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Department of Environment and Soil Science, University of Lleida, Spain

Rainfall distribution patterns and their change over time in a Mediterranean area

M. C. Ramos

With 10 Figures

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Summary

In dry farming areas, where rainfall is the only source of water for crops, changes in both quantity and distribution of rainfall during the year could affect the economy of an area. Inter-annual variability makes it difficult to assess rainfall variability, especially in areas with Mediterranean climate. In this paper, interannual rainfall variations in the Alt Penedès region were evaluated using 24-h rainfall records at Vilafranca del Penedès (1889–1999) and at Sant Sadurni d'Anoia (1960–1999). The distribution patterns during the year and their changes over the time were also analysed. Rainfall data were normalised and the values corresponding to the percentiles 0.1, 0.25, 0.5, 0.75 and 0.9 were calculated to analyse whether they were very dry, dry, normal, wet and very wet periods. Annual rainfall and the rainfall recorded during the main rainfall periods during the year and its trend were analysed. Annual rainfall did not show a clear tendency, although during the last decade reduced interannual variability occurred. The percentage of dry years did not increase but the percentage of wet and very wet years decreased. During the last decade, an increase of dry spring seasons and wet autumn seasons was observed, even in normal or wet years. These changes could affect the timing of when crops receive water and could therefore affect their yields.

1. Introduction

Climate change is very likely to have a major impact on the hydrological cycle and consequently on available water resources, flood and drought frequencies, natural and man-made ecosystems, society and the economy (Evans, 1996). A report of the Office of Technology Assessment (1993) pointed out that the anticipated intensification of the hydrological cycle would increase global rainfall by 7 to 15% and evapotranspiration between 5 and 10%. Therefore an increase in extreme events is assumed which will be disruptive to natural and human systems (IPCC, 1995). However, while in certain areas an increase of rainfall is expected, other areas will suffer from decreased rainfall. Several large-scale analyses of rainfall changes over the Northern and Southern Hemisphere land masses have been carried out (Bradley et al., 1987; Diaz et al., 1989). They have demonstrated that during the recent decades rainfall has tended to increase in the mid-latitudes and decrease in the Northern latitudes. However, these large-scale changes contain considerable spatial variability. An apparent increase in rainfall has been found over northern Europe with a suggestion of a decrease in southern Europe (Folland et al., 1993). On the other hand, Hulme et al. (1992) pointed out that rainfall increased in the northern Russia by up to 20% during the period 1961–90, in relation to the rainfall recorded from 1931–60. However, at latitudes between 10° N and 30° N, rainfall decreased between 20% and 50% during the same period. Other studies in different areas show that most rainfall trends seem to reflect decadal-scale variations rather than long-term trends (Hulme et al., 1994).

In agro-ecosystems soil water content determines the amount of water available to crops to produce yields and irrigation requirements. Different assessments have been carried out in order to evaluate the impacts that climate change could have on water resources, on forest and grasslands, and on agriculture (Folland et al., 1992; Folland et al., 1993; Dale and Rauscher, 1994; Leavesley, 1994; Parton et al., 1994; Rogers, 1994; Bazzaz and Sombroek, 1996; Evans, 1996; Tinker et al., 1996; Zwick, 1996; EU, 1997). The Mediterranean climate is characterised by a complex pattern of spatial and seasonal variability, with wide and unpredictable rainfall fluctuations from year to year. The principal rainy season is September to November, in which high intensity rainfall occurs (Ramos and Porta, 1994). The Spanish Mediterranean area has been shown to be very vulnerable to erosion. Imeson (1990) pointed out that the main climatic factors affecting the vulnerability of Mediterranean region to erosion are high intensity rainfall occurring after a very dry summer, and large climatic fluctuations over the short and long-term, especially in rainfall amounts. Serious problems of soil degradation and desertification have been identified and these could increase if dry periods become more frequent.

The objective of this study is to analyse rainfall variability and change in its annual distribution in a Mediterranean area, located in the NE of Spain. In this area dry farming is predominant, thus rainfall is the only water input, and changes in quantity and distribution through the year could seriously affect the economy of the area.

