Modelling climatic similarities in mediterranean areas. A potential tool for plant genetic resources and breeding programmes

Bennett, S.J[1*], Saidi, N[2] and Enneking, D[1]

1. Centre for Legumes in Mediterranean Agriculture, University of Western Australia, Nedlands, Western Australia 6907.
2. Institut National de la recherche Agronomique (INRA), Programme Fourrages, B.P: 415, Rabat, Morocco.

*Corresponding Author;

Dr. Sarita Bennett, Centre for Legumes in Mediterranean Agriculture, University of Western Australia, Nedlands, WA 6907. Australia.

Tel: 00-61-8-9380-7353

Fax: 00-61-8-9380-1140

E-mail: sarita@cyllene.uwa.edu.au

Abstract

Several locations with mediterranean climates were used to test the use of a software modelling programme called CLIMEX. This programme predicts the similarity of a nominated site to other locations within a specified area. For this study a number of locations were chosen in Morocco, Turkey and southern Australia, and compared with locations in Mediterranean Europe, north Africa and west Asia. A similarity index lists the percentage similarity of Mediterranean locations to the nominated site. A map and climate graph are shown for five of the specified locations. The robustness of the model was tested at two locations, Merredin and Turretfield in Australia, using a number of climatic simulations. The importance of rainfall pattern, and the affect of low humidity, to the agricultural system of southern Australia is considered and the potential relevance of this model to plant collection and plant breeding programmes is discussed.

Key words

Climatic modelling, CLIMEX, genetic resources, Mediterranean, Australia, plant introduction

1. Introduction

"CLIMEX is a dynamic simulation model which enables the estimation of an animal or plant's geographic distribution and relative abundance, as determined by its climate" (Skarratt *et al.*, 1995). It was developed at the Co-operative Research Centre for Tropical Pest Management in Queensland to predict a species distribution in locations independent from its existing distribution using the species climatic requirements. Its main use to date, in Australia,

has been in the prediction of the spread of weeds and pests, either following an initial introduction or under different climatic scenarios, and of the spread of a species for biological control. (McFadyen and Skarratt, 1996; Scott, 1991 and Sutherst *et al.*, 1996).

The mediterranean climate has warm to hot, dry summers and mild, wet winters, with rainfall occurring almost exclusively during the winter months (Nahal, 1981). Mediterranean climates occur predominantly between the latitudes of 32.00° and 40.00° in both the northern and southern hemispheres, and include, the Mediterranean basin of Europe, north Africa and west Asia, southern Australia, the south-west coast of the United States, central Chile and the Cape region of South Africa (Boyce *et al.*, 1991). In mediterranean Europe this extends further north than 40.00°N and in Western Australia this occurs further south (Nahal, 1981).

The aim of this study was to use CLIMEX for a novel approach, to determine the similarity between two or more regions with mediterranean climates to assist in plant collection missions and plant introductions. Climate has a strong influence on the vegetation of areas with arid or semi-arid climates (Nahal, 1981). By identifying climatic similarities between regions before a plant collecting mission, the mission can be targeted to areas with a high climatic similarity to the area for which the collected species are intended. This is important, for example, in southern Australia where new legume species are required for agriculture, but the cost of quarantine for each accession and the number of species on the quarantine list is continually increasing. Thus if climatic matching is combined with an ecogeographic study, another important component (Maxted *et al.*, 1995), key species can be targeted and those that are brought back should be well adapted and have a greater chance of survival and success in agriculture. The regions chosen for this study were southern Australia, Morocco and Turkey. Comparisons were carried out between centres and their countries and with other sites in the Mediterranean where plant collections have been made.

2. Methods and materials

The software programme CLIMEX for Windows v. 1.0 (Skarratt *et al.*, 1995) was used for this study. It comprises three major functions. These are:

1. To compare locations, which predicts the potential geographic distribution of a species based on its climatic requirements;
2. To compare years using data from consecutive years; and,

3. To match climates, which searches the meteorological database contained within CLIMEX for locations with climates similar to that of a nominated location.

