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THE BIOCLIMATE AND TREND OF GROWING SEASON IN THE EASTERN DANUBE DELTA AREA OVER 1951-2000 PERIOD

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Abstract: Results of research work concerning the assesse of climate, bioclimate type and growing season length of eastern Danube Delta area are reported. Data from Sulina meteorological station during the period 1961-1990 were analyzed and processed on a monthly basis for computing climate and bioclimate indices, and climate diagrams were constructed in order to evaluate eastern Danube Delta area. This area has a semiarid climate and according to Rivas-Martinez Bioclimatic Classification System has a Mediterranean pluviseasonal continental bioclimate subtype. The thermal growing season length was determined based on 5° C threshold for the second half of 20th century. The mean length of growing season was 254 days, with start day on 20 March and average date of ending on 28 November.

Key words: bioclimate, oceanity, semiarid, Bioclimatic Classification System

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INTRODUCTION

Climate exerts strong influences on geographical distribution of plants through specific physiological thresholds of temperatures and water availability (Andreau et al., 2007). Bioclimates are syntheses of climatic variables that facilitate comparative analyzes of biotic responses to climate conditions. In the context of plants and vegetation researches, bioclimatology is the discipline that deals with the interactions between climate and the distribution of plants and plant communities on Earth (Rivas-Martinez et al., 1999).

In the last three decades for bioclimatic classification of a study area is used a bioclimatic classification system established by Rivas-Martínez et al. (1999), and Rivas-Martínez (2005). It is known as Worldwide Bioclimatic Classification System (WBCS) and it is based on a set of bioclimatic indexes and climatic parameters, showing a close relationship between numerical thresholds values and plant formations (Mesquita & Sousa, 2009).

The second half of XX^{th} century was characterized by a global warming due to the increase greenhouse gasses concentration, especially CO2, which has the strongest radiative forcing (IPCC, 2001). The global warming changes climates and affects biological phenomena. One such phenomenon is the growing season length (GSL), which implies modifications of phenological phases of plants species and increasing of photosynthetic activity. From phonological point of

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view, GSL is defined as the period between bud burst and leaf fall (Linderholm, 2005). From the climatological perspective, GLS is regarded as the entire period in which growth can theoretically take place, and should be distinguished from growing period which is the period of actual growth (Carter, 1998). To define thermal GLS, the most used criteria are freeze criteria and temperatures averaged over a number of days (Bootsma, 1994; Jones & Briffa 1995; Carter, 1998; Jones et al., 2002; Frisch et al., 2002). According to Robeson (2002), GSL is the period between the date of the last spring freeze and the first autumn freeze, where the frost may be determined by thresholds of daily minimum temperatures. For mid and high latitudes, the 5 °C mean temperature threshold is widely accepted for determining the thermal growing season because 5 °C is generally recognized as the lowest temperature threshold for plant vegetation. Thus, Frisch et al. (2002), defines the GSL as the period between when daily temperatures are > 5 °C for 5 days and when daily temperatures are < 5 °C for 5 days. Variations of GSL are an indicator of climate changes. For the North Hemisphere, over second half of XXth century, many studies showed that the last spring frost had become earlier and the first frost dates had become later, resulting in an increase in the frost free period of a 10 days, at least (Linderholm, 2005; Walther & Linderholm 2005). Also, a lengthening of the growing season (designed by 5 °C) of 5.5 days to 24.5 days over 1951-2000 periods was founded in Germany (Metzel et al. 2003), Austria, Switzerland, and Estonia (Linderholm et al., 2005). According to Chmielewski and Rötzer (2002), the high positive North Atlantic Oscilation (NAO) in the late 20th century led to a nearly Europe-wide warming in the early spring (February-April) over the last 30 years (1969-1998) from the 20th century and this warming led to an earlier beginning of growing season by 8 days. Thus, since 1960s, the onset of spring has been advancing in the northern hemisphere on average by 2.5-2.8 days every decade (Nagy et al., 2013). The changes and variations of the growing season length have important implications for the competition and fitness of plants, which implies profound ecological consequences (Walther et al., 2002) such as extension of species range boundaries by establishment of new local populations causing extinction of former populations (Karlsson et al., 2007). Since November 1999, GLS is one of 10 suggested indicators for monitoring change in climate extremes world-wide that have recommended by World Meteorological Organization Commission for Climatology / Climate Variability Working Group on Climate Change Detection (Frich et al., 2002). The present work focuses on various climatic and bioclimatic indices that determine the bioclimatic conditions of the eastern part of Danube Delta (DD) area over second half of 20th century. An analysis regarding changing in GSL is presented for same study period time.

