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REGULAR ARTICLE

# Effects of climate change (precipitation variations), on rice crop yields in alluvial plains of the Tejo and Sado rivers

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## ABSTRACT

Agriculture is strongly dependent on weather conditions and climate change can alter precipitation patterns leading to extreme events as droughts and floods. Irrigated crops, such as rice, could be affected by water shortage due to prolonged drought periods or even floods. In Portugal, important paddy fields are located in Sado and Tejo river basins. Analysis of precipitation in meteorological stations from 1931/32 to 2016/17 in Sado basin and 1909/10 to 2016/17 in Tejo basin show similar variations. From record's beginning until 1949/50 a dryer season was observed, followed by a wet season from 1950/51 until 1994/95. An instable and drier season was observed from 1995/96 onwards, with a decrease in the precipitation pattern in parallel with a great oscillation compared with the trendline. Conversely, in wet periods the precipitation pattern is more alike with smaller variations in what regards the trendline. Thus, farmers are forced to select, the more drought resistant crops in order to face the insecurity of dryer periods. No extrapolations can be derived from yield and precipitation data within a short-time period of 11 and 10 years as seen in the Sado and Tejo basins. The increase in precipitation does not always means higher yields, since other interacting factors might influence productivity.

**Keywords:** Climatic change; Precipitation patterns; Rice yields; Sado basin; Tejo basin

## INTRODUCTION

Climate change is one of the biggest challenges that ecology face towards the future, which can affect natural, social and economic systems (IPCC, 2001). Europe is already experiencing climate change effects in precipitation - increasing in northern and decreasing in southern and Mediterranean areas (IPCC, 2001; Schröter et al., 2005). Globally, combined averages of land and ocean surface temperature shows increases of 0.85ºC over the period 1880 to 2012 (Olesen & Bindi, 2002; Stocker et al., 2013). Regarding Europe, from 2002 to 2011 period, the average land area temperature was 1.3ºC warmer comparing to pre-industrial levels (Füssel et al., 2012). An increase of temperature across Europe between 2.1ºC and 4.4ºC by the year of 2080 in different scenarios was predicted by Schröter et al., (2005). In southern Europe the warming effects are expected to happen in June-July and August period (Olesen et al., 2011). Continuous precipitation reductions with an increasing in warming effects enhance drought events. Western Europe and Mediterranean regions are especially vulnerable to droughts which have increased in its frequency and severity from the early 1990s onwards (Reboredo, 2014; Spinoni et al., 2015; Cook et al., 2016). Increasing instability of climatic system can lead to a less predictive weather behaviour. High precipitation events could result in floods and soil water logging with outcomes of economic losses, dike damages and soil erosion. Rising of sea level was a major concern which could result in an increased coastal erosion, coastal inundation and ecosystem losses (IPCC, 2012). The average global sea level rise from 1961 to 2003 was 1.8 [1.3 to 2.3]mm per year but, while during the 1993 to 2003 period the average was 3.1 [2.4 to 3.8]mm per

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year (IPCC, 2008) which can seriously threaten coastal, estuarine, transition and low elevation zones.

Ecological and agricultural systems are strongly dependent of environmental variations and weather conditions (Gornall et al., 2010; Filipe dos Santos et al., 2015) and yields are dependent on water availability, thus changes in precipitation patterns would have a direct influence in productivity with serious impacts on agriculture (Gornall et al., 2010; Reboredo, 2014) due to the water quantity and quality requirements of the crops (Eitzinger et al., 2013; OECD, 2014). Irrigated cultures, mainly rice paddies, are associated with floodplains nearby river streams (Förster et al., 2008), although flooding episodes from high precipitation occurrences, might also reduce rice yields (Gobin, 2018). Long periods of water shortage and increase of temperature, such as occurs in vulnerable regions of Western Europe and particularly Mediterranean areas, can turn water into a limiting factor for crop production and yield, especially during the period of grain formation (Schröter et al., 2005; IPCC, 2008; Bagulho et al., 2015; Gobin, 2018). Increasing evapotranspiration combined with a decreasing flow in surface water in Western Europe and Mediterranean regions can deplete the water quality of streams, increasing concentration of nutrients, organic matter and sediments (Mishra & Singh, 2010; García-Ruiz et al., 2011). Despite groundwater could provide a reliable and valid solution in water supplying the withdraw in groundwater levels can increase salinization in coastal regions with serious implications in water quality and permanent damage in aquifers (OECD, 2014).