This study focused on the use of function 3 to determine locations within the Mediterranean that have similar climates to a number of other specified locations. Matching climates queries a 'Match Index' for all the locations contained within the determined map area, in this case the Mediterranean. The match index is the product of five parameters, which individually indicate the level of similarity for average monthly maximum daily temperature, average monthly minimum daily temperature, average monthly rainfall, rainfall pattern and the relative humidity at 9am and 3pm. Each of these parameters can be are weighted, with values set between 0 and 1. The default value for all the parameters is set at 1, except for relative humidity which is set at 0.

CLIMEX uses a relatively simple procedure for the climate similarity model 'match climates'. The climatic similarities of a specified location to a location set, in this case the Mediterranean, are calculated on a percentage basis for five climatic parameters; maximum temperature, minimum temperature, total yearly rainfall, rainfall pattern and relative humidity. The total similarity between the specified location and any other location is calculated by averaging the percentage similarity values of the five parameters. By controlling the weighting of each of the parameters the emphasis of the climate can be controlled.

To show the robustness of the model, the climatic similarities of two locations have been simulated using a number of weightings for the climatic parameters. The locations chosen were Merredin in Western Australia and Turretfield in South Australia. These two locations were also used in the main study and so it is possible to see how changing the weighting affects the similarity of locations in the Mediterranean area. The weightings that were used were;

a. 1.0 for all parameters,
b. 1.0 for each parameter separately with the remaining parameters being set to 0.75 (e.g. when maximum temperature was set to 1.0, minimum temperature, monthly rainfall, rainfall pattern and relative humidity were all set to 0.75), and
c. rainfall pattern and relative humidity set to 1.0, with maximum and minimum temperature, and monthly rainfall set to 0.75.

The results of the match climate are returned as a map, table or graph and the similarities are displayed as a percentage for each individual parameters and as a total similarity. For the

purposes of this study only locations with a similarity of 65% or more are considered close to the target location. The spelling of locations used in this paper is that listed in CLIMEX.

The locations to be compared with the Mediterranean were chosen from three countries, Morocco, Turkey and Australia. Seven locations were nominated in Morocco; three from the Atlantic littoral region, two from the Middle Atlas region and two from the High Atlas. Three locations were nominated in Turkey, Izmir in the east, Antalya in the south-west and Adana in the south and four locations were nominated in Australia, two in Western Australia, one in South Australia and one in Victoria.

3. Results

The results of the model simulations for Merredin and Turretfield are shown in Appendix A and described below.

When the simulation was run for Merredin with all the climatic parameters set to 1.0, four locations show a similarity above 70%, Amman and Damascus in west Asia, and Tebessa and Idris in north Africa. For three of these locations the climatic parameter with the greatest similarity to Merredin was monthly rainfall, and for Damascus it was rainfall pattern (89.4%). When total rainfall is set to 1.0, with all the other parameters set to 0.75, the four locations listed above still show the greatest similarity to Merredin, plus Kairaouan, Tunisia also shows a climate match above 70%. These five locations and no others still show the greatest similarity to Merredin when maximum temperature is set to 1.0 and all the other parameters are set to 0.75, and when rainfall pattern is set to 1.0, and the other parameters to 0.75. When minimum temperature is set to 1.0, and the other parameters to 0.75, the number of locations with a similarity to Merredin of above 70% decreases to two, Amman and Damascus, and when relative humidity is set to 1.0, and the other parameters to 0.75, only Amman, Damascus and Tebessa show a climatic similarity of greater than 70% to Merredin.