2. Material and methods

The study area is located in the province of Barcelona (NE Spain), between the Anoia and Llobregat rivers. It has a Mediterranean climate. The annual mean temperature is about 15 °C, with maximum temperatures ranging from 10.3 to

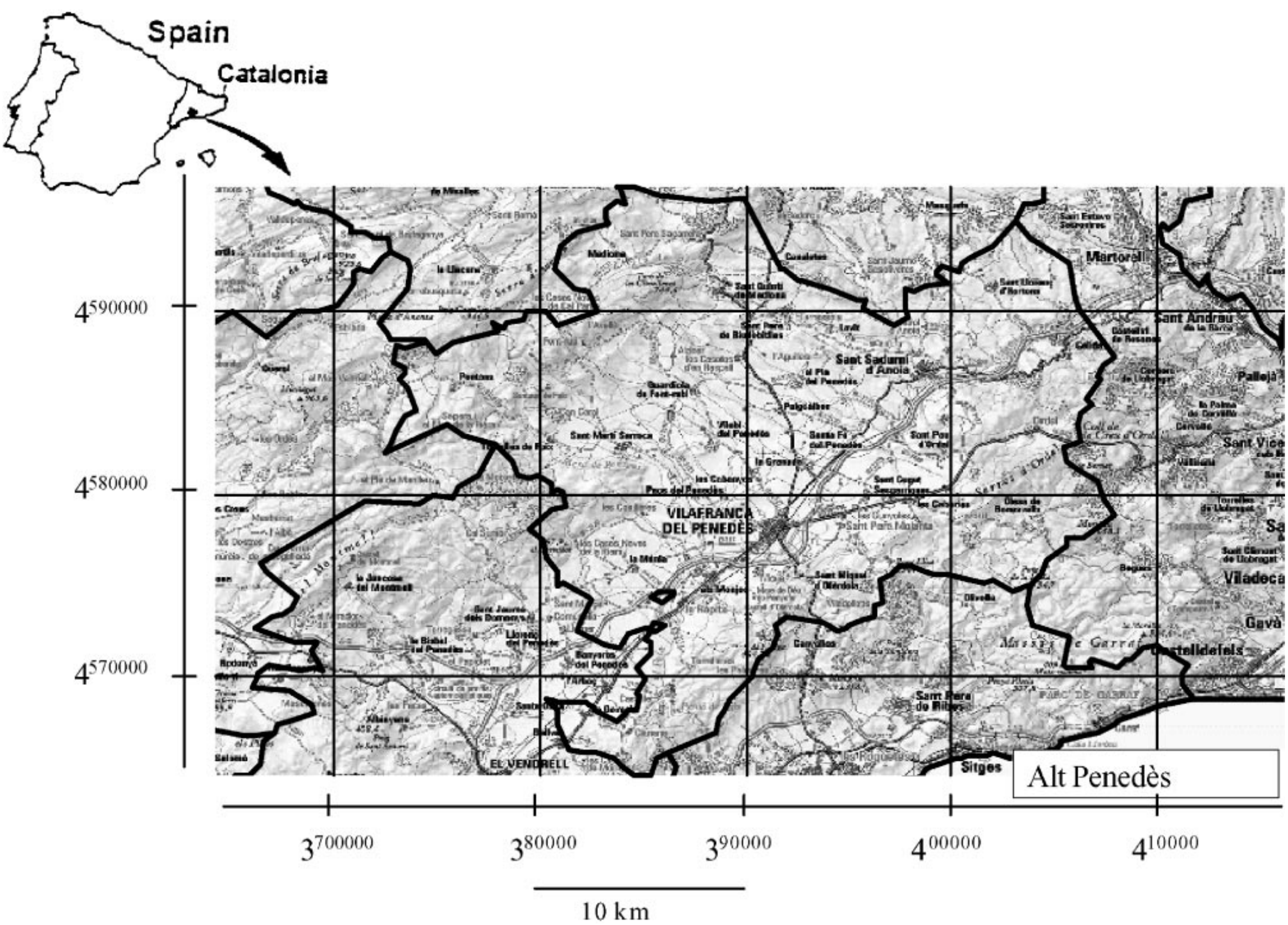

Fig. 1. Location of the studied area

29.7 °C, and minimum temperatures ranging from 2.5 to 19.5 °C (Elías Castillo and Ruiz Beltran, 1979). Mean annual rainfall ranges from 500 to 600 mm (Ramos and Porta, 1993), and is irregularly distributed throughout the year, but basically concentrated in two periods, spring and autumn, alternating with dry seasons. In this area dry farming crops are predominant: vineyards represents about 40% of the area, 15% are forest, 35% are urbanised and the rest is dedicated to other crops like olive trees, fruit trees, etc. (MAPA, 1990).

The study was performed using a large 24-h data set recorded at Vilafranca del Penedès (1889–1999) (UTM coordinate: X: 391612; Y: 4578191). In order to confirm trends, the study was completed with an analysis of a 30-year data set recorded at Sant Sadurní d'Anoia (1960–1999), 10-km North East of Vilafranca del Penedès (UTM coordinate: X: 398801, Y: 4586865) (Fig. 1). The observatory belongs to the Instituto Nacional de Meteorología (INM). Average annual rainfall and standard deviation were calculated for each decade and compared with the long term average. Anomalies were evaluated from the normalised rainfalls. Anomalies were defined as a value which falls outside the interval $R_{aver} - \sigma$, $R_{aver} + \sigma$ (standard deviation of normal distribution), which correspond to normalised values > 1 and < -1. Using