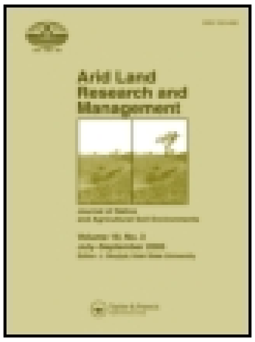

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Water deficit and corn productivity during the post-socialist period. Case study: Southern Oltenia drylands, Romania

Remus Prăvălie[a], Cristian Valeriu Patriche[b], Igor Sîrodoev[c], Georgeta Bandoc[a], Monica Dumitraşcu[d], and Daniel Peptenatu[e]

[a]Faculty of Geography, Center for Coastal Research and Environmental Protection, University of Bucharest, Bucharest, Romania; [b]Geography Department, Romanian Academy, Iaşi Divison, Iaşi, Romania; [c]Faculty of Geography, Interdisciplinary Center for Advanced Researches on Territorial Dynamics, University of Bucharest, Bucharest, Romania; [d]Romanian Academy, Institute of Geography, Bucharest, Romania; [e]Faculty of Geography, Bucharest University, Bucharest, Romania

ABSTRACT

Water deficit (WD) typically associated with drylands and poor land use currently represent a major limiting factor for agricultural systems in numerous regions of the world. The present study aims to analyze the relationship between water deficit and corn (*Zea mays* L) crop yields in southern Oltenia drylands. The study includes the post-1990 period, which is representative for Romania in terms of ample climate changes and poor land planning decisions affecting water resources. This analysis targeted the vegetation period of corn (April–September), the reference period covering a 14-year interval, from 1990 to 2003. The entire analysis was based on spatialized WD data (mm), obtained by interpolation methods used on climate data provided by regional weather stations, and agricultural yield data (tons/hectare/year), recorded in 113 administrative territorial units. Both data sets were analyzed in terms of interannual statistical relationships, established in compact climate zones delineated by Thiessen-Voronoi polygons. The results showed a clear statistical relationship between the two variables, with an average dependence of corn yields on water of approximately 65%. The range was from 55 to 78%, depending on region. The results showed an average yield decrease of 16.5 kg/ha/year for each mm rise of the WD, or loss of 1.65 t/ha/year when considering a deficit rise of 100 mm. Therefore, in the context of increasing future WD, urgent action is needed in order to reintroduce irrigation systems.

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Agricultural yields; corn; drylands; southern Oltenia; statistical analysis; water deficit

Introduction

Today's agricultural production systems are facing a major challenge, namely, adapting to the increasingly apparent climate change of the past decades. This global environmental problem consists of temporal and spatial changes in temperature, rainfall, atmospheric CO_2 concentration, as well as in other atmospheric variables (Parry et al. 2004; Masutomi et al. 2009; Nibleus and Lundin 2010; Steffen et al. 2011). In dryland areas (areas with dry subhumid, semiarid, arid, and hyper-arid climate classes), the status of agricultural systems is even more complicated, as aridity index values that characterize these areas (computed as

CONTACT Remus Prăvălie ✉ pravalie_remus@yahoo.com Faculty of Geography, Center for Coastal Research and Environmental Protection, University of Bucharest, 1 Nicolae Bălcescu str., Bucharest, Romania.

the ratio between precipitation and potential evapotranspiration) are less than 0.65 mm/mm (Middleton and Thomas 1997), indicating a considerable deficit of humidity in these territorial systems. In these areas the climatic restrictions on agricultural systems consist of a general lack of water resources (Glazer and Likens 2012; Ziadat et al. 2012; Leas, Dare, and Al-Delaimy 2014), climatic hazards (Middleton and Sternberg 2013), and land degradation processes (Le Houérou 2002). Such restrictions are more intense particularly in dryland areas totaling ~41% of Earth's land surface (Reynolds et al. 2007), large sections of which are covered by agricultural crops (Dregne 2002).

The Intergovernmental Panel on Climate Change Report (IPCC 2007) shows that by 2100 there may be 1.4–6.4°C rise in global temperature, with indirect effects on dryland expansion through increased potential evapotranspiration (Feng and Fu 2013). Therefore, many studies show the direct impact of future climate change on crops, both in drylands and nondryland areas (Jones and Thornton 2003; Funk et al. 2008; Lobell et al. 2008). In Europe, it is estimated that there will be a significant increase in the occurrence of heat waves associated with droughts (Parry et al. 2004), with negative consequences on agricultural systems. Climate change will particularly affect the drylands of southern Europe in which semiarid areas are expected to expand significantly throughout the twenty-first century (Feng and Fu 2013).

Due to climate change, agricultural production could enter a new phase in terms of dynamics and uncertainty (Charles et al. 2010). Therefore, it is important to increase crop water use efficiency. It is estimated that there are regions where water use efficiency will be lower for certain crops, for example, South Africa, Argentina, Australia, Southeast Asia, parts of the United States, East-European countries, and the Mediterranean Sea basin, which will have to adapt to the new climate (Fader et al. 2010). Crop adaptation includes development of new varieties more tolerant to drought and heat, and new management systems (Sadras and Monzon 2006; Kantolic et al. 2007). Preventing water deficit (WD) stress through irrigations is one of the most viable agricultural adaptation solutions (Sîrodoev 2010; Liu et al. 2014; Snyman 2014; Çiçek and Duman 2015; Liu et al. 2015).

Corn (*Zea mais* L.) is one of the most important food crops in the world, as are wheat and rice, and it is a key factor in ensuring that global food requirements are met. In addition, corn represents an essential element in animal feeding, various industrial products and biofuel production, etc. (Shiferaw et al. 2011).

A series of studies conducted on corn highlighted future changes in temperature, precipitation, light, and CO_2, as well as their inherent potential to reduce corn productivity and development of high yielding corn hybrids (Jones and Thornton 2003; Millar et al. 2010; Tao and Zhang 2011). These studies suggest practices in order to ensure the sustainability of future crop systems and to find new high yield varieties of corn.

In Romania, the evolution of the main climatic parameters reveals obvious temperature increases, hence producing uncertain precipitation dynamics over the past few decades (however, the high or low values trend recorded in various areas are not statistically significant, in general) (Marin et al. 2014). Climate warming, clearly visible in the summer months (which is the vegetation period of major crops, such as corn) enhanced the deficit of humidity (by accelerating potential evapotranspiration) and amplifying the climate stress on crops (Mateescu 2001; Croitoru et al. 2013a). The situation is even more complicated given that the country's southern and south-eastern areas, most of which are classified in the drylands category (subhumid and semiarid climate classes), are the most severely affected by droughts (Bandoc 2008; Bandoc and Golumbeanu 2010; Dragotă et al. 2011; Bălteanu et al. 2013; Murărescu, Murătoreanu, and Frînculeasca 2014) and aridity (Păltineanu et al. 2007b; Păltineanu et al. 2007a; Bandoc 2012; Păltineanu 2012; Croitoru et al. 2013b; Bandoc and Prăvălie 2015; Prăvălie and Bandoc 2015).