DATA AND METHODOLOGY

Study area

From geomorphological point of view, the eastern part of DD represents the marine delta plain. The relief is composed of more or less parallel, narrow sand ridges and inter-barrier depressions. Reed marshes and shallow lakes are present, too. The high sand barriers are about 1-2 m higher than the inter-barrier depressions that have saline slack marshes and swamp areas (Vespremeanu, 2004). The sandy beach is the best preserved stretch of sandy coastline in Romania and it has considerable scenic value. Also, it is habitat for rare psammophilous and halophilous plant species, some of them being endemic western Black Sea Coast (Strat, 2007, 2009; Sârbu, 2007).

On the high sandy barriers and stabilized dunes, with very dry soils, there is steppe-like vegetation whereas in inter-barrier depression is colonized by halophilous and hidrophilous vegetation. Therefore, in some local areas, special characteristics of the substrate (soil, groundwater table) have a stronger effect than the climate, which lead to azonal vegetation.

Climate data and indices

The purpose of this work is to investigate possible changes of the GSL on eastern part of DD for the 1951-2000 period. In addition, a bioclimatic characterization is made based on climate data for the Standard Climate Normals 1961-1990. For this purpose we considered monthly and annual mean values of air temperature and the amount of rainfall recorded at Sulina climatological station which is located in eastern extremity of Danube Delta. Climate data are available at *http://www.tutiempo.net/en/Climate/SULINA/153600.htm* and *http://www.weather.gov.hk/wxinfo/climat/world/eng/europe/ukr_lith/sulina_e.htm*.

The fallowing climate indices were evaluated: Johansson Continentality Index, Rail Lang Factor, Kerner Oceanity Index, Martonne Aridity Index, UNESCO Aridity Index, Ellenberg Quotient, Kira's Warmth Index, Kira's coldness Index, and Holdridge Annual Biotemperature. For bioclimatic diagnosis according to Worldwide Bioclimatic Classification System (WBCS) (Rivas-Martinez et al., 1999; Rivas-Martinez, 2005), the indedices that were computed are showed in table 1. There are a number of definitions for growing season of vegetation (Linderholm, 2006). In this study it is applied the definition suggested by Frisch et al. (2002), that the start and the end of the growing season are defined as when the daily mean air temperatures are above or below 5 °C during 5 consecutive days, respectively.

RESULTS AND DISCUTION

Climate and bioclimate characteristics

Air temperature is the main meteorological parameter that determines the climatic character of a particular area. In eastern part of DD, the mean annual temperature for analyzed period (1961-1990) is 11.4 °C. The hottest month is July (22 °C) and the coldest month is January (0.2 °C).

Warmer winter and spring temperatures have been noted over the last half of XX^{th} century. Therefore the January average value has turned positive. It increased from (-0.5 °C) for the 1901-1951 period to (+ 0.5 °C for the 1951-2000 period.

The annual temperature range is only 21.8 °C which means that all year long the sea breeze affects the climate of the region. Based on JCI value (23.1), the climate in characterized as marine. In counterpart, the oceanity of climate was assessed. The value of KOI (15.6), being higher than 10, suggests that, from thermal point of view, the climate of the study area can be characterized as marine, which reveals the influence of the Black Sea air masses.

The comparison of the average values of annual rainfall sums for the period of 1896-1970 (Bogdan et al., 1983) with the 1961-1990 period show lower volume of rainfall in second period with about 65 mm. Also, analysis of precipitation over the years 1951-2000 (Dragota & Baciu, 2008) shows lower amount (268.5 mm) than in normal period 1961-1990 (281 mm).