the method proposed by Elías and Castellví (1996), the percentage of dry, normal or wet years was also evaluated. This method consisted of calculating the value corresponding to the percentiles 0.1, 0.25, 0.5, 0.75 and 0.9. These values represent the limits of very dry, dry, normal-dry, normal-wet, wet and very wet periods. A test of seasonality was performed in order to analyse the seasonality of the series.

The monthly rainfall distribution and its variability were also analysed using average and standard deviation for each decade. The two main rainfall periods: spring (March, April, May and June) and autumn (September, October and November) were analysed using the method described above.

3. Results

3.1 Annual rainfall

Figure 2 shows the normalised annual precipitation anomalies in Vilafranca del Penedès. Large interannual variations of rainfall are evident without any consistent trend. A lack of seasonality was confirmed by calculating the autocorrelation function of the series and using a different test of randomness, which confirmed that the data were completely random. However, during recent decades the anomalies are less frequent and also less variability from year to year was observed. The normalised deviation was less than 1 in most cases and only one year, since 1960 presented a normalised anomaly as long as 3. Similar numbers of years with very high and very low rainfalls were recorded during the last 4 decades. Figure 2 shows the normalised values which correspond to the 0.1, 0.25, 0.5, 0.75 and 0.9 percentile, whose values are 346 mm, 426.4 mm, 512.9 mm, 606.3 mm and 685 mm, respectively. According to Elías and Castellvi (1996) these limits highlight