In southern Oltenia, south-western Romania, according to certain climate scenarios, it is estimated that during the twenty-first century the main changes in climatic parameters will be linked to an average annual temperature increase of up to 2.6°C and to a decrease of annual precipitation amounts exceeding 120 mm (up to the year 2100, compared to the 1961–1990 reference period) (Bălteanu et al. 2013). In this context, negative socio-economic and ecological effects (e.g., low agricultural productivity and substantial land quality degradation) are anticipated (Bălteanu et al. 2013).

The present study aims to validate the hypothesis that there is a relationship between WD and corn yields in southern Oltenia drylands in the post-socialist period of 1990–2003. The study period chosen is quite representative and had in view the significant climate changes and modifications in the management of agricultural systems after 1990 (e.g., irrigation systems collapsing following this political and socio-economic period of transition), this synergic context generally amplifying the dependence of crops on climatic variability.

Data and methods

Study area

The study area totals almost 7370 km^2 and encompasses 113 administrative territorial units (Figure 1b). It corresponds to the southern geographic region Oltenia (south-western Romania), and it overlaps, for the most part, the western extremity of the Romanian Plain, a major landform unit which is the country's main agricultural region (Figure 1a).

Climatically, the region has certain unfavorable conditions for crop production, which are related to frequent warm air advection processes starting in North Africa (that generate dryness and drought phenomena), irregular rainfall, intensified thermal regime and, implicitly, high evapotranspiration (Dumitraşcu 2006; Peptenatu, Sîrodoev, and Prăvălie 2013; Prăvălie, Sîrodoev, and Peptenatu 2014a; Prăvălie Sîrodoev, and Peptenatu 2014b). This results in stressful climatic conditions for corn, especially since these features generally become apparent during the corn vegetation period.

According to Păltineanu et al. (2007a), the study area is crossed by WD average multiannual isolines (over 1900–2000 period) values ranging from −50 mm (the north-west sector of the study area, covered by Drobeta Turnu Severin weather station) to −250 mm (in the south, in the area corresponding to the Calafat, Bechet and Turnu Magurele weather stations). During the corn vegetation period (April–September), it was found that the average multiannual WD values (between 1961 and 2009) exceeded the −300 mm threshold at most regional weather stations.

According to the UNEP (United Nations Environment Programme) aridity index, the study area almost fully (97%) corresponds to a dry sub-humid climate (in Romania, this dryland category totals ~95560 km^2, which covers approximately 40% of the country's total area of 238391 km^2). This climate class is defined by the ratio between precipitation and potential evapotranspiration falling into the 0.5–0.65 mm/mm interval (in the 1950–2000

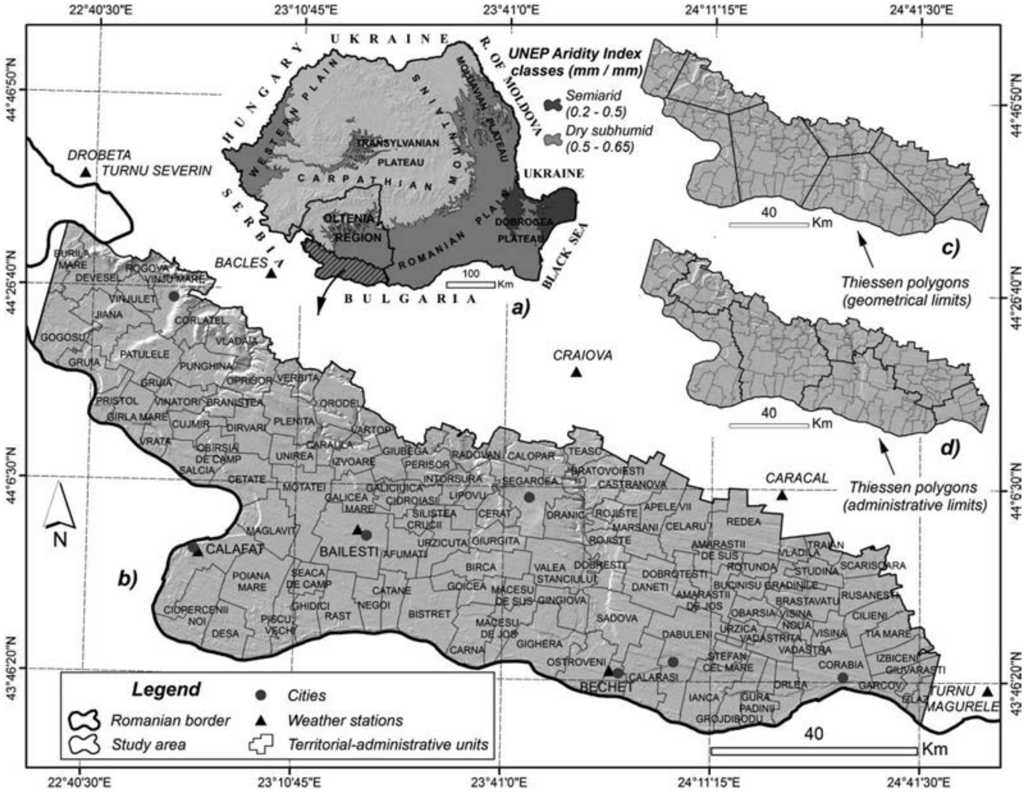

Figure 1. Location of study area in Romania and spatial representation of the UNEP (United Nations Environment Programme) Aridity Index (mm/mm) at country level (a, b); geometric (c); and administrative (d) delineation of Thiessen polygons.

multiannual period) (Trabucco and Zomer 2009) (Figure 1a). The study area is therefore classified as a dryland, featuring the country's highest climate aridity (alongside other areas in the south, west and east) after Dobrogea, located in south-eastern Romania (with dry sub-humid and semiarid climate classes) (Figure 1a) (Croitoru et al. 2013b; Bandoc and Prăvălie 2015; Prăvălie and Bandoc 2015).

Corn (*Zea mays* L.) is the major crop in the region. Although corn is a plant that can generally withstand drought conditions, the high WD recorded in the vegetation period, coupled with the general lack of irrigation systems, can generate significant disturbances in agricultural production in the study area.

Agro-climatic data

The study is based on two types of data, that is, climate and agricultural data.