Across the Europe, in 2016, were produced around 53 million tonnes of cereals, rice was the 5th most produced cereal with 4.2 million tons. In the 2006 to 2016 period Europe was the 4th region in rice production in the world with 0.6 % (Asia: 90.5 %; Americas: 5.1 %; Africa: 3.7 %; Oceania: 0.1%) (FAOSTAT Statistics Database, 2017). In Portugal, the rice production occurs in Mondego, Tejo and Sado riverbanks and estuaries. In 2014 were produced around 185,000 tons and consumed around 210,000 tons (CountryWatch Inc., 2015).

The aim of this study is to understand the pattern and variability of precipitation in Sado and Tejo river basins, to detect possible long-time trendlines and how these factors influence rice cultivation and yield.

### Study area

The Tejo and Sado rivers are located on the Iberian Peninsula and both have their mouths discharging into the Atlantic Ocean in Western Portugal (Fig. 1). The Tejo river is an international river which is born in Albarracín (Spain) with an extension of 1,100 km and a basin with 80,600 km$^2$ (Administração da Região Hidrográfica do Tejo I.P., 2011). The Sado river is a Portuguese river born in Serra da Vigia with an extension of 180 km and a basin of 7,692 km$^2$ (Agência Portuguesa do Ambiente, 2016). The Tejo basin is located north of the Sado basin. Tejo and Sado basins have a temperate Mediterranean climate with intra and interannual hydrologic variability (Aguiar et al., 2005; Administração da Região Hidrográfica do Tejo I.P., 2011; Agência Portuguesa do Ambiente, 2016). Agriculture is one of the main activities located in Tejo and Sado plains with special incidence in paddy rice (Marques & Vicente, 1999; Vasconcelos et al., 2007). Paddy rice is cultivated in Tejo and Sado plains and estuaries having a close relation with river stream. Data from Institute of Finance for Agriculture and Fisheries, (IFAP) shows in 2017 the cultivation of 7,013 ha of paddy rice in Sado basin and 13,547 ha in Tejo basin (in Sado basin rice is produced in Alcácer do Sal, Grândola, Odemira, Palmela, Santiago do Cacém and Setúbal municipalities and in Tejo basin rice is cultivated in Alcochete, Almeirim, Alpiarça, Azambuja, Benavente, Cartaxo, Chamusca, Coruche, Golegã, Salvaterra de Magos and Vila Franca de Xira municipalities).

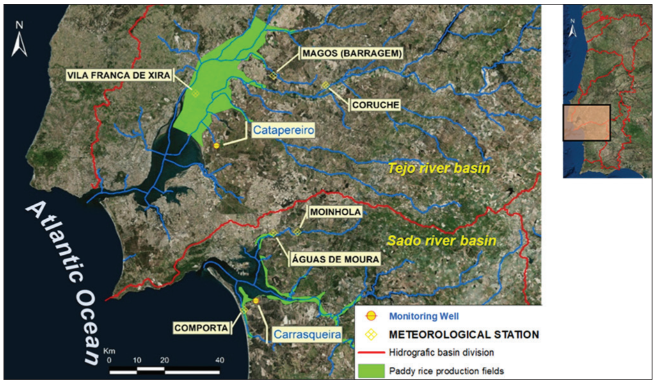

Fig 1. Tejo and Sado basins, rivers and streams, monitoring wells, meteorological stations and paddy rice production fields.