Monthly climate characteristics are shown by means of Péquy climograph (figure 1). In this respect, the study area is characterized by arid climate seven month per year (from May to October), whilst three months have a temperate climate (November, December and March) and two months (January and February) have an cold climate, when mean air temperature is close to zero but not negative. Analysis of Gaussen- Bagnous ombrothermic diagram (figure 2) reveals that reported to the moisture regime all months of the warm season are dry ($P<2T$) and the cold season is wet, March and October being the driest months. Monthly values of De Martonne Aridity Index, February-June and August-September intervals are semiarid, and July and October are arid months. The annual variation characteristics of rainfall which was analyzed with Angot pluviometric index reveals there is no high annual amplitude, rainy months belong to warm season and the highes value of thie index is for September (1.41).

Quantitatively, on the eastern part of DD area, precipitations are distributed almost equally in the two seasons, 143 mm in warm season and 138 mm in cold season, respectively. Annualy, potential evapotranspiration is 2.6 times higher than rainfall amount. The aridity indices allow a bioclimatic classification of the study area. According to IPCC (2007), the annual rainfall can be used solely as the simplest aridity index. Due to rainfall annual amount at Sulina is only 281 mm, based on IPCC criteria, the region is semiarid. Also, according to the calculated values for Aridity De Martonne Index (13.3) and Box Aridity Index (0.38), the study area is semiarid, too, although taking in account the Lang Climate Factor value (24.6), the climate type of this region is arid.

Table 1. Bioclinatic indices [1] calculated for Sulina climatological station over 1951-2000 period

Name of index	Formula	Value for Sulina station (1961-1990)
Johansson Continentality Index (Baltas, 2007)	JCI=[(1.7A/(sinL)]-20.4	23.1
Kerner Oceanity Index (Baltas, 2007)	KOI=100(To-Ta)/E	15.6
Box Moisture Index (UNESCO Aridity Index)	AI=P/PET	0.38
Lang Rain Factor (Devi, 1992)	LRF=P/T	24.6
Annual De Martonne Aridity Index (Maliva & Missimer, 2012)	DM I= P/(T+10)	13.3
Monthly de Martonne Aridity Index (Baltas, 2007)	MDMI = 12Pi/Ti+10	-
Pinna Combinative Index (Baltas 2007)	PCI = 1/2{[P/(T+10)] + [12Pd/(Td+10)]}	10.7
Continentality Index	Ic = Tmax-Tmin	21.8
Ombrothermic Index (Rivas-Martinez, 1996)	Io=(Pp/Tp)10	2.05
Ombrothermic index of the summer Quarter (Rivas-Martinez, 1996)	Iosq= P6-8/T6-8)/10	0.13
Thermicity Index (Rivas-Martinez, 1996)	It = (T + m + M) 10	1.21
Compensated thermal index (Rivas-Martínez et al., 1999)	CIT = It + C, where It is thermal index and C is the compensation value.	167.3
Kira's Warmth Index (Federici & Pignoti, 1991)	KWI =∑(T-5), For months in which T>5°C	90.6
Holdrige's Annual Biotemperature (Lugo et al. 1999)	ABT=∑T/12 ; 0°<T<30°	11.4
Angot's pluviometric index (k) (Dragota et Baciu, 2008)	K = (365xq)/(Qxn); k < 1, dry months; k>1, rainy months.	-

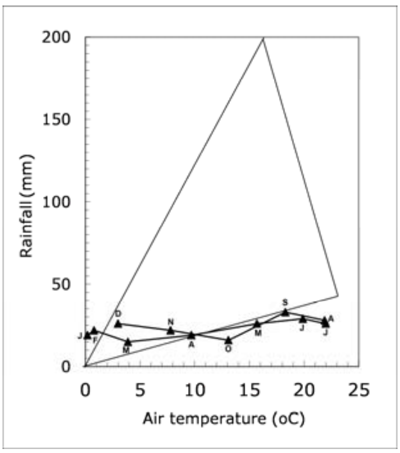

Figure 1. Péquy climograph for Sulina climatological station (Latitude: 45.16; Longitude: 29.66; Altitude: 9 m a.s.l.) over 1951-2000 period