The relative humidity appeared to be the most sensitive parameter, with only five locations showing a climate match of greater than 65%. This is partly a result of the southern Australian mediterranean climate that generally has a lower humidity than is found in much of the Mediterranean, but was also found to be a feature of the model. The rainfall pattern parameter was also found to be sensitive as only two locations showed a climate match of greater than 70%, compared to five for most of the other parameters. This parameter is considered to be

important in mediterranean agricultural systems as the length of the rain season determines the length of the growing system and this in turn determines the crop and pasture species that can be grown. With the importance of both the rainfall pattern and the relative humidity in mind, a final simulation was run with rainfall pattern and relative humidity set to 1.0, and the remaining parameters set to 0.75. This resulted in the same four locations as first listed above revealing a climate match of greater than 70%, but other than Damascus which had a very high rainfall pattern match to Merredin, the actual percentage similarity was lower.

A simulation of the model for Turretfield when all the climatic parameters were set to 1.0 reveals that four locations, Badajoz in Spain, Evora in Portugal, Setif in Algeria and Averroes in Morocco, show a climatic similarity of 70% or greater (Appendix A). These results do not change when rainfall pattern is set to 1.0 and the other parameters to 0.75. When maximum temperature is set to 1.0 and the other parameters are set to 0.75, the number of locations above 70% drops to three, with Setif returning a similarity match of only 68.8%. When minimum temperature is set to 1.0, the number of locations above 70% drops to two as both Setif and Averroes return a climate match below 70%, and when relative humidity is set to 1.0 only one location, Badajoz in Spain shows a climate match of greater than 70% at 74.7%. The number of locations with a climate match above 70% only increases when monthly rainfall is set to 1.0 and all the other parameters are set to 0.75. Despite the reduction in the number of locations that show a high similarity to Turretfield, the number of locations with a climate match above 65% is greater than compared to Merredin. The final simulation of rainfall pattern and relative humidity set to 1.0, and the other parameters set to 0.75 was also run for Turretfield. This resulted in three locations, Badajoz, Evora and Setif showing a climate match of greater than 70%.

The results of the simulations described above show that the first three to five locations consistently show a climate match of around 70% regardless of the weightings of the climatic parameters, and it is the order of appearance of those locations and the total percentage similarity that varies. The list of the locations with a climate match above 65% also shows little variation in the simulations (Appendix A), and it is the order of those locations that drops, especially in the lower percentage similarities.

Following the above simulations a decision was made to run the model using the following weightings for the parameters; 1.0 for rainfall pattern and relative humidity, and 0.75 for

maximum temperature, minimum temperature and monthly rainfall. As described above rainfall pattern is an important component of a mediterranean agricultural system with the majority of rain falling during the winter months, and little to no rain falling during the summer months (Nahal, 1981). Plants that grow under these conditions have to be adapted to long periods of drought, combined with high temperatures, plus need a mechanism to ensure that their seed does not germinate until the rain starts again at the end of the drought period (Fitter and Hay, 1987). Humidity is also very important in ecosystems that rely on a limited annual rainfall as it has a strong influence on the rate of evapotranspiration and in turn plant performance. In a humid environment, the amount of transpiration from leaves is reduced as their is less difference between the humidity of the atmosphere and the humidity inside the leaf. This reduces the amount of water that a plant requires to function and grow (Green *et al*.).

The results of the model simulations on locations in Morocco, Turkey and Australia using the weightings of 1.0 for rainfall pattern and humidity, and 0.75 for the parameters; maximum and minimum monthly temperature and monthly rainfall.

3.1 The Atlantic littoral of Morocco

3.1.1 Tanger

Tanger is located in the extreme north-west of Morocco at an altitude of 75m. It is situated on the peninsula that separates the Atlantic Ocean from the Mediterranean Sea. The climate of Tanger is described as humid with an average annual rainfall of 897 mm. The location with the greatest similarity to Tanger was, not surprisingly, Gibraltar, with a match of 73.7%. Only six other locations in the Mediterranean show a similarity of 65% or greater, four in Algeria and two in Morocco. The main difference between the climates of Tanger and Gibraltar is that Tanger has a slightly higher rainfall and Gibraltar a lower humidity all year at 3pm.