The climate data consist in monthly WD values (mm) recorded during the corn vegetation period (April–September) between 1990 and 2003. WD values were obtained by subtracting potential evapotranspiration (PET; mm) from precipitation (P; mm) values ($WD = P - PET$), parameters that resulted from the climate data recorded by all the weather stations in the region (a total of eight, namely Drobeta Turnu Severin, Bacles, Calafat, Bailesti, Craiova, Bechet, Caracal, and Turnu Magurele) (Figure 1b). The data were obtained from the European Climate Assessment & Dataset (ECA&D) platform (Klein Tank et al. 2002) and the National Meteorological Administration (NMA 2013). The potential evapotranspiration was obtained based on temperature values by means of the Thornthwaite methodology (Thornthwaite 1948):

$$\mathrm{PET} = 16 * \left(\frac{10t}{I}\right)^{a} F(\lambda)$$

where t is the average monthly temperature (°C); I is the annual thermal index calculated by the formula $I = \sum_{n=1}^{12} i_n,\ i_n = \left(\frac{t}{5}\right)^{1.514}$; $a = 6.75 * 10^{-7} * I^3 - 7.71 * 10^{-5} * I^2 + 1.79 * 10^{-2} * I + 0.49$; and F (λ) is the adjustment factor depending on the latitude and the month of the year.

This methodology has certain limitations, because unlike the Penman-Monteith method, recommended by FAO (Food and Agriculture Organization of the United Nations) (Allen et al. 1998), it does not account for more detailed climate parameters. It does however get satisfactory results with minimal data input and is a representative method for the Romanian territory (Păltineanu et al. 2007a; Bandoc, Dragomir, and Mateescu 2013; Bandoc et al. 2014; Prăvălie and Bandoc 2015).

The agricultural data consist of corn yields (CY; tons/hectare/year), recorded between 1990 and 2003 in the 113 administrative units making up the study area. Yield data were computed based on agricultural output recordings purchased from the County Departments for Statistics in Mehedinti, Dolj, and Olt (CDSMDO 2013). The 14-year period is due to the fact that, in Romania, production data were recorded only at administrative unit scale until the year 2003, after which company or county records are no longer relevant to the present study, as they are not appropriate for the targeted analysis.

Methods

The impact of climate on corn yields was evaluated in three main stages. In the first stage the weather stations' influence zones in adjacent areas were defined based on Thiessen-Voronoi polygons (Figure 1c). Polygon boundaries were subsequently modified in relation to the outer limits of administrative units overlapping at least 51% of the Thiessen perimeters' surfaces. As the Thiessen polygons did not match the administrative unit limits and in order to create the final compact spatial units for agricultural data analysis, it was assumed that the greater yields were obtained in the administrative units which overlap the geometrical polygons in terms of area percentage by at least half plus one (Figure 1d). The resulting eight influence areas were considered compact climate zones (Figure 1d), according to which agro-climatic data were clustered and analyzed statistically (Prăvălie et al. 2014).

The second phase focused on climate and agricultural data clustering with respect to the eight newly-defined units. Climate data clustering was performed by computing deficit spatialized raster pixels as average for each unit and each year between 1990 and 2003. In order to spatialize the WD, interpolation methods were applied on evapotranspiration and rainfall values (for each year, from April to September) by means of the ArcGIS 9.3 software. These parameters, originally obtained separately in raster format, were subsequently processed as raster subtractions (between precipitation and potential evapotranspiration) with software-specific tools. Parameter spatialization was performed through ordinary kriging, universal kriging, and regression-kriging methods (Dobesch, Dumolard,

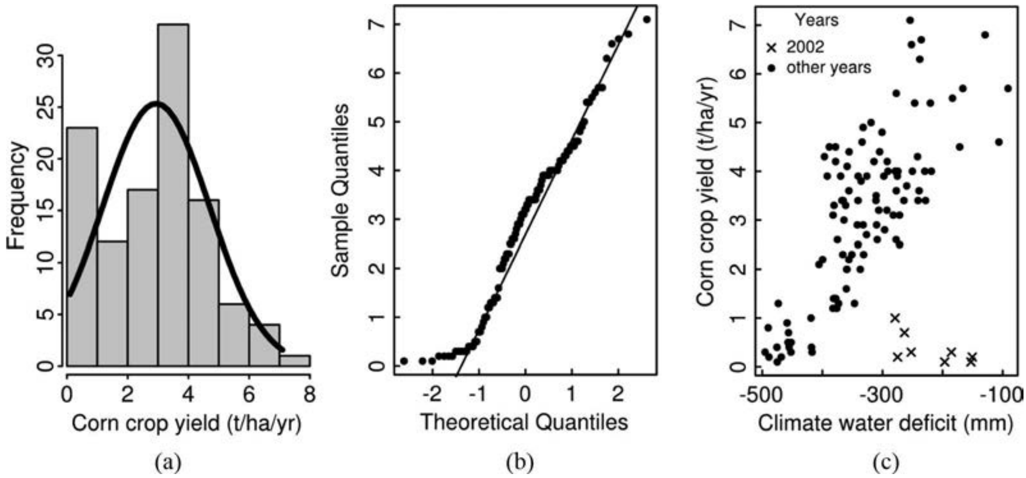

Figure 2. Processing of not normally distributed data: histogram (a) and normal q-q plot (b) of the distribution of untransformed corn yield; scatter plot of corn yield vs. water deficit per plot (c).

and Dyras 2007; Patriche 2009). The predictors used for improving the spatial interpolation models were the numerical terrain model obtained through Shuttle Radar Topography Mission (SRTM), with an 80 × 80 m resolution, and the stations' X and Y coordinates.

As elevation correlates particularly well with potential evapotranspiration values (one is inversely proportional to the other), this parameter was spatialized through regression-kriging in all cases. For rainfall, as the correlation is statistically significant only for the years 1995 and 2000, the same spatialization method was applied. For the other years, either ordinary kriging was used, if no significant correlations were identified for any of the three predictors (1990, 1992, 1993, 1996, 1997, and 2003), or universal kriging with first order polynomial trend, if significant correlations were found with the meteorological stations' X or Y coordinates (1991, 1994, 1998, 1999, 2001, and 2002).

Agricultural data clustering was performed by computing as average corn yields recorded in the administrative units overlapping the Thiessen polygons' surface by at least 51%.

The third phase covered data series statistical analyses in terms of interannual mathematical relationships established between the independent variable (WD) and the dependent one (CY). At this stage, the normal data distribution was tested by applying the Shapiro-Wilk test (Royston 1982), which showed that, in the eight climate zones, the data meet the normality criterion. Although a relationship analysis between climate and the overall study area production was also attempted, the agricultural data distribution analysis showed that the normality criterion was not met (Figure 2a, b), as simple correction procedures applied on the data string failed to yield results. Moreover, data processing revealed abnormal productivity values for 2002 (Figure 2c), which is why they had to be eliminated from our subsequent modelling, and analyzed separately.

Results and discussion

Following the spatialization of the WD and CY for each administrative territorial unit, a first visual assessment reveals spatial similarities of the two variables between 1990 and 2003 (Figure 3a–n1).