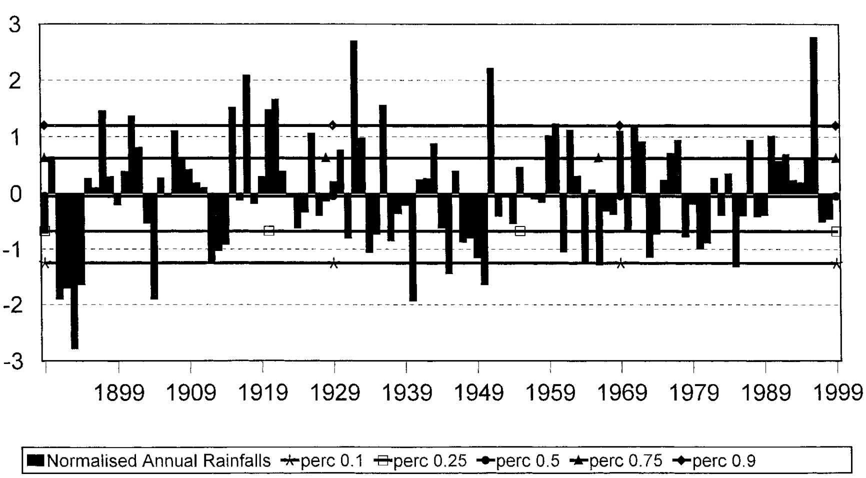

Fig. 2. Normalised annual precipitation anomalies and values corresponding to the limits of very dry (< percentile 0.1), dry (percentile 0.25), normal-dry (percentile 0.5), normal-wet (percentile 0.75), wet (percentile 0.9) and very wet (> percentile 0.9) in Vilafranca del Penedès (Barcelona, Spain)

Table 1. Mean annual rainfall for each decade and its standard deviation in Vilafranca del Penedès

Years	Vilafranca del Penedès	
	Average annual rainfall (mm)	Standard deviation (mm)
19th cent-90's	443.5	240.1
20th cent-00's	554.0	272.4
20th cent-10's	528.8	265.3
20th cent-20's	564.4	274.0
20th cent-30's	547.0	279.0
20th cent-40's	449.8	225.5
20th cent-50's	530.2	264.2
20th cent-60's	512.7	255.5
20th cent-70's	526.6	258.1
20th cent-80's	475.2	230.8
20th cent-90's	589.7	288.5
Average	520.1	248.0

Table 2. Mean annual rainfall for each decade and its standard deviation in Sant Sadurní d'Anoia

Years	Sant Sadurní d'Anoia	
	Average annual rainfall (mm)	Standard deviation (mm)
20th cent-60's	580	146
20th cent-70's	590	126
20th cent-80's	512	110
20th cent-90's	541	111
Average	542	122

the dry, normal and wet years recorded throughout the time. During the nineties no dry no very dry years were recorded. Most years could be classified as normal-dry or normal-wet years, and only one year was classified as very wet.

By decade, the average annual rainfall ranged from 443 mm and 589 mm. The driest years were recorded during the last decade of the 19th century and during the 1930s, 1940s and 1980s. The relative standard deviations were similar, although during the 4 last decades it is slightly lower. Table 1 shows the average annual rainfall by decade and its standard deviation.

A similar analysis was done for the other station and the normalised anomalies are shown in Fig. 3, compared with those obtained for the same years at Vilafranca del Penedès. Average values for each decade are shown in Table 2. We can observe coincident anomalies in the same years, without any consistent trend.

3.2 Monthly and seasonal rainfall

Figure 4 shows the average monthly rainfall and its variability over the decades. The distribution throughout the year presents a maximum rainfall period during September, October and November. The average values during these months were 65 mm, 66 mm and 48 mm, respectively, but with maximum values up to 289 mm (maximum recorded in October). A second maximum is observed during the spring, with maximum precipitation up to 204 mm in May. Figure 4 also shows the values corresponding to the 0.1, 0.25, 0.5, 0.75 and 0.9 percentile for each month.

The total amount of rainfall during these two periods of maximum rainfall represents about 70% of the total annual rainfall, with an average of 30% in spring and 40% in autumn. However,

