Possible effects of climate change on the early development of pea, broad bean, maize and sunflower in Mediterranean region

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1. INTRODUCTION

Crop productivity depends largely on the early development of plants. Extreme variations of soil temperature close to the surface of bare soils and fast changes of soil water content due to irregular rainfall and high evaporative demand are typical of Mediterranean climates. These characteristics reduce the success of germination, emergence and early leaf production, leading generally to poor crop establishment (Abreu, 1987).

Climate change in Southern Europe is expected to worsen hygrometric and thermal conditions through higher air temperatures and more severe drought (IPCC, 2007). Associated changes in soil temperature and water availability may decrease the success of both crop establishment and crop productivity. However, studies about impacts of global changes on soil temperatures and, by consequence, on crop establishment are scarce.

The aim of this study was to evaluate the thermal conditions in the top layer of a Luvisol and a Vertisol, under different climate change scenarios, and their effects on the emergence of some representative crops of Mediterranean agriculture: pea (*Pisum sativum*, L.), broad bean (*Vicia faba* L.), maize (*Zea mays* L.) and sunflower (*Helianthus annuus* L.).

2. MATERIALS AND METHODS

2.1. SITE DESCRIPTION AND MEASUREMENTS

Field experiments were located at Monte dos Álamos, Évora (38º30'N, 7º45'W, 210 m) and at Tapada da Ajuda, Lisboa (38º42'N, 9º11'W, 60 m). Climate in both places is Csa according to Köppen. Mean annual temperatures are about 15.7ºC in Évora and 16.2ºC in Lisboa. July is the hottest month (23.2ºC in Évora and 22.2ºC in Lisboa) and January the coldest (9.4ºC in Évora and 11ºC in Lisboa). Mean annual rainfall is 625 mm in Évora and 681 mm in Lisboa, of which more than 75% falls between October and March. The soils are a Luvisol in Évora and a Vertisol in Lisboa (FAO, 1998). The former is loam-sand textured, with a bulk density of 1.48 in the upper layer (0 - 20 cm depth); the Vertisol is loam-clay textured, with a bulk density of 1.22 (0 - 15 cm depth).

In both soils, temperature was measured with type T thermocouples at 2 and 4 cm sowing depths. Air temperature was measured at 1.5 m height with a ventilated psychrometer (H301, *Vector Instruments*). A data logger (CR 10, C*ampbell Scientific, Inc*.) was used for data acquisition and logging. Average air and soil temperatures were recorded hourly and daily, from 2001 to 2003.

2.2. ANALYTICAL PROCEDURES

To predict future values of soil temperature from expected global changes in air temperature, measured soil temperatures were compared to those measured in the air. Monthly mean values of temperature, calculated from daily values, were used to analyse these relationships. Two different scenarios of climatic change – increases of 1º and 2ºC on mean air temperature – were considered to discuss their eventual consequences on crop establishment.

To analyse the impact of simulations on the size, speed and dispersion of emergence, values of bioclimatic parameters determined by Andrade (2001) for the emergence of the four crops were used, namely the base and the optimum temperature for emergence rates, the thermal time for 50% final emergence and the maximum temperature for high final emergence (Table 1). Bioclimatic parameters were calculated based on the thermal time concept (Monteith, 1977). High emergence was defined by final emergence above acceptable agronomic minimum percentages, which are 70% for pea and sunflower, 80% for broad bean and 85% for maize (Miguel, 1983). Dispersion was taken as the standard deviation of the frequency distribution of thermal times, which was lowest for temperatures around the optimum (Andrade, 2001).

Table 1. Base and optimum temperatures for emergence, maximum temperature for high final emergence, thermal times for 50% emergence (θ) and dispersion of emergence (σ) for pea, broad bean, sunflower and maize in two types of soil (Andrade, 2001)

Crops	Soils	T_{base} (ºC)	T_{opt} (ºC)	$T_{máx'}$ (ºC)	θ (ºCd)	σ (ºCd)
Pea	Luvisol	-1.9	17.3	18.5	137.0	40.0
	Vertisol	5.1	19.7	17.2	76.3	33.9
Broad bean	Luvisol	1.3	16.9	18.8	137.0	46.2
	Vertisol	3.4	19.2	19.6	125.0	118.7
Sunflower	Luvisol	3.4	24.0	18.0	126.6	28.6
	Vertisol	5.3	20.2	23.6	89.3	15.6
Maize	Luvisol	6.8	23.7	20.5	95.2	29.3
	Vertisol	7.6	23.5	22.8	76.3	17.3

Where required, statistic differences between means were tested at 5% significance level (*P<0.05) with paired Student's t-tests using least significant differences procedures (Walpole and Myers, 1978). Multiple regression was used to compare regression models, namely to evaluate the statistical significance of differences between two simple regressions (Draper and Smith, 1981).