With intervals of 50 (mm) for the climatic deficit and of 1 (t/ha/year) for agricultural yields, for a uniform comparison spanning over the 14 years, it can be noticed empirically that there were years in which high and very high deficit values (e.g., 1992, 1993, 2000, and 2003) showed low corn yield values (Figure 3c–c1, d–d1, k–k1, n–n1). Conversely, an overall spatial relationship was identified between lower deficit values and higher yield values in certain years such as 1991, 1997, and 1999 (Figure 3b–b1, h–h1, j–j1).

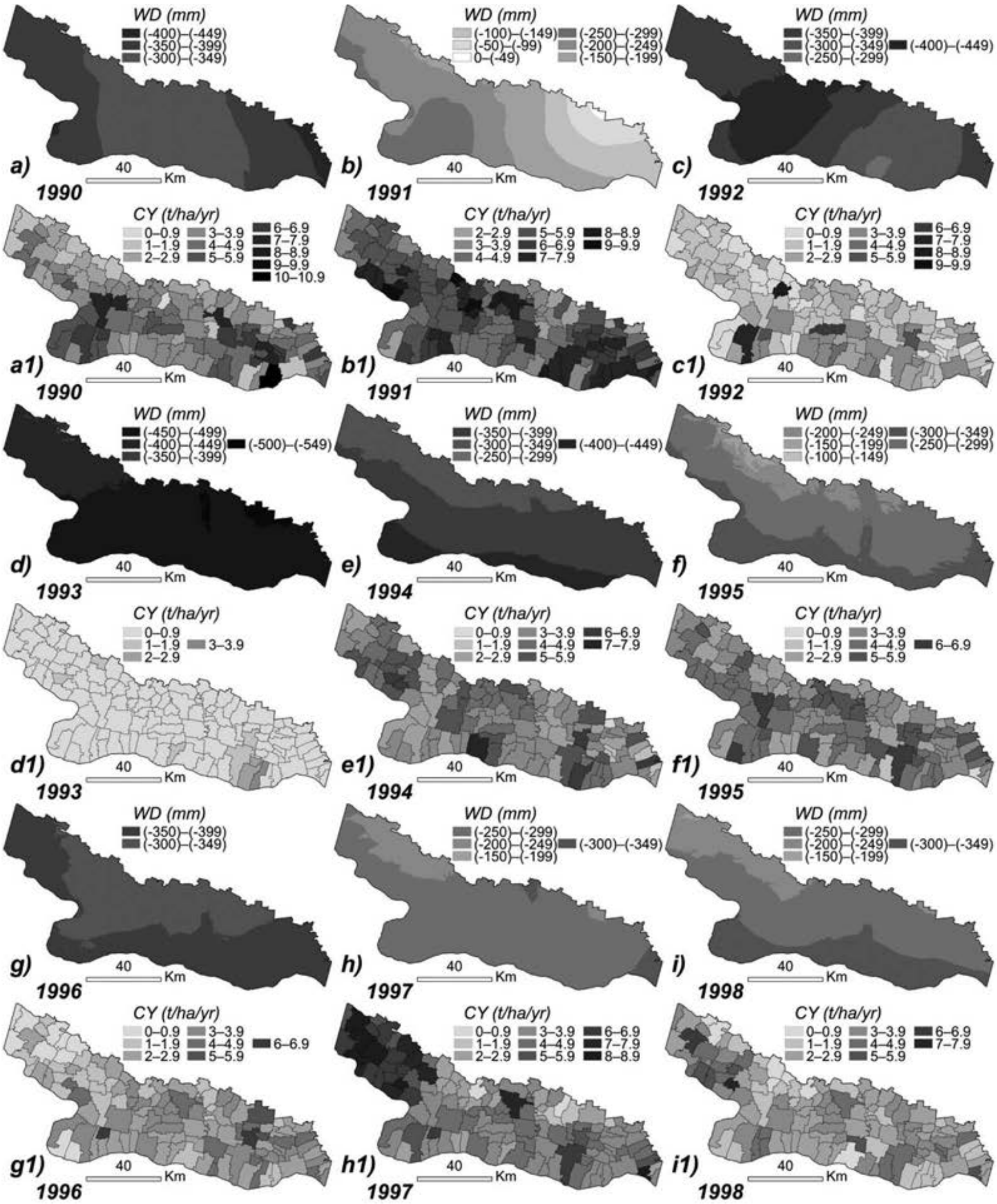

Figure 3. WD (Water Deficit) and CY (Corn Yield) spatial representation (April–September) relative to administrative units, for the years 1990 (a, a1), 1991 (b, b1), 1992 (c, c1), 1993 (d, d1), 1994 (e, e1), 1995 (f, f1), 1996 (g, g1), 1997 (h, h1), 1998 (i, i1), 1999 (j, j1), 2000 (k, k1), 2001 (l, l1), 2002 (m, m1), and 2003 (n, n1).

