Local climatic changes assessment and influence over edaphic characteristics in the Mediterranean basin

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Abstract: - Mediterranean basin soils are markedly degrading due to several anthropic pressures while the general population continues to rise. In order to feed the actual and projected population in 2050 several strategies are in order, but all depend on the preservation and optimization of land resources. Resources that must be assessed and monitored in order to verify if such objectives are reachable. Using registered data from 1965 and 15,0000 soil samples collected in 2012 in a western Mediterranean basin field with 15,000 ha we track key edaphic health predictors where rain-fed evolution was measured. We tracked soil organic matter (SOM), pH and exchangeable bases (Ca^{2+}, Mg^{2+}, K^+ and Na^+). We found that while SOM, pH, exchange Ca^{2+}, Mg^{2+} and K^+ were significantly increasing, exchange Na^+ was significantly decreasing. Normal climatic data comparisons revealed that climate has changed from sub-humid with great water excess (*C1B2s2b4*) in 1951/1980 to sub-humid with moderate water excess (*C1B2sb4*) in 1981/2010 to semi-arid with little or none water excess (*DB2db4*) in 1991/2016 according to the Thornthwaite classification. Our results suggest that this Mediterranean basin area is departing from sustainable goals of soil conservation and proper soil conservation and management practices, that face the local climatic changes, should be adopted.

Key-words: Mediterranean basin, soil degradation, anthropic pressure, desertification, semi-arid

1 Introduction

Soils from all over the world are increasingly subject to several anthropic pressures with soils previously under tropical forest being used to agricultural productivity (FAO - Food and Agriculture Organization, n.d. a), or previously pastured and fallow fields forever under construction in order to accommodate the increasing population (Foley et al., 2011). Accordingly, new leisure sites (i.e.: golf courses, parks, artificial lakes) that accompany the urbanization sprawl surge every now and then. Both practices contributing to the increase in land take and soil sealing (Prokop, Jobstmann & Schönbauer, 2011). Also, more pressure is put on agricultural soils demanding that they be able to feed the ever-growing members of our global community (Ray, Mueller, West & Foley, 2013), with a clear focus on irrigation sites but also, although on a much lower scale, on other cultural systems as soilless crops, vertical growing, urban gardens, etc, although with discontinuous resources. As commonly practiced today, agricultural intensification has a double bind effect on the whole ecosystem with soils losing its richest layer to the sea through the accelerated erosion created by anthropic weathering such as tillage, ploughing, harrowing or scarification, (Khatelli et al., 2016) factors responsible for the continuous decrease of SOM levels and soil compacting. Also, due to the high rate of fertilizer input in irrigation water, there is also an increased salinity in soils. The air we breathe is chemically polluted and the application of chemicals, like glyphosate, that according to the Office of Environmental Health Hazard Assessment (OEHHA, 2017) are 'known to cause cancer' are still a common practice in Europe where its legal use was prolonged until 2023 ("European Commission - PRESS RELEASES - Press release - Questions & Answers: Commission replies to European Citizens' Initiative on Glyphosate and announces more transparency in scientific assessments," n.d.). An increase in allergies and several other diseases have already been correlated to bad agricultural practices (Davis, Brownson, Garcia, Bentz & Turner, 1993; Alavanja, Hoppin & Kamel, 2004; Heederik & Sigsgaard, 2005; Di, Di, Verna & Di, 2007; Yan, Zhang & Yan, 2016). Drought is increasing and daily access to safely managed drinking water doesn't reach 2B people (30% of the population) as in 2015 (UNICEF, 2018) and yet runoffs and contamination of the water tables are still common results from agricultural irrigation practices that consume 70% of the world's available freshwater (Meat Atlas, 2014). There is a registered unsustainability of the ecosystem with ever growing sites unevolving from temperate to semi-arid, from semi-arid to arid and from arid to desert conditions due to global and local climatic changes and its agents and from local malpractices with its soils becoming more saline, more alkaline and more deprived of organic matter content (Szabolcs, 1990; Lavee, Imeson, & Sarah, 1998; Farifteh, Farshad & George, 2006; Khatteli et al., 2016, Francaviglia, Ledda & Farina, 2018). In this study we compared soil data from the western Mediterranean region of Alentejo, Portugal, since 1965 and correlated it with the normal climatic data of 1951-1980, 1981-2010

and 1991-2016 so to contribute to a better understanding the impact that local climatic changes, have in rain-fed soils. In the extended version we will include the comparison to irrigated soils by Reference Soil Group (RSG) (FAO, 2014) regarding SOM, EC, pH, Ca^{2+}, Mg^{2+}, K^{+}, Na^{+} and the equitable exchange cations.

