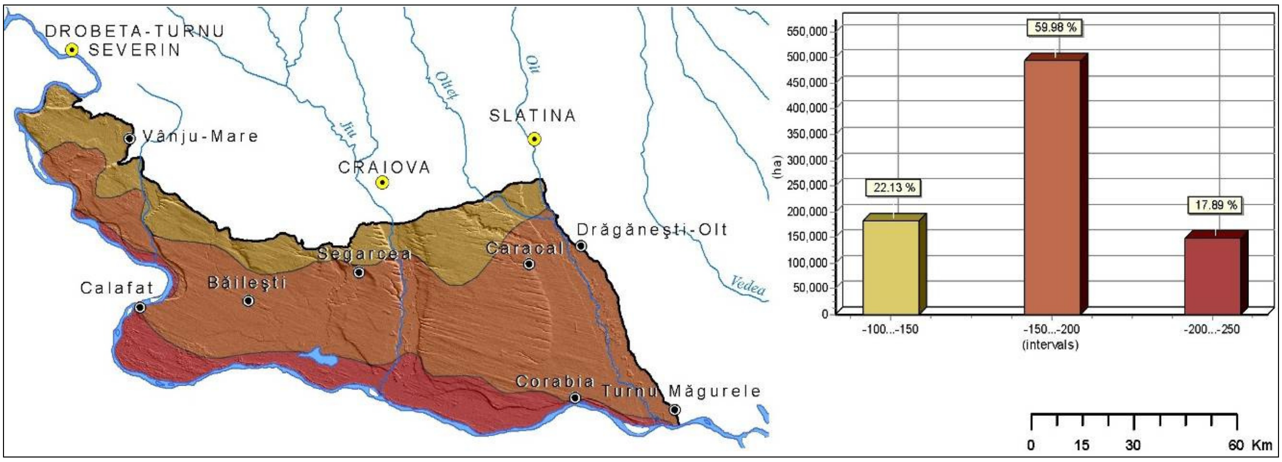

Fig. 8. Spatial distribution of mean annual climatic water deficit versus ET_0 – TH in South Oltenia

Towards South, especially in the Danube Floodplain, the values of this parameter increase, reaching -200 ... -250 mm (about 20% of the entire analyzed territory). Here the water requirements for crops are balanced by the intake of water provided from the underground. In the northern part of the study-area the climatic water deficit is lower (-100 ... -150 mm) covering more than 20% of the territory (Fig. 8).

Following the complex assessment of the impact of aridity and drought phenomena (consequences of the local expression of global climate changes) on the main agricultural crops (wheat, maize and sunflower) in South Oltenia, one could explain several spatial and quantitative differences of the climatic water deficit during the high growing season. Thus, the water deficit for **wheat** registers moderate values in June, since is also the month with maximum rainfall in southern Romania. For **maize** and **sunflower** however, the values of this agroclimatic parameter are higher in July, the month with maximum biological activity of this plant, overlapped on its thermal characteristics (maximum values during the year) (Table 8).

Climate is one of the most important factors determining the productivity of agricultural production systems (Mateescu and Alexandru, 2010). The climatic potential of Southern Oltenia appears generally favourable to all crops but especially to autumn wheat and maize as it frames, from agroclimatic point of view (Berbecel şi colab., 1984), into the **1st Area – Warm and droughty**. The main features of this agroclimatic area are defined by ***rich thermal and radiative resources*** and ***restricted hydric resources*** (because of the deficient precipitation amounts) with negative impacts on crops' productivity (Mateescu, 2001; Sandu *et al.*, 2010).

Current climate variability and change trigger a wide range of impacts on agricultural productivity, primarily determining the increasing water needs

Table 8

Water requirements and consumption parameters for the main crops during the high growing season in the South Oltenia

Main crops	Water requirements (mm)	PP (mm)	Water deficit (mm)	Spatial distribution in the test areas
Wheat (June)	60-70	55-70	-50…-60	*Northern Blahniţa, Desnăţui and Romanaţi Plains*
	70-80		-60…-70	*Danube Floodplain (Calafat-Corabia Sector)*
Maize (July)	100-110	50-65	-70…-80	*Northern and Center Desnăţui and Romanaţi Plains*
	110-120		-80…-90	*Danube Floodplain (Drobeta Turnu Severin-Rast Sector)*
Sunflower (July)	100-110	50-65	-70…-80	*Northern parts of Blahniţa, Desnăţui and Romanaţi Plains*
	110-120		-80…-90	*South-western part of Băileşti Plain, Danube Floodplain*