3. RESULTS

Fig. 1 shows monthly mean temperatures on the air and at 2 and 4 cm depth in the soil, in Évora and Lisboa. In both places, the hottest month was August and the coldest was January. Monthly mean air temperatures ranged from 8.9ºC to 25.7ºC in Évora, while in Lisboa, by the ocean, they ranged from 12.3ºC to 23.7ºC only.

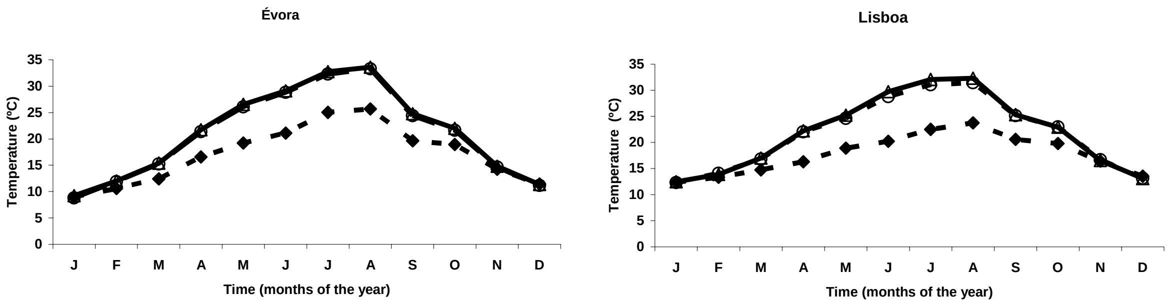

Fig. 1. Mean monthly temperatures in the air (---◆---), and at 2 cm (—Δ—) and 4 cm (---o--) depth in a Luvisol in Évora and in a Vertisol in Lisboa.

Monthly mean temperatures at 2 cm depth ranged from 9.2ºC to 33.6ºC in the Luvisol (Évora) and from 12.5ºC to 32.3ºC in the Vertisol (Lisboa), while at 4 cm depth they ranged from 8.8ºC to 33.3ºC in the Luvisol and from 12.5ºC to 31.4ºC in the Vertisol. In both places, soil temperatures were significantly greater (*P<0.05) than those recorded in the air between February and October, but they were not statistically different (*P<0.05) in November, December and January. The greater the day length the greater was the difference between temperatures in the top soil layer and in the air. Differences varied between about 1ºC in February to 7-8ºC in June and August in Évora and between 1ºC in February to about 9ºC in June and July in Lisboa. Consequently, mean soil temperatures at sowing depth are greater than mean air temperatures during the beginning of the sowing season (October and November) of winter legumes and particularly during the sowing season (April and May) of summer crops.

The relationship between mean monthly soil temperatures at 2 cm depth and mean monthly air temperature is shown in Fig. 2, for the Luvisol and the Vertisol. At 4 cm, the relationship (not shown) was similar to that at 2 cm. In both locations there are two different relations, one for the first semester and another for the second, probably due to the different time course changes in insolation in each semester. Thus, in each soil two linear regressions were established between temperature at 2 cm depth and air temperature, one for each semester of the year (Fig. 2). All correlations were statistically very significant (*P<0.001). In each location, differences between the two linear regressions were also significant (*<P<0.05). The analytical expressions for each correlation show that an increase in air temperature is accompanied by a proportionally greater increase in temperature of top soil layer. This impact is greater in the 1st semester in both locations and is greater in the Vertisol (Lisboa) than in the Luvisol (Évora).

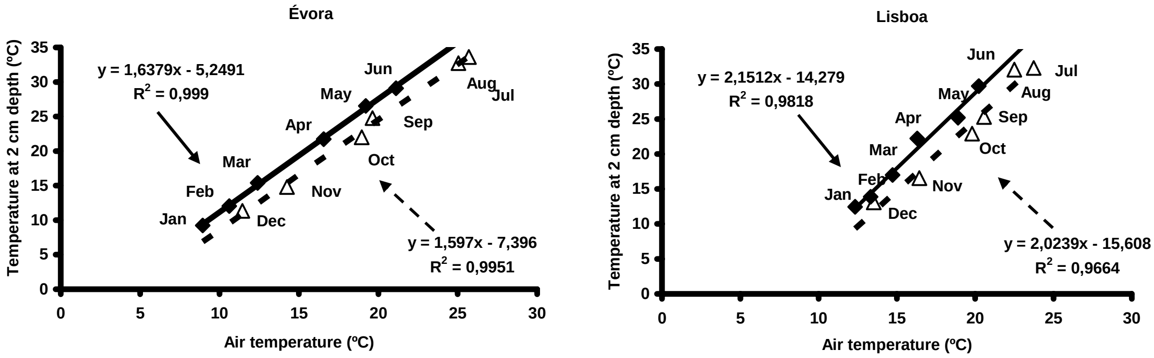

Fig. 2. Relationship between mean monthly temperatures at 2 cm depth and in the air from January to June (—◆—) and from July to December (---∆---), in Évora (Luvisol) and Lisboa (Vertisol).