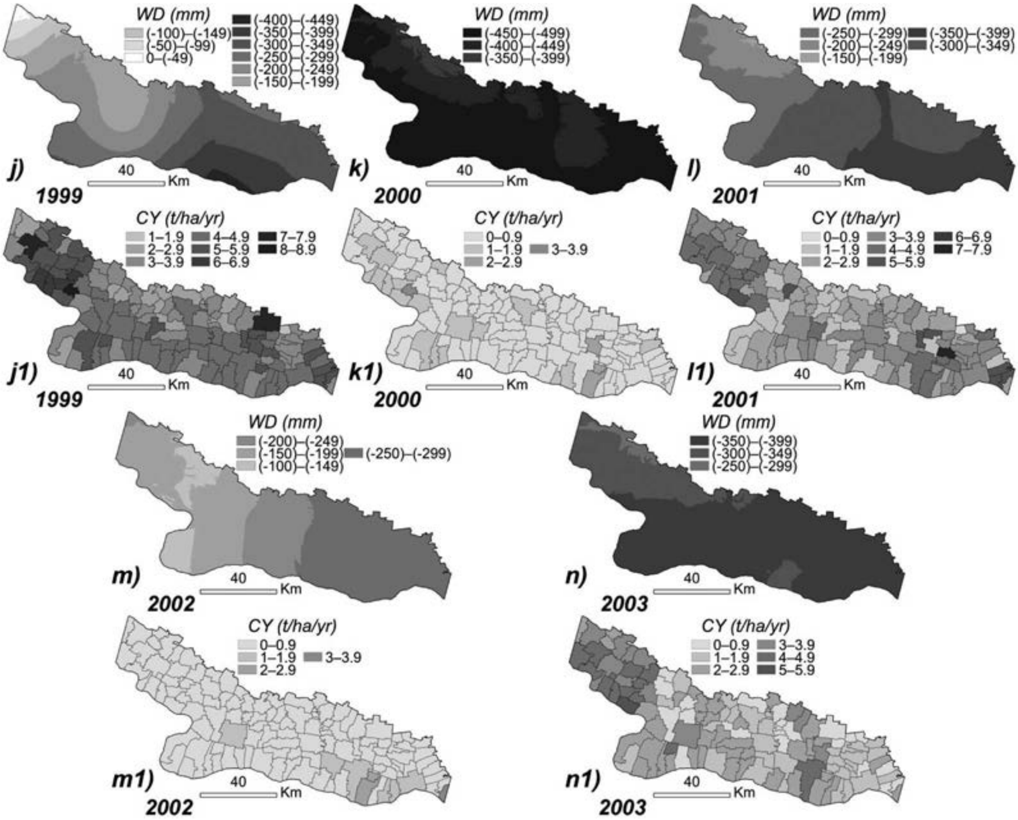

Figure 3. Continued

However, climate value spatial dynamics depend on a relatively small number of available weather stations in the study area, whereas agricultural data have a much higher variability from one administrative unit to another. A more accurate comparison of agro-climatic oscillations can therefore be carried out based on the data extracted for the Thiessen polygons (Figure 1d, Table 1), as in these compact units the two variables can be analyzed proportionally (Prăvălie et al. 2014).

Upon analysis of data variation in Thiessen zones, agro-climatic variability graphs indicate an overall oscillation similarity over the 14 years, except for 2002, characterized by abnormal productivity levels (Figure 4). In this case, too, clear instances of high deficit and low yields were noticed (especially in 1993, 1996, and 2000), as well as lower deficit values coupled with higher agricultural values (the obvious cases of 1991, 1995, and 1999) (Figure 4a–h).

In order to quantify the real relationship between the two set of variables in the post-socialist study period, the appropriate statistical analysis methods were used. Therefore, the modelling of WD influence on corn productivity was performed through linear regression. The results of the analysis applied to each climate zone show remarkable model consistency (Table 2).

Based on regression analysis, WD was responsible for the variation of corn productivity in the study area at a rate of about 60–64% in most cases, except for Craiova and Drobeta

Table 1. Agroclimatic data (ACD) extracted for the eight climate zones (CZ) resulting from the delineation of Thiessen-Voronoi polygons for the corresponding weather stations.

ACD / CZ		Drobeta T. Severin	Bacles	Calafat	Bailesti	Craiova	Bechet	Caracal	Turnu Magurele
Water Deficit (mm)	1990	−375.0	−366.0	−378.0	−326.0	−332.3	−332.2	−378.1	−396.6
	1991	−241.7	−220.4	−251.8	−238.0	−171.6	−166.4	−91.2	−129.3
	1992	−382.4	−377.6	−399.6	−405.7	−381.4	−326.6	−337.0	−355.9
	1993	−417.2	−418.1	−452.3	−468.4	−488.9	−490.2	−495.3	−475.1
	1994	−335.6	−333.9	−388.5	−358.8	−340.5	−391.9	−367.5	−382.2
	1995	−277.9	−239.1	−304.8	−274.3	−259.7	−292.2	−275.3	−306.2
	1996	−376.1	−346.6	−351.0	−341.9	−331.4	−364.2	−355.9	−380.7
	1997	−254.1	−235.6	−277.1	−277.1	−290.9	−278.9	−264.4	−300.8
	1998	−228.4	−240.8	−297.7	−271.6	−277.4	−309.8	−271.7	−296.5
	1999	−106.3	−183.6	−246.5	−218.7	−292.7	−355.6	−314.2	−319.1
	2000	−456.4	−418.9	−473.4	−452.0	−455.4	−458.7	−457.2	−475.6
	2001	−250.3	−229.6	−282.1	−308.7	−340.7	−361.3	−340.7	−369.6
	2002	−185.4	−152.9	−150.6	−196.5	−252.3	−263.4	−274.9	−279.1
	2003	−310.9	−310.6	−365.5	−359.6	−360.1	−359.1	−380.0	−373.1
Corn Yield (t/ha/yr)	1990	2.6	2.3	4.2	3.9	2.9	4.9	4.5	4.3
	1991	4.3	5.4	6.6	6.3	4.5	5.7	5.7	6.8
	1992	1.2	1.4	2.2	2.1	1.4	2.7	2.0	2.2
	1993	0.3	0.4	0.3	0.2	0.2	0.8	0.3	0.1
	1994	3.8	4.6	4.5	4.1	3.9	3.9	3.4	3.1
	1995	4.0	3.6	4.4	4.0	3.7	4.2	3.9	3.2
	1996	1.2	1.3	2.3	2.9	2.3	3.0	3.6	3.3
	1997	7.1	6.7	5.6	3.6	4.0	4.0	3.4	4.8
	1998	3.4	3.4	3.9	2.5	2.6	2.9	3.1	2.8
	1999	4.6	5.5	5.4	4.0	3.2	4.4	4.2	5.0
	2000	0.7	1.0	1.3	0.5	0.4	0.9	0.5	0.4
	2001	4.0	4.0	3.1	2.6	2.5	3.3	3.4	3.9
	2002	0.3	0.1	0.2	0.1	0.3	0.7	0.2	1.0
	2003	3.4	3.5	3.4	2.0	1.6	2.0	1.4	1.3

Turnu Severin climate zones (78 and 55%, respectively) (Table 2, Figure 5). The positive slope of the regression line indicates a direct relationship between the two variables (Table 2, Figure 5). Therefore, a 1 mm deficit increase would result in a corn productivity decrease ranging from 13 kg/ha/year (Caracal climate zone) to 20 kg/ha/year (Calafat and Bacles climate units). When WD increased by 100 mm, agricultural losses ranged between 1.3 and 2 t/ha/year, which signals an obvious sensitivity of the dependent variable on WD. In the entire study area, an average productivity loss of 16.5 kg/ha/year was noticed when the WD was amplified by 1 mm (or 1.65 t/ha/year at a deficit variation of 100 mm).

Following our analysis, it can be stated that there is a clear relationship between climate and agricultural variabilities in south-western Romania drylands during the post-socialist period, which confirms the study's research hypothesis. In all eight cases, climate/agriculture statistical correlations showed a dependence of corn production to the climate variable which exceeded 50%.

Of the two parameters constituting the climatic deficit, rainfall had the greatest importance in relation with agricultural yield dynamics, given that the variation coefficients fall within 24.1–36.2% for rainfall, and range from 3.3 to 4.2% for evapotranspiration. Therefore, rainfall variability almost ten times higher than that of evapotranspiration (which is far more stable) was noticed. Thus, for a more thorough understanding of the rainfall/yield relationship, this parameter dynamics must be monitored between April and September.