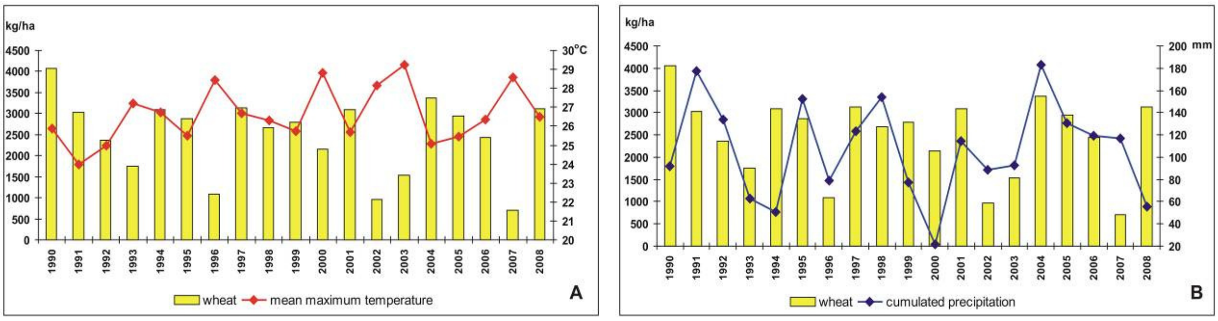

Fig. 10. Correlation between wheat yields and the main climatic elements (temperature-A and precipitation-B) from the season with maximum biological activity in southern Oltenia

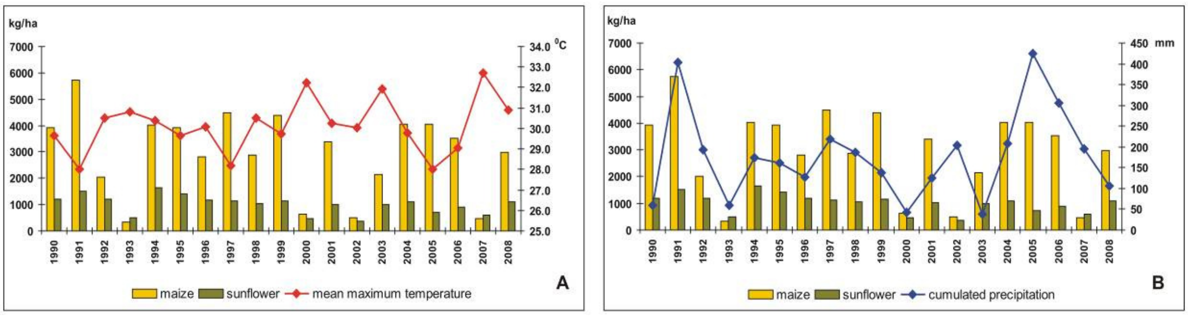

Fig. 11. Correlation between maize and sunflower yields and the main climatic elements (temperature-A and precipitation-B) from the season with maximum biological activity in southern Oltenia

and deficit for the main crops and, ultimately reducing the irrigations water requirements. In the South Oltenia climate change impacts on agricultural production are augmented by several socio-economic drivers such as: the lack of functional irrigation systems, the shrink of natural and chemical fertilisers, the pronounced agricultural land fragmentation, the use of inadequate agricultural practice etc.

Nevertheless, in South Oltenia there were large areas equipped with irrigation facilities (491 thou ha), most of them being destroyed after 1990, or left in an advanced state of degradation. In 2009, only 14.5% of the total agricultural area equipped with irrigation systems was managed for irrigation. In the absence of irrigation during long periods of severe drought cereal productions were dramatically diminished. Output variations in the main crops (wheat, maize and sun-flower) on non-irrigated grounds were climate-related. Average production/ha for main crops, in the very dry years (1993, 1996, 2000, 2002, and 2007), were extremely low (under 500 kg/ha for maize and under 600 kg/ha for sun-flower).