[1] Tmax: mean temperature of the hottest month [°C]; Tmin: mean temperature of the coldest month [°C]; P: annual precipitation [mm]; T: mean annual temperature [°C]; Pi: precipitation sum of the given month [mm]; Ti: mean temperature of the given month [°C]; Pd: precipitation of the driest month [mm]; Td: mean temperature of the driest month [°C]; PET: annual accumulated potential evapotranspiration calculated by the Thornthwaite equation [mm]; A: mean annual air temperature amplitude [°C]; L: latitude of the site [absolute value]; Pp: yearly positive precipitation [mm] (total average precipitation of those months whose average temperature is higher than 0°C); Tp: yearly positive temperature [°C] (sum of the monthly average temperature of those months whose average temperature is higher than 0°C); m: average minimum temperature of the coldest month of the year [°C]; M: average maximum temperature of the coldest month of the year [°C]; To and Ta are the monthly temperature of October and April months [°C]; Td and Pd are precipitation and temperature means in the driest month; Q: annual rainfall amount (mm); q: daily volume of precipitation in a month; n: number of days in a particular month.

Based on values of bioclimatic indices (table 1), which were computed using Rivas-Martinez methodology (Rivas-Martinez et al., 1999), the eastern DD area fit within the Mediterranean – eutemperate macrobioclimate, and it has a Mediterranean pluviseasonal continental bioclimate subtype. The termotype is Supramediterranean and the ombrotype is dry.

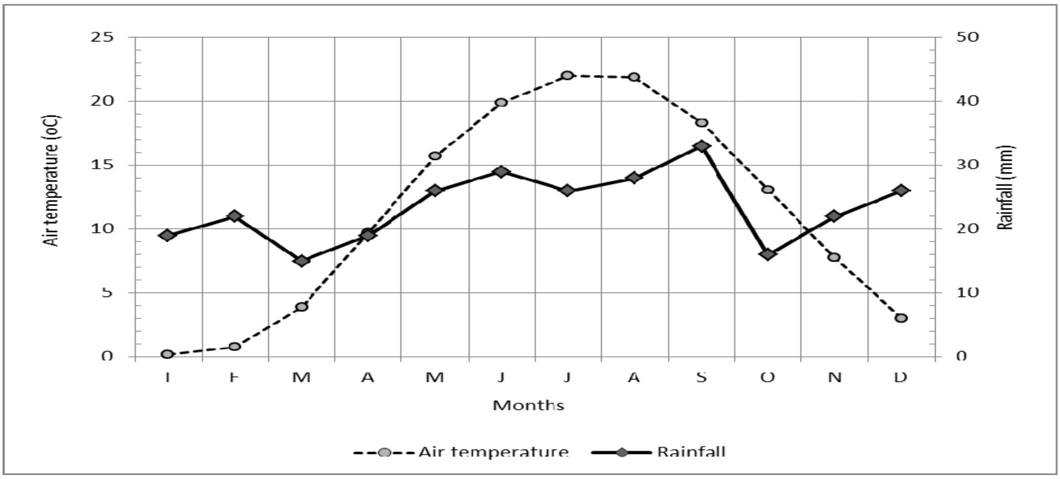

Figure 2. Gaussen-Bagnouls ombrothermic diagram for Sulina climatological station over 1951-2000 period

Growing Season Length

In the last half of 20th century, the mean thermal GSL in eastern DD area was 254 days. The average date of starting growing season was 20 March and the average date of ending growing season was on 28 November. The earliest start (figure 3) was in 1995 when it began on 17 February and GSL was 263 days, and in 1966 when it began on 18 February and GLS was 292 days. The latest start of Growing season was in 1963, on 12 April. In that year, the GSL was 240 days. With each decade, the start of growing season has became earlier (figure 4), from 25 March in 1951-1960 decade to 13 March in 1991-2000 decade.