In Romania, corn water requirements throughout the entire vegetation period is a minimum of 250–300 mm, however, in order to obtain an above-average production, an

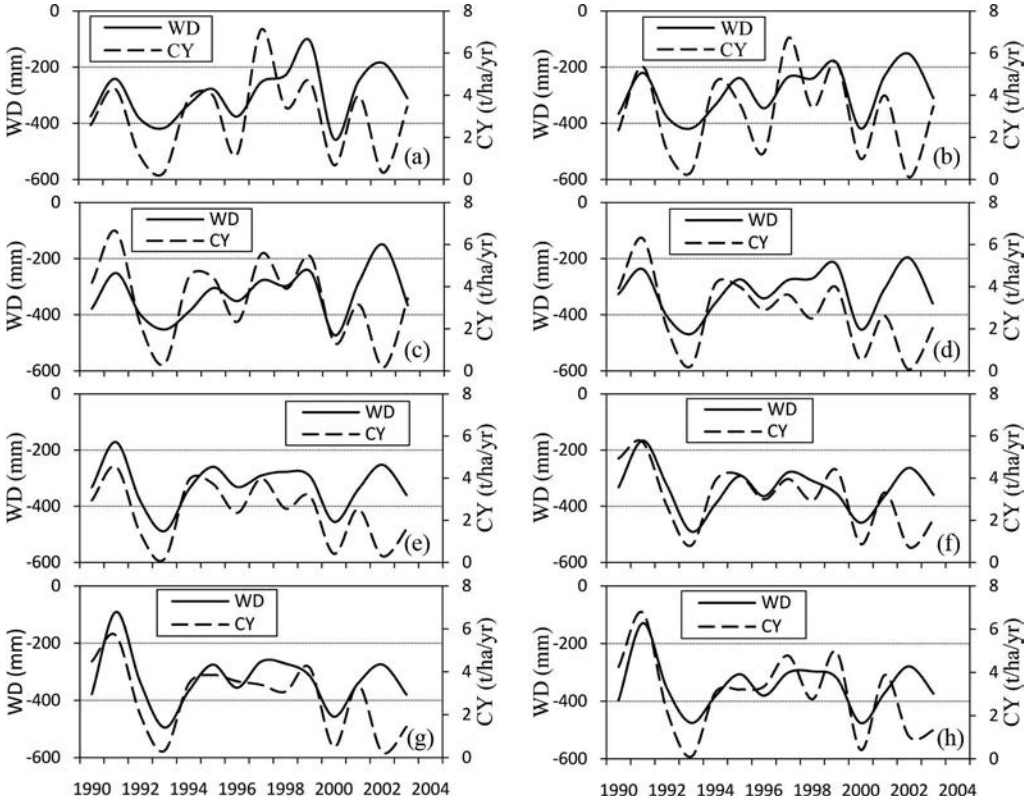

Figure 4. Interannual dynamics (1990–2003) of WD (Water Deficit) (mean pixels in Thiessen zones) and CY(Corn Yield) (administrative units overlapping Thiessen perimeters) values at the weather stations in Drobeta Turnu Severin (a), Bacles (b), Calafat (c), Bailesti (d), Craiova (e), Bechet (f), Caracal (g), and Turnu Magurele (h).

amount of approximately 300–400 mm is required (Salontai and Muntean 1982; Bîlteanu 2003). Rainfall amounts recorded between 1990 and 2003, showed a quantity of 250 mm of water in 70% cases, considering 112 entries resulting from eight stations and 14 years.

The required 300 mm threshold was met in 49% of cases, and the 400-mm threshold in 10% of cases. Although these values may indicate that corn water requirements were met for the most part (taking into account the large share of years in which the minimum quantity of 250 mm was reached), the situation is relative, as the uniform rainfall distribution during the essential months is more important than the total rainfall amount recorded from April to September (Figure 6).

Table 2. Regression analysis parameters ($n = 13$) for the eight climate zones (see also Figure 5).

Climatic zone	Slope	Intercept	R^2 adjusted	*p*-value
Drobeta T. Severin	0.015	7.8	0.55	0.002
Bacles	0.020	9.5	0.69	0.000
Calafat	0.020	10.4	0.63	0.001
Bailesti	0.017	8.6	0.63	0.001
Craiova	0.015	7.5	0.78	0.000
Bechet	0.015	8.3	0.62	0.001
Caracal	0.013	7.2	0.60	0.001
Turnu Magurele	0.017	9.3	0.64	0.001

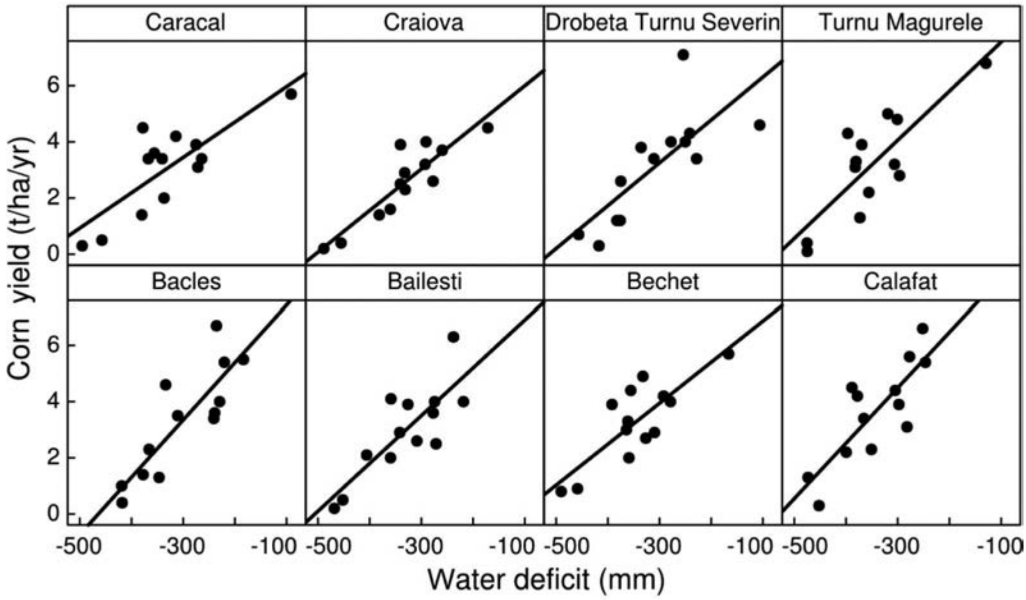

Figure 5. Scatter plot and regression of corn yield vs. water deficit for the eight climatic zones (regression line shown in black) (see also Table 2).