2 Material and Methods

The study area is located in the NUTS II Alentejo region between the townships of Campo Maior and Elvas, Portugal, in the Mediterranean basin region as described in Loures et al. (2017) and Telo da Gama et al. (2019). Till 1965 none of the soils here presented were exposed to an extended irrigation practice and, thus, rain-fed soil evolution was obtained by comparing SOM, pH and the exchange bases Ca^{2+}, Mg^{2+}, K^{+} and Na^{+} from the years 1965 and 2012.. We followed the general methodology presented in figure 1.

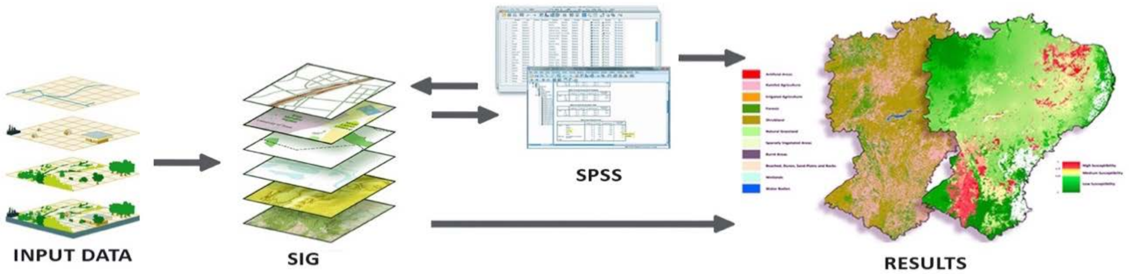

Fig. 1: Data treatment - general methodology

2.1 Soil Data

Soil data for 1965 was obtained from *Os solos de Portugal* (Cardoso, 1965) that sampled soils in the studied area using the Portuguese Soil Classification system. The samples were related to the soils of the study area via Geographic Information Systems (GIS) software by main and predominant classification parameter (e.g., a soil characterized as 'Pag/Pac' was identified solely as a Pag in the study area as the Pag is the main classificatory detected) and a weighted arithmetic mean was performed for every different soil type in order to express the average weight of each soil in the final equations. A flaw in this study was to assume that the registered data from 1965 represents the mean values for that kind of soil. Soil data for 2002 and 2012 was obtained in field as described in Material and Methods and Analytical Methods in this paper.

2.2 Climatic Data

Climatic data for the 3 sample periods was collected and a 30-year mean (normal year) was arranged in order that any given sampled year was the nearest possible to the normal year mean and so for the 1965 sampled data we analyzed climatic data from 1951 to 1980, for the 2002 sampled data we analyzed the years ranging from 1981 to 2010 and for 2012 we analyzed the data from 1991 until 2016.

The normal climatic data from:

- 1951/1980 was obtained from weather station observations in *Elvas* region registered in the book *O clima de Portugal* of the national institute of meteorology and geophysics (INMG, 1990).
- 1981/2010 and 1991/2016 was calculated from monthly data obtained at weather station observations for the *Elvas* region registered in the ‘*Caia* Beneficiaries Association’, a non-profit organization under the supervision of the Ministry of Agriculture and which is in charge of the management, exploitation and conservation of the *Caia* Hydro-agriculture Project and
- *Caia* Irrigation Perimeter. ET0 was determined with an unadjusted version of the Hargreaves equation (equation 1). Radiation (Ra) was obtained from the Portuguese Institute of the Sea and the Atmosphere (IPMA). Logistics in climatic observations remained constant throughout the sampled years guaranteeing the homogeneity of the sampled data.

$$ET0 = a + b \times \frac{1}{\lambda} \times 0{,}0023 \times \left(\frac{Tmax + Tmin}{2} + 17{,}8\right) \times \sqrt{Tmax - Tmin} \times Ra \quad (1)$$

Tmax(°C) is the maximum daily air temperature; Tmin(°C) is the minimum daily air temperature, Ra (MJ m-2.d-1) is the extra-terrestrial solar radiation. Parameters a (mm d-1) = 0, b = λ= 1.

2.3 Analytical Methods

pH water was determined in one soil part to five parts water (1:5 (v/v)) solution. The measurement was performed by a potentiometric method using an MTROHM 692 pH/Ion Meter potentiometer (Buurman, Van Lagen, & Velthorst, 1996).