The earliest end of growing season was in 1988, on 10 November (figure 4). In that year the GSL was only 229 days, the shortest growing season in whole period. The latest end of growing season for same period was in 1960, on 25 December, when the GSL was 282 days.

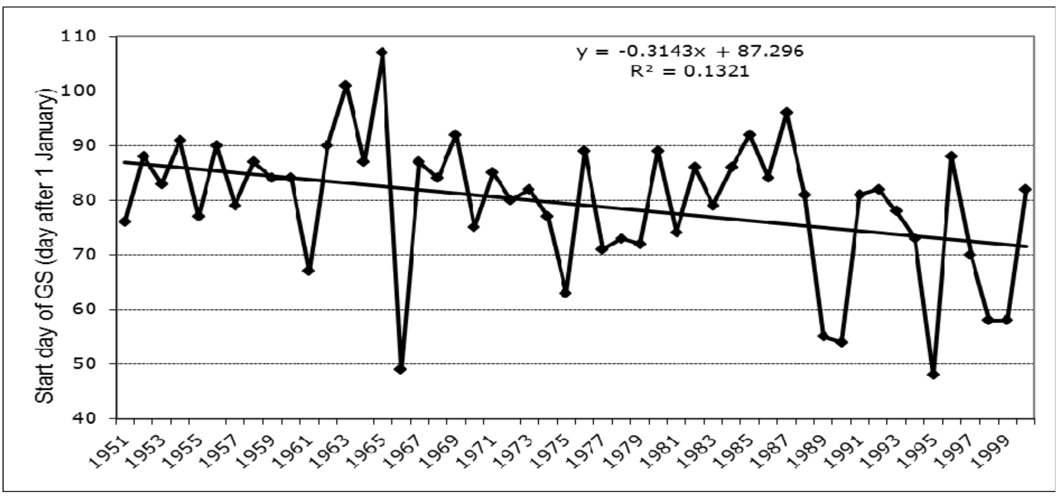

Figure 3. Start day of thermal growing season for eastern Danube Delta area from 1951 to 2000

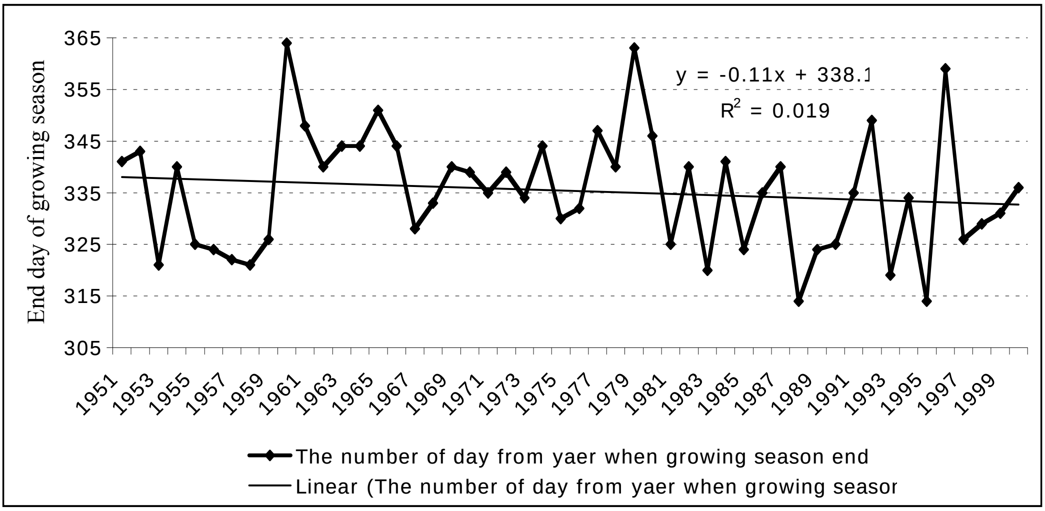

Figure 4. End day dates of growing season (days from 1 January) in the eastern Danube Delta area from 1951 to 2000