## METHODS

For this study, a series of precipitation values and groundwater levels were used. The meteorological stations selected were the closest to the rice paddies and with the longest observation series, located in the Tejo and Sado river basins. The temporal reference used across this approach was the hydrological year, which is defined as the period from 1st October to 30th September of next year. In Sado basin, were selected Águas de Moura, Comporta and Moinhola meteorological stations with data from 1931/32 until 2016/17. Yearly mean precipitation was 633 mm, 514 mm and 632 mm for Águas de Moura, Comporta and Moinhola stations respectively within the above-mentioned temporal period. For Tejo basin were selected Coruche, Magos (Barragem) and Vila Franca de Xira meteorological stations with records from 1909/10 until 2016/17. Yearly mean precipitation was 603 mm, 597 mm and 587 mm for Coruche, Magos (Barragem) and Vila Franca de Xira stations respectively within the above-mentioned temporal period.

Precipitation records resulted from meteorological stations of the National Water Resources Information System (SNIRH, APA, 2018). In each meteorological station, the missing data from precipitation was completed with data from stations nearby regarding the higher correlation indexes. Missing data could result from temporary interruptions due to technical faults and others.

In Sado basin, Águas de Moura meteorological station (code 22E/01UG), 38º35'N, 8º41'W, elevation 17 m, present records from December 1931 to July 2016. Comporta meteorological station (code 23E/01C), 38º23'N, 8º47'W, elevation 2 m, has records from January 1934 until September 2016. Moinhola station (code 22F/03C), 38º35'N, 8º37'W, elevation 41 m, present data from July 1935 to September 2016.

In Tejo basin, Coruche (code 20F/01UG), 38º57'N, 8º32'W, elevation 73 m, presents records from January 1910 to November 2009. Magos (Barragem) station (code 20E/01C), 39º00'N, 8º41'W, 43m elevation and has data from January 1938 to September 2016. Vila Franca de Xira station (code 20D/01C), 38º57'N, 8º57'W, elevation 1 m, presents records from October 1957 to September 2017. With the scope to fill some missing data was used Lisbon (IGIDL) meteorological station, 38º43'N, 9º09'W, with recorded data from October 1900, to correlate with Vila Franca de Xira station. Correlation indexes for each meteorological station is shown in Table 1.

With the full available data (measured and correlated), a mean yearly precipitation for each hydrological year was projected across the series and a trendline was adjusted to those projections. The 6th degree polynomial trendline was used because has shown the greatest fit to the available data with the highest $R^2$.

Groundwater levels were collected from National Water Resources Information System (SNIRH, APA, Environmental Ministry of Portugal) and were chosen two monitoring wells, in Sado and Tejo rivers basins. In the Sado river basin was selected Carrasqueira monitoring well which has 98 m depth and water level records from March 1980 to May 1994. In the Tejo river basin Catapereiro monitoring well was selected with records from May 1979 to January 2018 and presents a depth of 6,5m. Groundwater levels were projected and a polynomial 6th degree trendline was applied to evidence water level behaviour.

## RESULTS AND DISCUSSION

### Sado river basin

The analysis of the precipitation in the different meteorological stations allow us to establish three different periods as well as to trace the sixth-order polynomial trendline (Figs. 2, 3 and 4), although, it must be emphasized that within the Sado basin the Comporta Station exhibited the lowest precipitation records, always.

The first period, from 1931/32 to 1949/50, shows a slight increase in precipitation, followed by another increase, as seen by the average precipitation, during the period from 1950/51 to 1994/95. The third period, from 1995/96 to 2016/17 shows a clear decrease of precipitation in the region.