The correlation between climate variability and change and land use dynamics in southern Oltenia is more applicable and easier to measure in terms of arable land and agricultural production. In this respect, the correspondence between the main crops (wheat, maize and sunflower) and the most significant climatic parameters for the periods with maximum biological activity (May-June for wheat and June-August for maize and sunflower) (Păltineanu *et al.*, 2007) points to an accurate representation of the dependence thermal and hydric resources have to annual production. As representative parameters of the thermal and hydric resources, mean maximum temperatures and cumulated monthly precipitation amounts were selected.

For ***wheat***, a good correlation between the years with low productivity and the high values of mean maximum temperatures in May and June can be distinguished (the years 1996, 2002–2003, 2007, etc.). When discussing the relationship between the crop productions and the cumulated precipitation amounts for the same time span, a directly proportional relationship is highlighted. Hence, the decreased yields are related to low precipitation amounts (the years 1993, 1996, 2002–2003, 2007 etc.), while increased productions are related to excess rainfall (the years 1991, 1995, 1997, 2004 etc.) (Fig. 10).

As for the ***maize*** yields, the correlation with the same climatic elements is much too firm stressing, in the case of thermal resources, some years with very low productions related to high maximum temperatures (the years 1993, 2000, 2002–2003, 2007), which highlights a strong dependency of this crop to the thermal factor. When talking about the hydric resources, the correlation between the production and the cumulated precipitation amounts indicates the same increased dependency (the years 1991, 1993, 2005) but also situations when moderate precipitation (150–200 mm) conditions increased productions (the years 1994, 1995, 1997, 1999 etc.) (Fig. 11).

The ***sunflower*** develops a quite week correlation between productions and temperature/precipitations. The higher temperature values determines production shrinking (the years 1993, 2000, 2002–2003 etc.), while increased and moderate precipitation amounts provide higher productions (the years 1991, 1994 etc.). Therefore, following the correlation between the productions of the main crops and the ecoclimatic favorability of the study-area, several critical agroclimatic years (1993, 2000, 2002–2003, 2007) were identified pointing out the restrictive impact thermal and hydric resources have on yields' quantity and quality.

CONCLUSIONS

In the southern Oltenia, over the last 20 years, land use changes and crop production are triggered by the complex interaction between several categories of drivers (political, demographic, economic, technological and climatic drivers) which varied in space and time, depending on the specific human environmental conditions. The expansion of areas affected by extreme and intense climatic phenomena was facilitated by the destruction and abandonment of irrigation systems, deforestations, land fragmentation, inadequate farming practices, etc., which enhanced the vulnerability of agricultural terrains to environmental perturbation.

In this respect, the processing of the most relevant aridity climatic indexes and parameters (SPI, Thornthwaite and WD) on annual basis and especially for the growing season in relation with the main agricultural crops in southern Oltenia specifies that is affected differently by these restrictive climatic phenomena.

From this point of view and also based on the resulted values/parameters one could frame the study-area into the category of regions most affected by aridity and drought phenomena, ranking it as second in Romania, after the Eastern Dobrogea Region. Therefore, as main outcome, both the extent of natural vegetation and agricultural crops for this area depends primarily on the climatic water deficit, but also on the main environmental features of the region.

The consequences of the impact of climate changes have been seen in many ways: very low outputs in the dry years, important crop losses during flooding, hailstorms, etc., the development of invasive plants, of some pests and diseases, the shortening of the vegetation period for certain crops, higher plant water requirement. Negative effect had also the abandonment of agricultural terrains in severely affected areas, etc.

In order to predict practical measures to control aridity and drought, sand dunes reactivation and apply irrigations, complex and complete assessments for relating the most relevant climatic extreme phenomena to agriculture crops must be undertaken.

The importance of estimating climate change at local and regional level would help forecasting its major components, improving agricultural decision making at the farm or policy level and ultimately assuming specific measures for diminishing their consequences and impacts.

Furthermore, this study is complying with the current European Union actions aiming to contribute to the establishment of a European Climate Services system able to increase resilience of society regarding the impact of climate change on different economic sectors (e.g. EU FP 7 projects - ECLISE, CIRCLE-2, ECLAIRE, CLIMSAVE etc.) and for the implementation of the EU Strategy for the Danube Region.

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