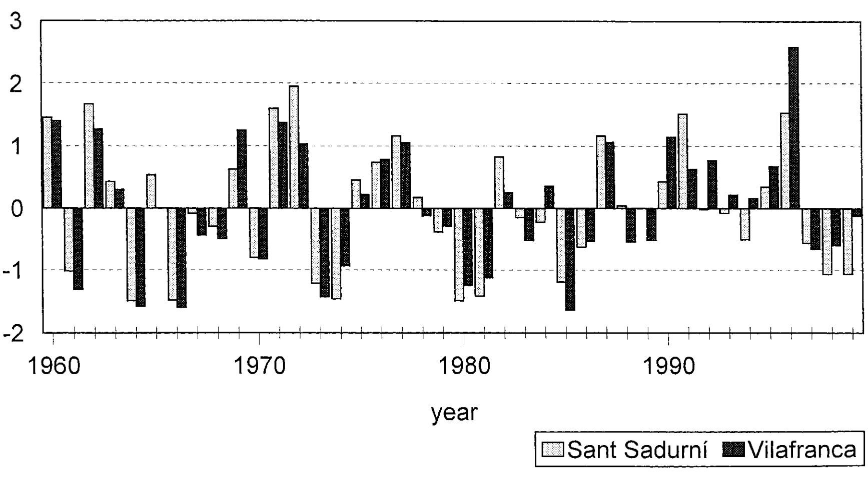

Fig. 3. Normalised annual precipitation anomalies in Sant Sadurní d'Anoia and Vilafranca del Penedès (Barcelona, Spain) during the last four decades

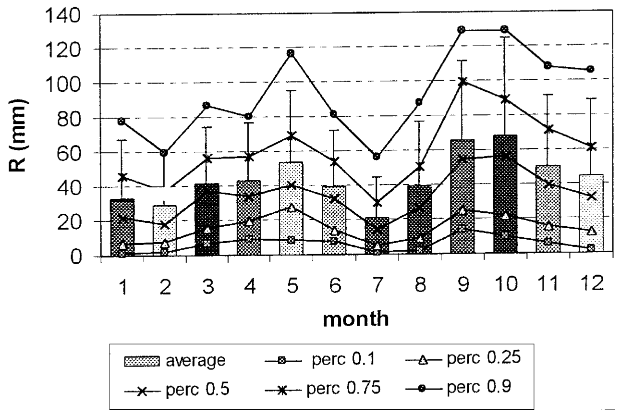

Fig. 4. Average monthly rainfall in Vilafranca del Penedès (Barcelona, Spain) for the period 1889–1999 and values corresponding to the limits of very dry (< percentile 0.1), dry (percentile 0.25), normal-dry (percentile 0.5), normal-wet (percentile 0.75), wet (percentile 0.9) and very wet (> percentile 0.9)

the rainfall characteristics of these two periods are different. Ramos and Porta (1994) pointed out that the autumn rainfall in this area is high intensity and short duration whereas spring rainfall is low intensity and longer duration. The total rainfall recorded during the two main periods was calculated for every year to determine whether they were dry, normal or wet periods. Figures 5 and 6 show the normalised deviations for these two periods.

The decades with highest frequencies of dry spring periods were the last decades of the 19th century and the 1940s and 1960s. Although in the most recent decades the percentage of dry periods was not so high that it has something in common with the decades mentioned before: three consecutive years recorded very low rainfalls (< 95 mm) during the spring period. The 1980s contained the highest percentage of normal-normal dry years.

The decades with the highest percentage of dry or very dry autumn seasons were the last decade of the 19th century and the 1940s. The average rainfall during these periods ranged from 66 to 81 mm, while the average rainfall is about 200 mm. The highest percentage of wet or very wet autumns was recorded during the first and the last decade of the 20th century.

The average autumn rainfall shows an increase during the last three decades (151.8–171.0–223 mm), reaching the highest values, above all the other decades, while a decrease of precipitation is observed during the spring (199–146–167 mm). In 57% of all years, the total rainfall of April + May + June + July + August is lower than 195 mm, but the percentage increases up to 65% for the last 4 decades. This value was given as a minimum value to cover the moisture needs of grapevines (Barnes et al., cited by Hidalgo (1999)), which is the main crop grown in the area.