Statistic evaluation for each meteorological station and for each period (Table 2) shows that the average of precipitation during the 2nd period is 642.7 mm, the highest

**Table 1: Correlation indexes of meteorological stations used for precipitation series**

| | Águas de Moura | Comporta | Magos (Barragem) | Vila Franca de Xira | Lisboa (IGIDL) |
|---|---|---|---|---|---|
| | Correlation with Moinhola ($R^2$ Value) | Correlation with Moinhola ($R^2$ Value) | Correlation with Coruche ($R^2$ Value) | Correlation with Magos (Barragem) ($R^2$ Value) | Correlation with Vila Franca de Xira ($R^2$ Value) |
| October | 0.8781 | 0.8006 | 0.8429 | 0.8376 | 0.8222 |
| November | 0.9137 | 0.8492 | 0.7527 | 0.8561 | 0.8808 |
| December | 0.9198 | 0.8900 | 0.8747 | 0.9104 | 0.9446 |
| January | 0.9036 | 0.8988 | 0.8816 | 0.8921 | 0.5986 |
| February | 0.9432 | 0.8361 | 0.8915 | 0.9006 | 0.9153 |
| March | 0.8475 | 0.8284 | 0.7522 | 0.8870 | 0.9260 |
| April | 0.8516 | 0.7434 | 0.6359 | 0.7518 | 0.7547 |
| May | 0.9010 | 0.7672 | 0.7318 | 0.7583 | 0.6395 |
| June | 0.7692 | 0.7951 | 0.5482 | 0.5147 | 0.6561 |
| July | 0.6555 | 0.5462 | 0.6221 | 0.7734 | 0.5828 |
| August | 0.5962 | 0.0174 | 0.7883 | 0.4702 | 0.8472 |
| September | 0.7973 | 0.6587 | 0.7749 | 0.5766 | 0.6241 |

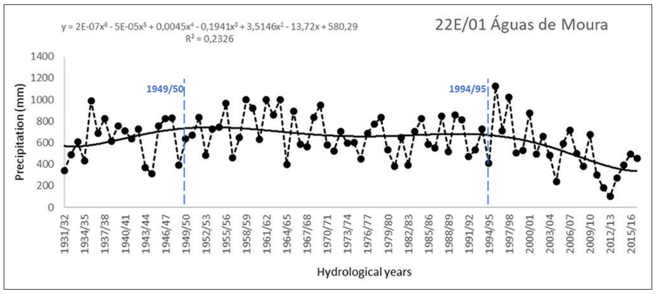

**Fig 2.** Precipitation distribution in hydrological years between Oct. 1931 and Sept. 2016 in Águas de Moura meteorological station.

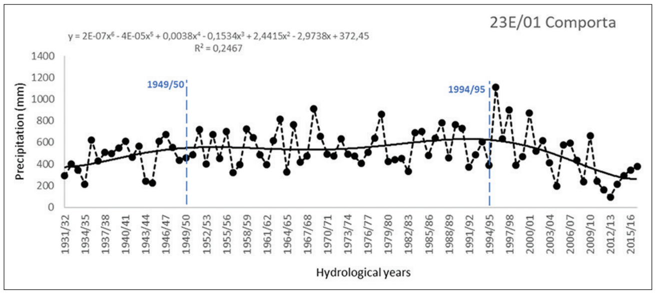

**Fig 3.** Precipitation distribution in hydrological years between Oct. 1931 and Sept. 2016 in Comporta meteorological station.

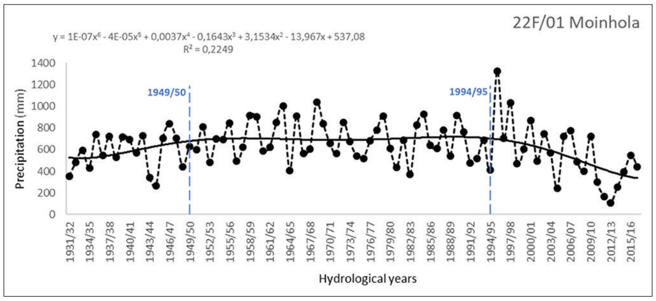

**Fig 4.** Precipitation distribution in hydrological years between Oct. 1931 and Sept. 2016 in Moinhola meteorological station.