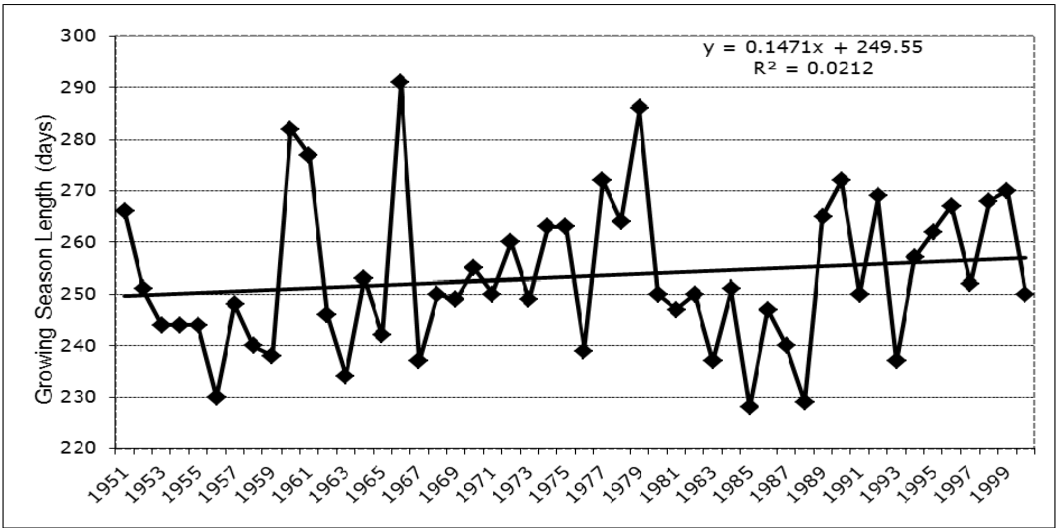

Figure 5. The length of growing seasons in the second half of 20th century in the eastern Danube Delta area

The largest growing season in the 1951-2000 intervals was 292 days in 1966 and 1995. Thus, the amplitude was 63 days and the GLS over 1951-2000 ranged by an average of 14.4 days from de mean of 254 days. The slight lengthening of growing season is mainly coused by the advancing of date of the beginning of growing season (figure 3).

Regarding the end of growing season, there was a sligt earlier ending of growing season. Therefore, for whole period, the lengthening of growing season based on an earlier start was attenuated by an earlier ending.

Decennial analysis shows tendencies for an earlier growing season start (figure 7). The start of growing season was earlier with 8 days in 1991-2000 decade related to the average of 1951-1960 period. Also, in 1991-2000 decade, the start of growing season was earlier with 12 days than 1951-1960 decade. Because of that, GSL for 1991-2000 decade was the longest from all decades, 262 days repectivelly.

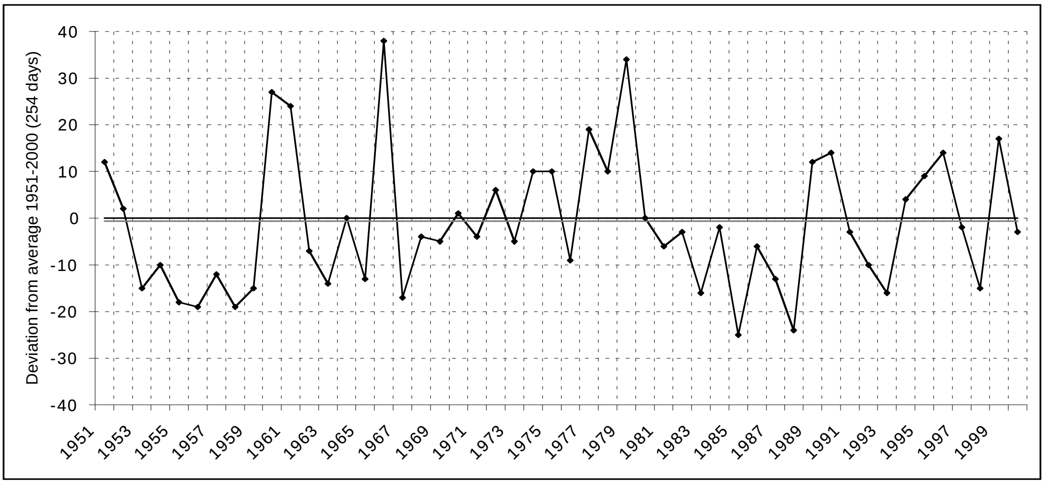

Figure 6. Observed changes in thermal growing season length in the eastern Danube Delta area in the second half of 20th century compared with a 1951-2000 average (254 days). For each year, the line represents the number of days shorter or longer than long term average.