SOM was determined by the wet oxidation method with potassium dichromate, followed by a dosing of the excess dichromate by titration with ferrous sulfate (USDA, 1996, Nelson & Summers, 1996; Buurman, Van Lagen & Velthorst, 1996).

2.3.3 Exchange Ca^{2+}, Mg^{2+}, K^{+} and Na^{+}

The exchange cations were extracted with 1 N NH4OAc (Ammonium acetate solution) buffered at pH 7.0 as described in the Soil Survey Laboratory Methods Manual (Charts, M. S. C., 1994).

2.4 Statistical Analysis

All statistical analyses were performed as in Telo da Gama et al. (2019) using SPSS v.25 software package where Shapiro-Wilk tests of normality (Shapiro & Wilk, 1965; Razali & Wah, 2011), inspection of skewness and kurtosis measures and standard errors (Cramer, 1998; Cramer & Howitt, 2004; Doane & Seward, 2011) and a visual inspection of the histograms, normal Q-Q plots and box plots were performed in order to assess if the data was normally distributed. Levene’s tests for homogeneity of variances (Nordstokke & Zumbo, 2010; Nordstokke et. al., 2011) were performed in order to assess the homoscedasticity/heteroscedasticity of the data and, thus, if it could be compared in their respective categories. Independent Sample T-Test and one-Way ANOVA with Tukey's post-hoc test were performed on all normally distributed with homogeneity of variances data and, as we have more than 30 samples per subgroup, by the application of the Central Limit Theorem we consider that our non-normally distributed data approach the normal Bell curve and, thus, we also applied the aforementioned tests in non-normally distributed, but with homogeneity of variances, data. Non-normal distributed, with no homogeneity of variances, data was either transformed with Tukey's Ladder of Powers (Tukey, 1977), Box-Cox (Box & Cox, 1981) or Two-Step (Templeton, 2011) methods or directly analyzed by Mean Rank (MR) through the Mann-Whitney U Test (U) or Kruskal-Wallis H test (H) in which case a 1.000 sub-samples bootstrap was applied to the data in order to compare means – Bootstrapped Means (BM). Our results have a Confidence Interval (CI) >= 95%. All null hypothesis (H0) were rejected for a p < 0,05. All GIS analysis were performed in ArcGIS v 10.5 software package. Predictive maps were created with the Ordinary Kriging interpolation adjusted for a logarithmic factor equation and aided by ancillary variables when available (Hengl, Heuvelink, & Stein, 2004; Li, 2010; Sun, Minasny, & McBratney, 2012; Zhang, Huang, Shen, Ye, & Du, 2012; Behera & Shukla, 2015). Getis-Ord Gi Hotspot analysis were performed with inverse distance squared for the conceptualization of spatial relationships.

3 Results and Discussion

Since 1951/1980 precipitation has declined approximately 15% and ET0 has increased 6% in the studied area. Consequently an aridity index, or precipitation-to-evaporation ratio, average has increasingly decreased from 0,70 in 1951/1980 to 0,57 in 1991/2016 with extreme values as high as 0,98 and as low as 0,33 and although according to the United Nations Environment Programme (Barrow, 1992) a semi-arid climate is only found where aridity index < 0,50 the UNCCD World Atlas of Desertification (Cherlet et al., 2018) considers areas susceptible of desertification, the drylands, where the aridity index ranges from 0.03 to 0.65. Furthermore, the Thornthwaite climatic classification system for the different normal years reveals that the study area climate has changed from *mesothermal sub-humid climate with large excess water in the winter and very low thermal efficiency in the summer* (C1B2s2b4) in 1951/1980 to *mesothermal sub-humid climate with moderate excess of water in the winter and very low thermal efficiency in the summer* (C1B2sb4) in 1981/2010 to *mesothermal semiarid climate with little or no excess water in the winter and very low thermal efficiency in the summer* (DB2db4) in 1991/2016. According to Brady & Weil (2015) salt-affected soils are typically distributed in areas where precipitation-to-evaporation ration is 0,75 or less. The 1991/2016 normal year is presented in Table 1. The average annual rainfall is approximately 465,8 mm, most coinciding with the coolest temperatures from October to March. When compared with the corresponding IPMA normal year (Loures et al., 2017) the average monthly temperature of the hottest month has changed from July to August and the coolest month continues to be January. In a relatively near area (a distance of 100km in a straight line) from the studied site, Verslype (Verslype et al., 2016) found an arid climate correlated with the precipitation decrease and temperature increase.