value observed in the Sado basin. Conversely, the average during the 3rd period is 521.9 mm, a considerable decrease indicating a drier trend that is observed mainly in the Iberian Peninsula and Mediterranean areas. The first period shows us an intermediate value of 555.9 mm regardless some critical drought years between 1943 and 1946, recognized as one of the most serious and longest period, with 52% of the Portugal's mainland affected for more than 24 months (IPMA, 2018; Pessoa et al., 2014). Even in the 2nd period various drought episodes were noted some of them affecting the areas located north or south of the Tejo river, or even both. In fact, during the years 1964 to 1965, 1974 to 1976 both areas were equally affected by severe and extreme drought (Pires, 2008), while during the years 1980 to 1983 and 1994 to 1995, the Southern region was the most affected.

**Table 2: Descriptive statistics of the precipitation values measured in the aguas de moura, Comporta and moinhola meteorological stations in Sado basin**

| | Águas de Moura | Comporta | Moinhola |
|---|---|---|---|
| Period 1 1931/32 to 1949/50 | | | |
| Min. | 310.8 | 213.9 | 265.5 |
| Mean | 628.9 | 457.8 | 580.9 |
| Max. | 992.1 | 673.9 | 839.6 |
| Std. Dev. | 187.3 | 137.5 | 156.3 |
| Period 2 1950/51 to 1994/95 | 380.7 | 319.4 | 373.0 |
| Min. | 683.2 | 558.2 | 686.6 |
| Mean | 999.8 | 913.1 | 1 041.6 |
| Max. | | | |
| Std. Dev. | 180.1 | 153.6 | 171.2 |
| Period 3 1995/96 to 2016/17 | | | |
| Min. | 100.5 | 96.8 | 105.5 |
| Mean | 532.5 | 470.6 | 562.6 |
| Max. | 1 125.2 | 1 112.5 | 1 326.6 |
| Std. Dev. | 251.6 | 254.6 | 283.8 |

The decrease in the precipitation volume from 1994/95 onwards was most pronounced in the last period (2016 to 2017) with 97% of the Portugal's mainland in November 2017 with severe and extreme drought according the PDSI index (IPMA, 2017). Fig. 5. Water level in Carrasqueira monitoring well between March 1980 and May 1994.

Regarding Carrasqueira monitoring well water levels (Fig. 5), located in the Sado basin, it was observed a certain constancy during 1980s and until 1993/94, precisely when a dry period from 1994/95 was initiated, affecting mainly the Southern regions, as stressed before.

### Tejo river basin

The trendline of the Tejo basin (Figs. 6, 7 and 8), is similar to that observed for the Sado basin suggesting the possibility of applying the same periods used previously (1909/10 to 1949/50; 1950/51 to 1994/95; 1995/96 to 2016/17).

Meteorological stations of Coruche, Magos (Barragem) and Vila Franca de Xira evidence an instable and dryer season from the record´s beginning followed by a transition to an increasing precipitation period giving an average value of 550.3 mm (Table 3). It must be emphasized that the precipitations series began in 1909/10, two decades before the data observed in the Sado basin. The 2nd period represents a more hydrologically prosper season with an average of 678.0 mm of precipitation. The last period (1994/95 to 2016/17) can be characterized by instability as seen by strong variations in the precipitation volumes, that worsens the water availability and reliability. In this particular case, the average value is 519.2 mm.