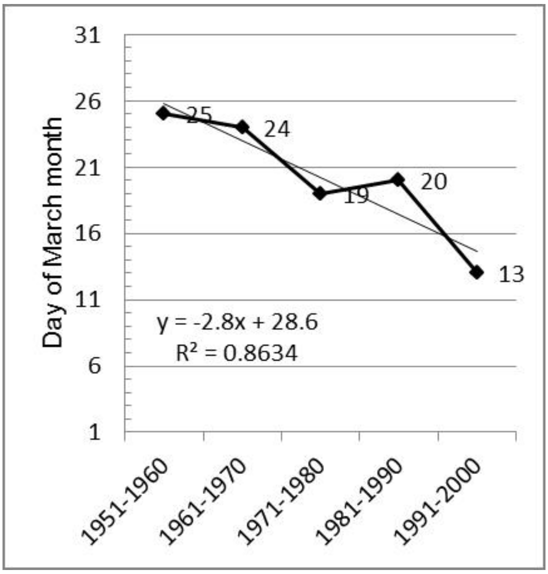

Figure 7. The mean date of growing season start for each decade of 1951-2000 period at Sulina climatological station

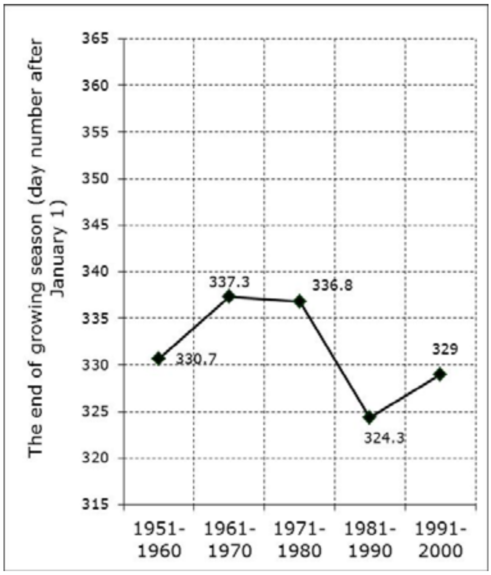

Figure 8. The mean date of growing season end for each decade of 1951-2000 period at Sulina climatological station

Regarding the end of growing season, a general tendency was for an earlier end o. f growing season. The later end of growing season was in 1911-1970 decade, when the average date was 3 December, which is different from general tendency of 1951-2000 period (figure 4, 8).

The shortest growing season (248 days) was in 1951-1960 decade and the longest growing season was in the last decade of 20th century (262 day). After applying Mann-Kendall test (Hamed, 2008), the value of τ/σ ratio (1.63) is within the limits of ± 1.96 and hence there is no evidence of increasing or decreasing trend in data series. Positive deviations of GSL from average 1951-2000 were less than negative deviations (figure 6), and they were clustered in 1971-1980 decade and in last decade of 20th century. The growth rate of GSL was 1.2 days per decade.

CONCLUSION

The values of aridity indices show that eastern DD area is semiarid and it has a Mediterranean pluviseasonal continental bioclimate subtype, according to Rivas- Martinez Bioclimatic Classification System. From thermal point of view it is characterized as marine, with a growing season length around 254 days that starts on 20 March and ends on 28 November. Over 1951-2000 period, GSL has become 4 days longer but the trend has been moderate. The inter-annual and decadal variability was more pronounced. However, the longest growing season was in 1991-2000 decade, with a mean value by 262 days.

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