The most important months in terms of rainfall distribution are May, June, July, and August, while April and September are less important due to low corn water requirements. Therefore, according to specialized assessments, in order to obtain optimum yields, a uniform distribution must reach a minimum amount of 60 mm in May, 100 mm in June, 100 mm in July and 40 mm in August (Salontai and Muntean 1982; Bîlteanu 2003). The analysis of negative deviations (relevant for low corn crop yields) of rainfall amounts recorded between May and August, relative to optimal quantities for each month, showed that they reached the highest values (close to −100 mm in numerous cases) in June and July (Figure 6). In conjunction with the year's highest temperatures, which are normally recorded during these months, this led to an even greater amplification of the influence of climatic stress on corn yields.

It is interesting to note that, although 2002 was an anomalous year in terms of agricultural yields recorded between 1990 and 2003, the highest negative rainfall deviations did not correspond to this year (Figure 6). However, while climate-related causes can explain this exceptional situation as well, more detailed data are needed in order to investigate the issue, as a daily precipitation amount distribution analysis is required. Thus, although the total monthly precipitation amounts, compared to previous years, are not generally low in 2002, it is possible that this year's irregular distribution of daily precipitation (during the four analyzed months) may have been sufficiently irregular as to have determined very low agricultural yields.

At the same time, it must be noted that although the close relationship between the two variables was proven, corn yield variation sensitivity to deficit conditions was not extremely high (a maximum loss of 20 kg corn/ha for a one-unit deficit increase), although it is still remarkable. This can be explained by endurance/adaptation particularities to WD conditions. These features consist mainly of a reduced transpiration coefficient (by leaf turning

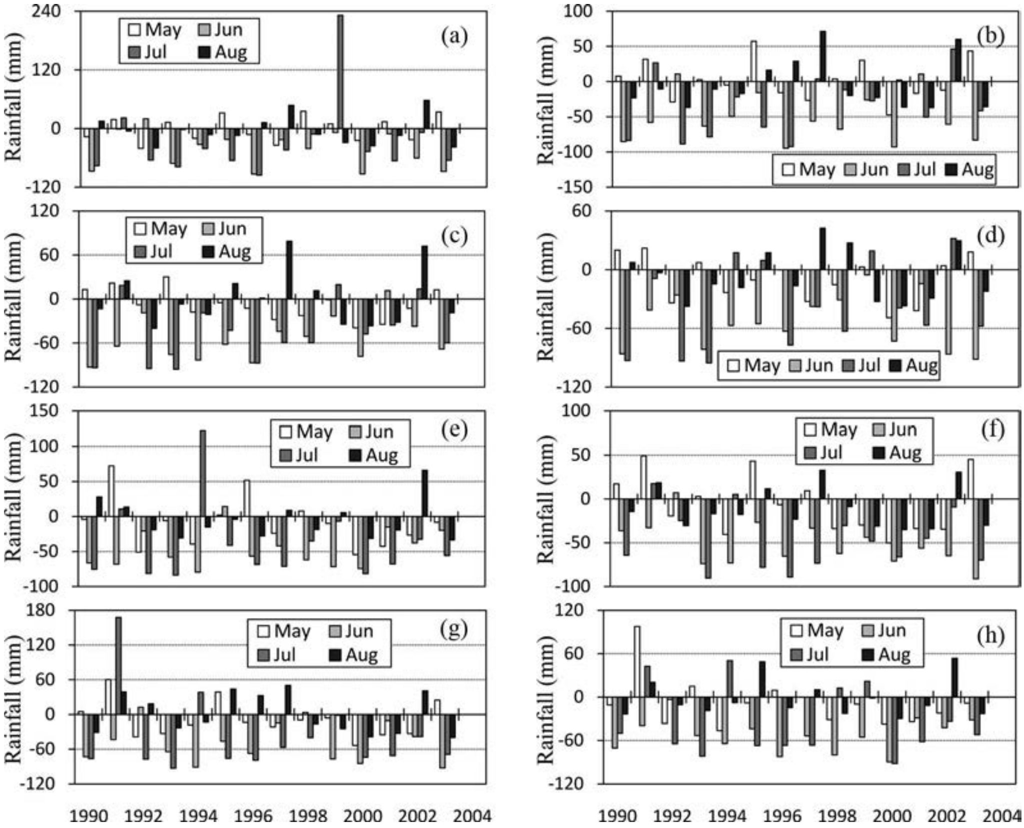

Figure 6. Interannual variation (1990–2003) of rainfall amount deviations from the optimal quantities May (60 mm), June (100 mm), July (100 mm), and August (40 mm), at the weather stations in Drobeta Turnu Severin (a), Bacles (b), Calafat (c), Bailesti (d), Craiova (e), Bechet (f), Caracal (g), and Turnu Magurele (h).

during droughts) and better developed root system (which can reach down to a 3 m depth) (Roman, Ion, and Epure 2006). Compared with other regions in the country with severe climatic conditions, such as Dobrogea (south-eastern Romania) (Prăvălie and Bandoc 2015), corn crops in this study area were more sensitive to climatic water variations. The sensitivity difference, in certain cases, reached up to 300%: 20 kg/ha in Oltenia, as opposed to 7 kg/ha in Dobrogea (Prăvălie et al. 2014). Considering the mean sensitivity values, the ones in the analysed area are twice as high as those in the case of south-eastern Romania.

At the same time, in the context of global climate change, low corn productions were reported also in other parts of the world, but comparisons with the results obtained in our case study are not relevant as the methods used, the analyzed parameters and the temporal series of agroclimatic data are different. A relatively recent study has shown that over the past three decades (1980–2008) global temperatures and precipitation have reduced corn yields by some 3.1 and 0.7%, respectively (Lobell, Schlenker, and Costa-Roberts 2011). Regional studies have revealed that post-1980 climate trends led to important losses in Rusia, China, or Brazil (Lobell, Schlenker, and Costa-Roberts 2011). Although some experimental research has shown that climate change could be beneficial for some crops (wheat, rice, and soybean) through carbon fertilization (the three crops having ~0.1% increase by each additional CO_2 ppm in the atmosphere), corn proved immune to CO_2 enrichment (Lobell and Field 2007; Lobell, Schlenker, and Costa-Roberts 2011), being therefore an extremely sensitive crop to climate change.

It is important to note that during the case study period there were also other factors (natural and anthropogenic) that influenced the dynamics of corn crop yields. Natural factors have led to a decrease of groundwater levels (due to the increasing potential evapotranspiration rise), but the anthropogenic factors are also responsible for this situation considering the collapse of irrigation systems, both registered especially after 1990 (Dumitraşcu 2006; Bălteanu et al. 2013; Prăvălie, Peptenatu, and Sîrodoev 2013). Previous research conducted in the study area showed a clear statistical relationship between groundwater levels and the main crops yield values (wheat, corn and sunflower) (Prăvălie, Peptenatu, and Sîrodoev 2013), groundwater level oscillations being largely influenced by climate variations.