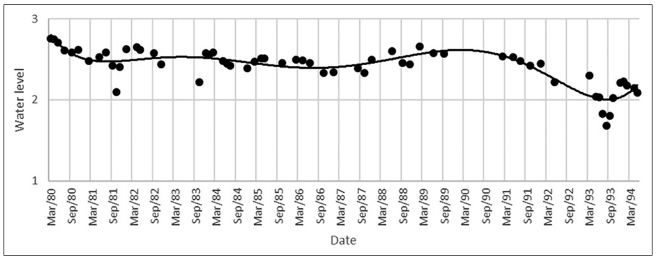

**Fig 5.** Water level in Carrasqueira monitoring well between March 1980 and May 1994.

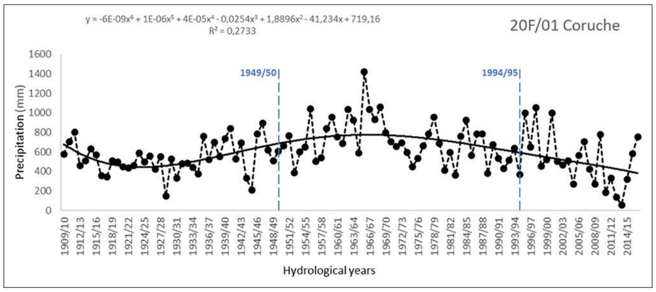

**Fig 6.** Precipitation distribution in hydrological years between Oct. 1909 and Sept. 2016 in Coruche meteorological station

The most wet season was observed during the 2nd period (1950/51 to 1994/95) and Coruche meteorological station gave us an impressive volume of precipitation of 1,421 mm in the 1965/66 year. The 3rd period is the most instable because combines the highest and the lowest precipitation volumes, for Magos (Barragem) and Vila Franca de Xira meteorological stations. Furthermore, in the 3rd period occurs the driest year (2013/14) with 56 mm, 49 mm and 171 mm for Coruche, Magos (Barragem) and Vila Franca de Xira meteorological stations, respectively, and the smallest mean value for all meteorological stations.

Water levels of Catapereiro monitoring well in Tejo basin show us two different periods (Fig. 9). The first one, more stable since May 1979 until August 2000, followed by a continuous decrease onwards where the monitoring water levels reach the lowest values in February 2008 and March 2014, leading to a possible depletion. Decreasing water levels could result from an increased extraction from water wells, regardless the role of climate changes, and the decrease of precipitation in this basin, which do not allow to recharge the aquifers, thus reducing the availability of hydric resources. Fig. 9. Water level in Catapereiro monitoring well from May 1979 to January 2018.

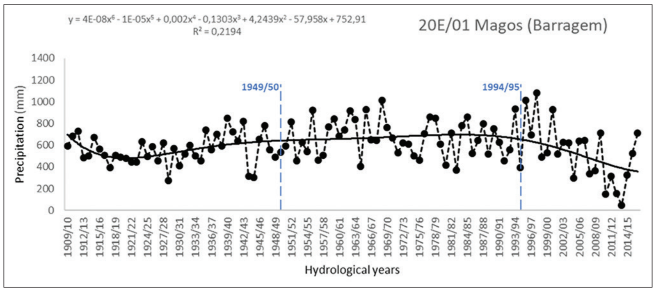

**Fig 7.** Precipitation distribution in hydrological years between Oct. 1909 and Sept. 2016 in Magos (Barragem) meteorological station

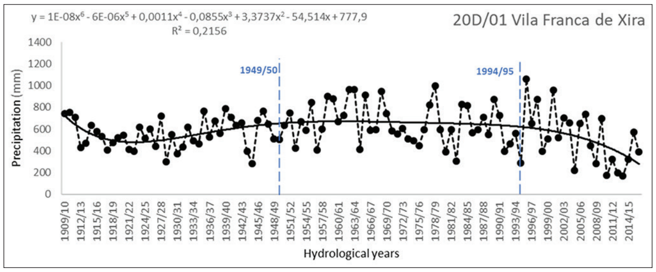

**Fig 8.** Precipitation distribution in hydrological years between Oct. 1909 and Sept. 2016 in Vila Franca de Xira meteorological station.