Table 1: normal year 1991/2016 of the studied area

Month	Mean Temp. (ºC)	Max. Temp. (ºC)	Min. Temp. (ºC)	Precipitation (mm)	ET0 (mm)
January	8,9	13,5	4,4	53,0	18,7

Month	Mean Temp. (ºC)	Max. Temp. (ºC)	Min. Temp. (ºC)	Precipitation (mm)	ET0 (mm)
February	10,1	15,0	5,2	39,8	24,3
March	13,2	18,9	7,6	38,4	51,0
April	15,3	21,1	9,4	42,7	63,2
May	18,9	25,5	12,3	43,8	93,9
June	22,3	29,7	14,8	11,4	123,2
July	26,0	34,5	17,5	1,8	151,9
August	26,1	34,6	17,6	4,0	131,0
September	23,0	29,5	16,4	27,6	78,3
October	18,4	23,6	13,1	72,7	40,4
November	12,7	17,2	8,3	71,1	25,3
December	9,8	14,1	5,6	59,4	15,0
Year	17,1	23,1	11,0	465,8	816,2

3.1 Rain-fed soils

Rain-fed soils were analyzed, compared and correlated with such variables as land cover, water table distance, soil useful depth, physiographic position, hydromorphic symptoms and stoniness. SOM, pH and exchange bases variability in rain-fed soils are mainly dependent on the soil parent material, environmental conditions and quality of added residues that serve as food source for the soils micro-organisms. Of all the analyzed variables that could explain the variability of the parameters only crop variability and the increase in ET0 appeared as statically significant ($p < 0,05$) whose consequence, according to (Lavee, Imeson, & Sarah, 1998), is lower soil permeability, surface crusting and dramatic decrease in infiltration rate leading to salt accumulation and pH rise. Table 2 shows the average SOM, pH, exchange Ca^{2+}, Mg^{2+} and K^{+} content that has been increasing and exchange Na^{2+} has significantly decreased since the parameters were first assessed in 1965. The increase in SOM probably occurs because of the less-to-no tillage observed in the new crop systems diminishing annual respiration losses causing the low oxygen levels to preserve plant and microbial compounds which tend to accumulate when there is a sufficient constant addiction of plant residues that compensates the microbial oxidation of humus. Soil pH increase is closely related to the registered increase in the exchange bases that accumulate because precipitation being lower than ET0 it is not enough to leach them away leading to a lesser content of H^{+} ions in the soil exchange complex increasing the free negative charges present in the clays and humus increasing the cation exchange capacity (CEC) of the soil. The weathering of the parent material floods the soil solution and soil exchange complex with Ca^{2+}, Mg^{2+}, K^{+} and Na^{+} ions that, in the case of Ca^{2+}, Mg^{2+} and K^{+} accumulate as they are not being leached. As Na^{+} ions are not being added to the soils and because this ions are less tightly held than Ca^{2+}, Mg^{2+}, K^{+} it is being leached from these soils.

Table 2: evolution of selected soil parameters in rain-fed soils from 1965 to 2012

	N	1965	2012	Statistic test	p value
MO (%)	525	1,26	1,55	T(524): 9,809	0,000
pH	526	6,43	6,92	T(525): 10,819	0,000
exchange Ca^{2+} ($cmol_{(+)}.kg^{-1}$)	526	9,66	15,445	T(525): 10,316	0,000
exchange Mg^{2+} ($cmol_{(+)}.kg^{-1}$)	526	2,25	2,73	T(525): 5,797	0,000
exchange K^{+} ($cmol_{(+)}.kg^{-1}$)	526	0,15	0,44	T(525): 24,982	0,000
exchange Na^{+} ($cmol_{(+)}.kg^{-1}$)	521	0,32	0,16	T(520): -32,653	0,000

4 Conclusions

Climate is changing globally, and the Mediterranean basin is no exception. The NUTS II region – Alentejo - where this study was conducted is a rural area that has been subject to intensification in the last decades and where only recently certain soil destructive practices as ploughing are being discarded in favor of sustainable ones. Alentejo is the main national livestock producer and meat production has increased ever since 1950 and nowadays nearly 60% of its agricultural land is used for cattle breeding. More and more land is reclaimed in order to grow cattle or cattle feed but the registered soil salinity, alkalinization and loss of organic matter content that intensification of agricultural soils in the Mediterranean basin are showing and the direct link to local climatic changes should be enough to raise some concerns about the future of this practice. In the extended version of this paper we will compare the results here presented with the irrigation practice.

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