During these two periods different patterns of rainfall were observed: a) years with normal-dry springs and normal-wet autumns; b) years with wet springs and normal-wet autumns; c) years with normal-wet springs and dry autumns; d) dry years, with dry autumns and dry springs, and e) wet years and with very wet springs and very wet autumns. These first three patterns presented similar frequencies (ranging between 22–27%), while pattern *d* occurs in 14% of the years and

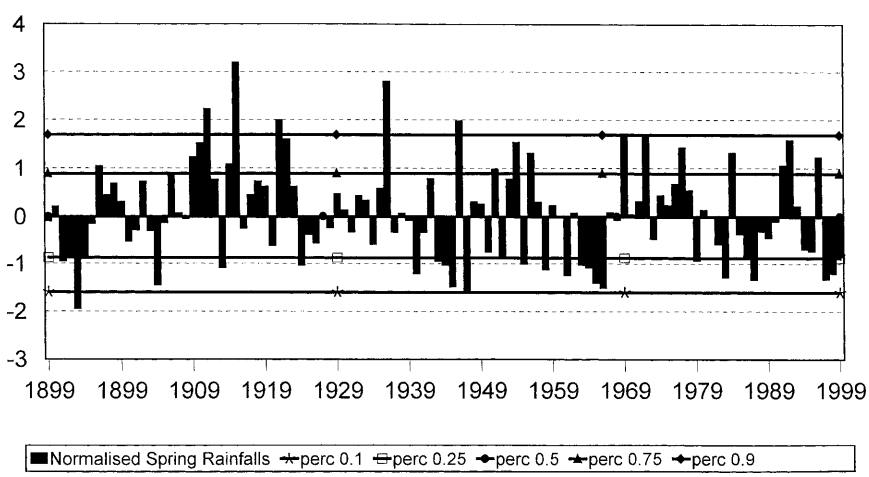

Fig. 5. Normalised spring precipitation anomalies and values corresponding to the limits of very dry (< percentile 0.1), dry (percentile 0.25), normal-dry (percentile 0.5), normal-wet (percentile 0.75), wet (percentile 0.9) and very wet (> percentile 0.9) in Vilafranca del Penedès (Barcelona, Spain)

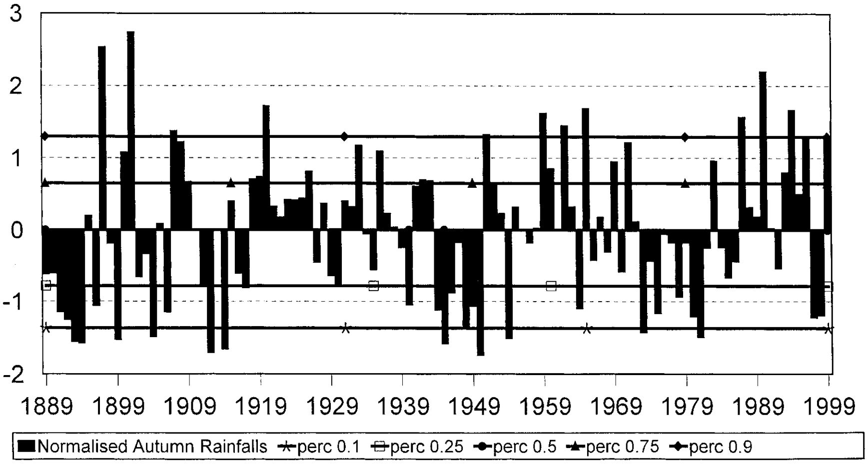

Fig. 6. Normalised autumn precipitation anomalies and values corresponding to the limits of very dry (< percentile 0.1), dry (percentile 0.25), normal-dry (percentile 0.5), normal-wet (percentile 0.75), wet (percentile 0.9) and very wet (> percentile 0.9) in Vilafranca del Penedès (Barcelona, Spain)

pattern *e* in only about 10% of the years. Pattern *a* includes a significant number of years in recent decades. The other patterns occurs in all decades.

For the other observatory (Sant Sadurní) the tendency is similar. Table 2 shows the average annual rainfall for 4 decades the standard deviation. The average annual rainfall during the last decade was 10% below the previous decades.