**Table 3: Descriptive statistics for coruche, magos (Barragem) and Vila Franca de xira meteorological stations in Tejo basin**

| | Coruche | Magos (Barragem) | Vila franca de Xira |
|---|---|---|---|
| Period 1<br>1909/10 to 1949/50 | | | |
| Min. | 145.3 | 272.4 | 282.8 |
| Mean | 535.7 | 558.0 | 557.1 |
| Max. | 892.7 | 847.7 | 790.1 |
| Std. Dev. | 159.9 | 131.1 | 131.2 |
| Period 2<br>1950/51 to 1994/95 | 360.8 | 370.2 | 307.6 |
| Min. | 709.5 | 669.8 | 654.9 |
| Mean | 1 421.4 | 1 010.3 | 998.7 |
| Max. | 218.3 | 164.3 | 178.4 |
| Std. Dev. | | | |
| Period 3<br>1995/96 to 2016/17 | | | |
| Min. | 56.1 | 49.2 | 171.6 |
| Mean | 517.3 | 527.1 | 513.3 |
| Max. | 1053.4 | 1079.7 | 1062.1 |
| Std. Dev. | 266.8 | 261.2 | 250.8 |

## Rice yield and precipitation in the Tejo and Sado river basins

In the Sado basin, rice yield data from Portocarro paddy with an area of 13.5 ha, consists of 11 years of records, from 2007 to 2017. The precipitation data from the closest meteorological station (Comporta) was used to be crossed with yield data (Fig. 10). The yield in this paddy exhibits a strong fluctuation regardless the variations in the precipitation amounts in Comporta which is located near the shoreline. Also, we do not know if these yield variations are due to different cultivars or different management techniques. Adaptation measures as alterations in planting and harvest dates, changing in cropping sequences, better water management or optimized use of fertilizers (Korres et al., 2017) could provide a reliable way to maintain and increase yield in a climate change reality.

Although our analysis has been focused on a single paddy, in both basins, it is well known that paddy rice production in the Sado basin was strongly conditioned in 2017 due to the scarce precipitation, while for 2018 rice and other spring crop productions are threatened and farmers struggle to find some alternative crops to monetize their land. Furthermore, the Instituto Nacional de Estatística (INE, 2018) states in the January report, that the minimum historical production land for winter cereals is 121,000 hectares. The average air temperature was 0.2ºC higher than normal for January and precipitation 35% less than normal amount. Thus, precipitation in the winter months was not enough to cover or approximate the normal values of soil moisture, and also not enough to maintain water demand to irrigation of spring crops, which leads farmers to equating production of alternative and more drought stress resistant crops. In February 2018, in 10 dams situated in the Sado basin, 6 of them present levels below 15% of its storage capacity, which have close relation to irrigation and present a dramatic situation to farmers, local economy and environmental planning (SNIRH, APA, 2018).

Regarding Tejo basin, rice yields between 2008 and 2017 refers to Saragoça paddy, with 47.54 ha. Precipitation records of the closest meteorological station (Vila Franca de Xira) were crossed with yield data (Fig. 11). It seems that the yield is relatively constant despite the fluctuations in the precipitation amount. This independence may well be related to agronomical and technical factors which are not addressed in this study. However, it must be emphasized that from 2012 onwards, four different rice cultivars were used, probably in order to achieve the best options in terms of drought and pest resistance and yields. It is well known that climatic instability could increase the uncertainty of crop planning, leading to an income decrease to farmers and industrial players. Since paddy rice is an irrigated crop, shortage of water could seriously threaten production in both basins, although the lack of information regarding yields in a more extensive period and the absence of complementary data, such as cultivars used and temperature might give us a more comprehensive approach of interacting factors related to yield.

## CONCLUSIONS

The monitoring of changes in precipitation across records series provides valuable information about climate uncertainty and instability. Less predictive climatic behaviour, especially in drier periods, transmit hydric insecurity to farmers affecting crops planning and productivity.