Other examples of natural causes may be related to soil characteristics that vary throughout the entire study area. Loam and sandy loam soils, with favorable air-to-water balance, are considered to be among the most important for obtaining optimal corn yields (Roman, Ion, and Epure 2006). In the study area, friable sandy soils (generally arenosols, according to the WRB-SR 2006 classification) cover large areas (~1120 km^2, about 34% of the country's sandy soils). However, they can be restrictive to farming systems due to low organic content and water retention capacity, as well as to the wind deflation phenomenon that can cause mechanical damage to crops (Nuță 2005). At the same time, it is important to note that, although soil characteristics generally determine spatial differences, in this particular case soils can also account for certain temporal discrepancies, as they have deteriorated to some extent over recent decades due to either the increasingly severe climatic conditions or poor land management implemented especially in the post-socialist period.

However, the most important additional causes that influenced agricultural yield dynamics are those of anthropogenic origin. They consist mainly in crop management practices. The collapse of irrigation systems following the political transition period in 1990, due to a poor national strategy and this sector's reform over the past two decades (Prăvălie 2013), was the main factor fueling farming system vulnerability and, implicitly, corn yields.

The cartographic analysis has shown that the total irrigated surface in the study area was approximately 566,000 ha in 1990, shrinking by over 96% (~21,100 ha) in 2008 (Figure 7a, b) (Prăvălie 2013). Since cartographic analysis was only possible for the aforementioned years, a general outlook on agricultural area dynamics, over the study target period of 1990–2003, required investigations based on information of irrigated areas in Dolj county (a territorial unit covering most of the study area, with irrigated sectors generally overlapping the study area) (Figure 7c), purchased from the National Agency for Land Improvements (NALI 2012).

It was found that between 1991 and 2003 the extent of irrigated areas decreased, on average, by 87% (~357,350 ha) compared to the 1990 baseline (~412,500 ha in Dolj county) (Figure 7d, e). Therefore, while the average percentage of sustained irrigated areas did not exceed 13% (~55,150 ha) compared to 1990, there were apparent fluctuations from one year to another (Figure 7e). Although these values do not cover the exact limits of

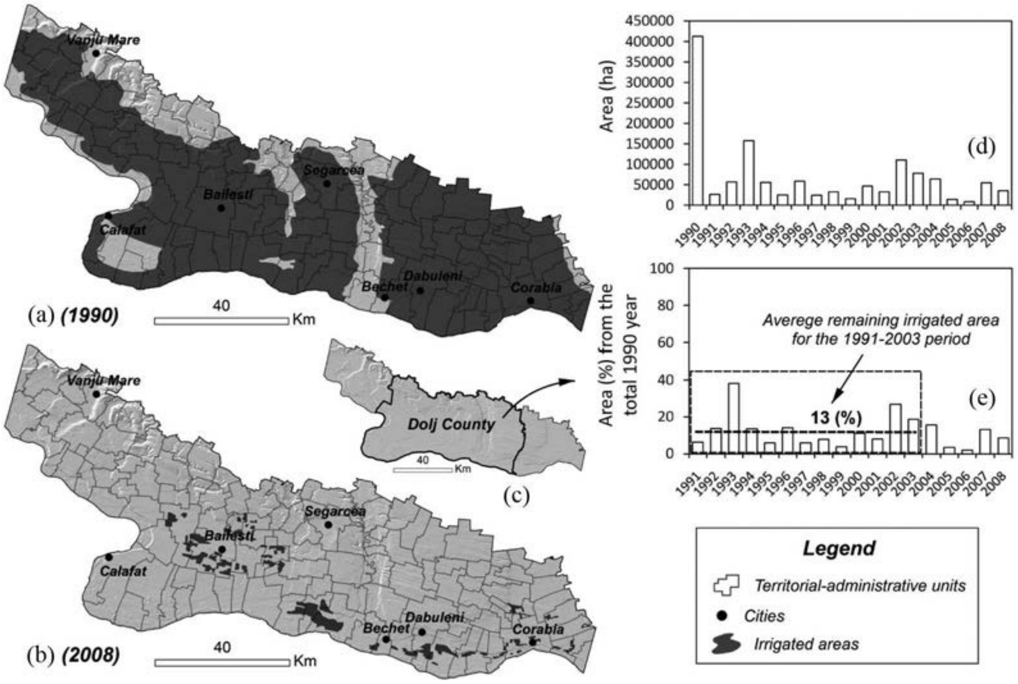

Figure 7. Spatial and temporal dynamics of irrigated sectors in the study area in 1990 (a) and 2008 (b); Dolj County (c); fluctuations of irrigated areas, in absolute (1990–2008) (d); and percentage (1991–2008) (e) values.

our study area, analyzing their dynamics during the post-socialist period is representative for the analyzed region in south-western Romania, as well as for southern Oltenia (considering that county-scale irrigated areas overlap the study area for the most part).

Other factors that influence agricultural productivity dynamics could be related to agricultural land fragmentation, a country-wide phenomenon in the post-socialist period, which resulted from the ownership status change following Law 18/1991 and other similar laws (Bălteanu et al. 2013). Moreover, other important variables not taken into account in this study, but which could potentially influence resulting yields, include farming techniques (density, sowing depth, etc.) and fertilizer amounts (of which N, P and K are particularly important). Therefore, for a full understanding of the causes and mechanisms that influenced agricultural systems in south-western Romania over the past two decades, these additional variables must also be included in future agro-climatic analyses.

Conclusions

Results show that the relationship between corn productivity and WD values in the study area is unmistakable. The statistical analysis of climate zones revealed significant relationships between the two variables for most of the analyzed cases. Therefore, corn production in southern Oltenia drylands has a significant dependence (65%, on average) on climate conditions, at least in terms of the WD. Corn yields decrease due to WD was of 16.5 kg/ha/year (on average) for a 1 mm deficit increase, or 1.65 t/ha/year for a 100 mm deficit increase. Furthermore, lower determination coefficient values found for Drobeta Turnu Severin climate zone showed that there were other important variables influencing agricultural yields, which were not taken into account in the present study.

The overall statistical results should be interpreted somewhat cautiously, given the limited period considered for the case study, due to the unavailability of administrative unit agricultural data after 2003. On longer hypothetical data series, although it is possible that the dependence/sensitivity degree between the two variables be different, it is also highly likely that the climate-agricultural yield relationship would be close over the last decades, when climate changes intensified both nationally and globally. However, up to 1990 agricultural production dynamics may have been less influenced by climate conditions than in the post-socialist period, first of all due to the extensive irrigation availability.

Given that it is highly likely that future climate change will generate even higher corn crop sensitivity to climate conditions, it is necessary to urgently reintroduce irrigation systems, considering that they represent one of the most viable strategies for adapting agricultural crops to future climate changes.

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