Figures 7 and 8 show the normalised spring and autumn anomalies for Sant Sadurní d'Anoia, and the normalised values corresponding to the percentiles 0.1, 0.25, 0.5, 0.75 and 0.9 which re-

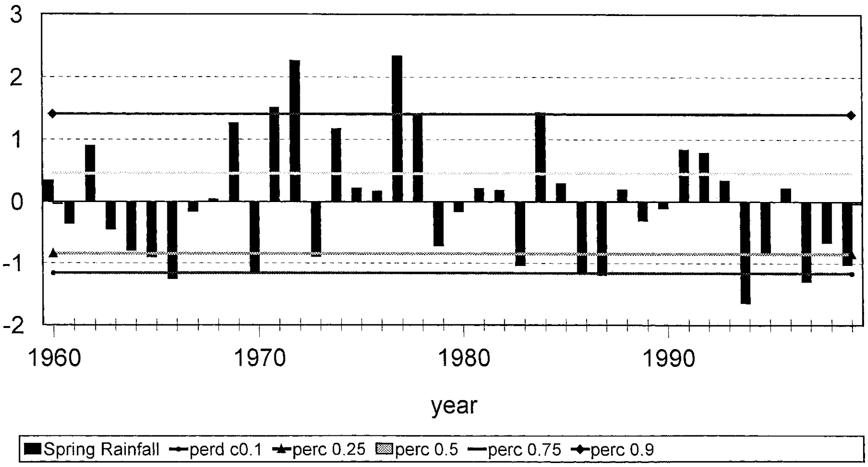

Fig. 7. Normalised spring precipitation anomalies and values corresponding to the limits of very dry (< percentile 0.1), dry (percentile 0.25), normal-dry (percentile 0.5), normal-wet (percentile 0.75), wet (percentile 0.9) and very wet (> percentile 0.9) in Sant Sadurní d'Anoia (Barcelona, Spain)

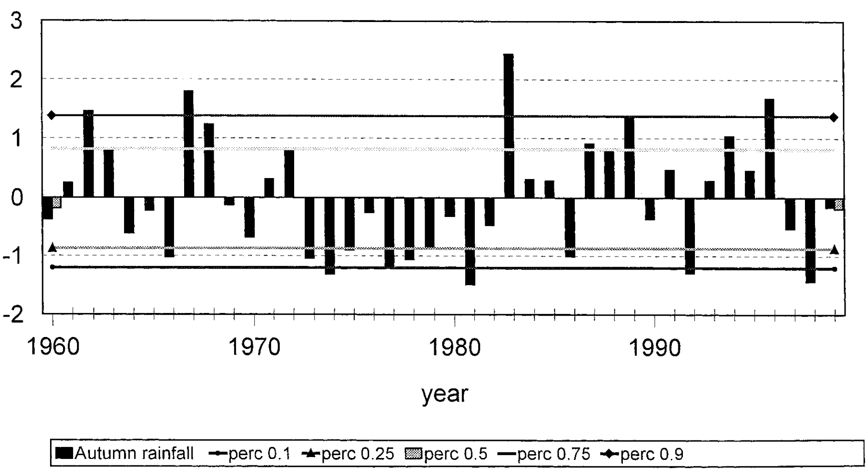

Fig. 8. Normalised autumn precipitation anomalies and values corresponding to the limits of very dry (< percentile 0.1), dry (percentile 0.25), normal-dry (percentile 0.5), normal-wet (percentile 0.75), wet (percentile 0.9) and very wet (> percentile 0.9) in Sant Sadurní d'Anoia (Barcelona, Spain)

present the limits for very dry, dry, normal-dry, normal-wet, wet and very wet periods. The values that correspond to these limits are 82 mm, 108 mm, 173 mm, 212 mm and 288 mm for spring and 60 mm, 95 mm, 167 mm, 272 mm and 323 mm for autumn, respectively.

There is high variability in the distribution of the rainfall during these two periods. However, the most remarkable result is that during the last two decades anomalies in spring rainfall are mainly negative, declining to the level of dry and very dry spring seasons, while autumn rainfall anomalies are in most cases positive, reaching the level of wet and very wet periods. Average spring rainfall decreases from 233 mm to 157 mm during the last 3 decades, while autumn rainfall increases from 141 mm to 226 mm. Figures 9 and 10 show the spring and autumn trends for the last 30 years. The minimum value to cover the requirements of the vineyards was not reached in the 57% of years. These situations lead to soil moisture values near or even below the permanent wilting point (PWD-soil moisture at −1.5 MPa matric potential) for many consequtive days in the second half of the critical period for grape production (80–240 days). This value represents the water percentage of a soil in which plant growth is reduced, causing a wilted condition, from which they cannot recover in an approximately saturated atmosphere. These periods of water deficit are clearly reflected in grape production (Nacci et al., 2000). If this trend is maintained, the economy of the area could be seriously affected and new strategies should be implemented to maintain yields.