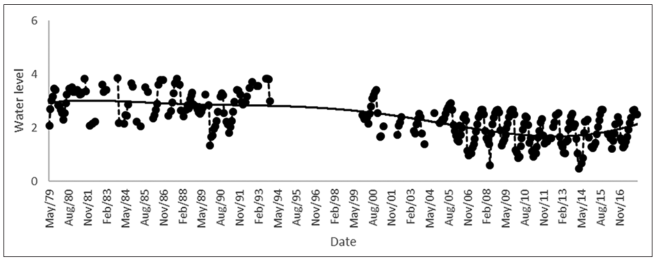

**Fig 9.** Water level in Catapereiro monitoring well from May 1979 to January 2018.

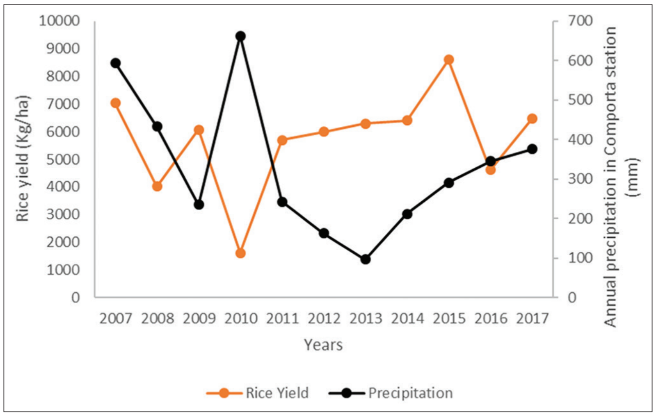

**Fig 10.** Rice yield between 2007 and 2017in the Portocarro paddy at Sado basin and annual precipitation amount in Comporta meteorological station.

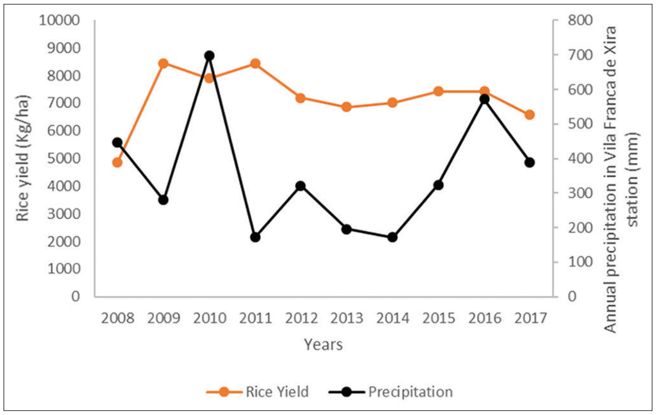

**Fig 11.** Rice yield between 2008 and 2017 in the Saragoça paddy at Tejo basin and annual precipitation amount in Vila Franca de Xira meteorological station.

Throughout the sixth-degree polynomial trendline it was possible to establish three different periods across the precipitation series in the Tejo and Sado basins. In general, were distinguish a first period with a slight increase in precipitation, followed by another period where this tendency was stabilized. The third period corresponds to a clear decrease in the precipitation amount, a trend which is supported by a general framework of the whole mainland.

In what regards, rice yields no simple correlations can be derived between precipitation and yields. In the Saragoça paddy at the Tejo basin it seems that the yield is relatively constant despite the fluctuations in the precipitation, while, in what concerns the Portocarro paddy (Sado basin), the yield exhibits a strong fluctuation regardless the variations in the precipitation registered in Comporta meteorological station.

Managing water resources in short and medium term could provide a reliable solution to use water throughout dryer periods without compromising agricultural production. Adaptation measures such as the appropriate choice of crops resistant to water stress could be the best response to water deficit periods.

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### Author's contributions

All authors had an equal participation in the conception of this journal article.

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