Future temperatures at sowing depth in both soils were predicted from mean air temperatures during the sowing seasons of winter legumes and summer crops for the two climate change scenarios, using the linear regressions from Fig. 2. Table 2 shows the predicted values and also the mean air temperatures for the reference climate period of 1961-1990. For example, for the scenario of 1ºC increase in October mean air temperature in Évora (from 17.3 to 18.3ºC), temperature at sowing depth in the Luvisol will increase from 20.2ºC to 21.8ºC; in Lisbon, if air temperature increases from 18.0 to 19.0ºC, temperature at sowing depth in the Vertisol increases from 20.8ºC to 22.8ºC.

Table 2. Predicted mean temperatures (in ºC) at sowing depth in the Luvisol and the Vertisol from mean air temperatures, actual and increased by 1 and 2ºC, for the sowing months of winter legumes and summer crops.

	Winter crops		**Summer crops**	
	October	**November**	**April**	**May**
Mean air temperature (1961-19901) - Évora	17.3	12.7	13,4	16,3
Mean temperatures at 2 cm depth (Luvisol)				
at mean air temperature	20.2	12.9	16.7	21.4
at mean air temperature +1ºC	21.8	14.5	18.3	23.1
at mean air temperature + 2ºC	23.4	16.1	20.0	24.7
Mean air temperature (1961-1990) - Lisboa (ºC)	18.0	14.2	14.3	16.6
Mean temperatures at 2 cm depth (Vertisol)				
at mean air temperature	20.8	13.1	16.5	21.4
at mean air temperature +1ºC	22.8	15.2	18.6	23.6
at mean air temperature + 2ºC	24.9	17.2	20.8	25.7

From the bioclimatic parameters shown in Table 1 for the four crops and from the expected temperatures at sowing depth shown in Table 2, it is possible to predict impacts on the success of crop establishment of an increase in air temperature of 1ºC or 2ºC in October and November for winter legumes and in April and May for summer crops. In October, the speed of emergence and the final emergence of both winter legumes pea and broad beans will decrease in both scenarios while the dispersion of emergence around the most likely thermal times will not be affected; in November, the speed of emergence is expected to increase and both a high final emergence and a low dispersion of emergence will be assured. In April, an increase in temperature will speed up significantly the emergence of sunflower and maize, even if the former is sown in the Vertisol and exposed to the warmest scenario; both final emergence and dispersion of emergence of these summer crops will not be affected by an increase of temperature, but sunflower final emergence may decrease for the warmest scenario in the Luvisol. In May, final emergence of both crops will be affected in both scenarios and the speed of emergence may be reduced, especially in the Vertisol; in both cases, low dispersions of emergence will be expected in May.

4. DISCUSSION

The results suggest the need to anticipate sowing dates of Mediterranean summer crops. April will become more favourable for emergence than May. However, sowing dates may have to be anticipated even further because of the limited water conditions for these climatic areas predicted by *IPCC Fourth Assessment Report* (IPCC, 2007). Since reduced soil water contents during sowing increases the thermal times for emergence, mainly in the Vertisol (Andrade, 2001), an anticipation of sowing dates into March may be required for most of these crops, unless irrigation is available. Without irrigation, the search and use of cultivars with lower base temperatures and shorter thermal times for emergence will become of great importance for the outcome of Mediterranean agriculture.

The winter legumes may have to be sown slightly later, eventually late November, since October will become too hot for a successful emergence of pea and broad beans. However, thermal times for the emergence of these crops are affected negatively by soil water contents close to field capacity in both soils (Andrade, 2001), so that soil moisture monitoring will become important.

5. CONCLUSIONS

Mean soil temperatures at sowing depth are significantly greater than those found in the air above ground in most months of the year, including the usual sowing months. The relationships between air and top soil temperatures depend on both the type of soil and the season of the year.

Final emergence and speed of emergence of several Mediterranean crops will be more affected by global warming than the dispersion of emergence around the most likely thermal times. To cope with it, changes in sowing dates and cultivars are required.

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