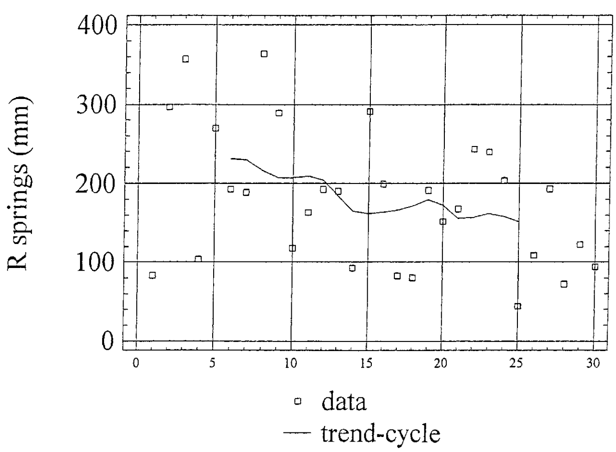

Fig. 9. Trend of the spring rainfalls recorded at Sant Sadurní d'Anoia during the last 3 decades

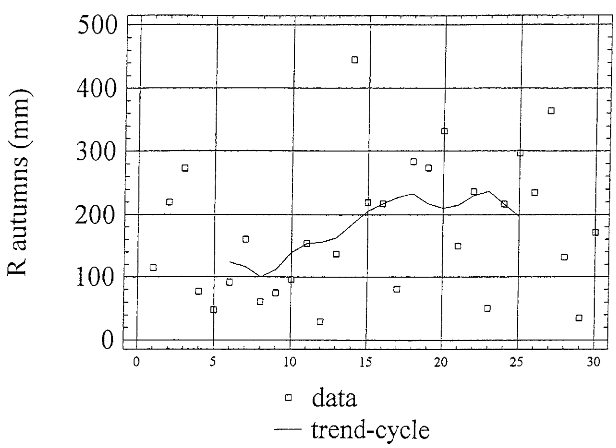

Fig. 10. Trend of the autumn rainfalls recorded at Sant Sadurní d'Anoia during the last 3 decades

4. Conclusions

Variation in mean annual rainfall during a period of 110 years did not follow a consistent trend in the Alt Penedès area. Annual rainfall ranged from 135 mm to 901 mm, but the decadal average values ranged from 443 mm to 589 mm, with standard deviations that ranged from 225 mm to 288 mm. Dry, normal and wet years were not regularly distributed over time. However, during the most recent decades less annual variability was observed. The normalised anomalies during this time were mainly between − 1 and + 1. The years with normal rainfall increased, but rainfall was more irregularly distributed throughout the year. According to the rainfall recorded during the two main periods, different patterns were observed: a) years with normal-dry springs and normal-wet autumns; b) years with wet springs and normal-wet autumns; c) years with normal-wet springs and dry autumns; d) dry years, with dry autumns and dry springs, and e) wet years and with very wet springs and very wet autumns. These patterns had different frequencies over time.

The patterns of different year types, including those with dry years or dry springs and wet autumns, seemed to increase during the most recent decade, affecting soil moisture availability when it is most critical for the crops. The spring and summer rainfall in roughly 50% of the years was lower than 195 mm, the minimum rainfall requirements or vineyards, the main crop, in the area. During the last two decades this percentage of dry years has increased up to 65%.

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Author's address: Mª C. Ramos (E-mail: cramos@macs.udl.es), Department of Environment and Soil Science, University of Lleida, Alcalde Rovira Roure 177, E-25198 Lleida, Spain.