3.1.2 Casablanca

Casablanca is located on the west Atlantic coast of Morocco, at an altitude of 50m. It has an average annual rainfall of 400mm and a semi-arid climate. The climate of Casablanca is similar to a large number of locations around the mediterranean (Figure 1), with the greatest similarity found with Ghazaouet in Algeria at 86%. Most of the sites with good climatic matches with Casablanca, above 65%, are located on the coast. Locations in north Africa are

recorded from Algeria, Morocco and Tunisia, and locations in Europe are recorded from Spain, Greece, Portugal and Italy. A graph of the climates of Casablanca and Ghazaouet in Algeria (Figure 1), shows little difference in rainfall and temperature. The main source of variation is the greater morning humidity in Ghazaouet, that is present all year.

3.1.3 Agadir

Agadir is located in the south-west of Morocco on the Atlantic coast. It is found at an altitude of 50m and has an average annual rainfall of 226 mm, which classifies it as an arid climate. Most of the locations with a climatic match to Agadir of 65% or above were found in north Africa, especially in Libya, Egypt and Tunisia. The only location in Europe with a similarity of 70% or greater was Almeria in Spain with a match of 73.7%. Again, all of the sites are located along the coast.

3.2 The High Atlas Mountains of Morocco

3.2.1 Marrakech

Located at an altitude of 465 m and in the arid zone of Morocco, Marrakech has an annual rainfall of only 240 mm. Only nine locations show a similarity match of 65% or greater to Marrakech. All of these, apart from Athenai, Greece, are in north Africa. Few other European locations have a similar climate to Marrakech, as there are no mediterranean sites with arid climates at high altitudes. A graph of the climates (Figure 2) of Marrakech and Kairouan, Tunisia is shown. These two sites have a climate match of 79%, and both sites are characterised by very high maximum temperatures in summer and a large diurnal variation throughout the year.

3.2.2 Ouarzazate

Ouarzazate is characterised by its arid climate and a very low annual rainfall of 110 mm. It is located inland at 1135 m. Nearly all the sites with a climatic similarity to Ouarzazate of 65% or greater are located in north Africa, and east to Iraq, and the majority of them are inland. This emphasises the differences between arid north Africa and mediterranean Europe. Ar Rutba in Iraq was found to show the closest similarity to Ouarzazate, with a climatic match of

79%. Tindouf in Algeria was the location with the most similar rainfall pattern and humidity to Ouerzazate, but both the maximum and minimum temperatures are higher all year round.

3.3 The Middle Atlas Mountains of Morocco

3.3.1 Fez

Fez is situated at an altitude of 410 m, with a sub-humid climate and an annual rainfall of 536 mm. It shows more climatic similarity to southern Europe than to north Africa, with only four locations with a similarity greater than 65% in north Africa (Figure 3). In Europe, sites with a climate match of 65% or greater are found from Portugal to Greece and western Turkey. The location showing the greatest similarity is Constantine in Algeria with a climate match of 73.5%. Tunis in Tunisia also shows a high similarity of 72.1%. The climates of Constantine and Fez are shown in figure 3, where it can be seen that the minimum temperature and relative humidity at 3pm are almost identical, and the only noticeable difference is that Fez has a slightly higher maximum temperature and relative humidity at 9am for some of the year.

3.3.2 Ifrane

Ifrane is the highest site of the Moroccan locations, with an altitude of 1635 m. It has an annual rainfall of 1112 mm and its climate is classified as humid. This is not a true mediterranean climate despite its location in Morocco and this is reflected in the absence of locations in the Mediterranean that show a climatic match of 65% or greater. Konya, Turkey (57.2%), followed by Evora in Portugal (56%) were the locations with the closest climates. They do not show a high similarity because of a much lower total rainfall at both locations and higher minimum temperatures at Evora.

3.4 Coastal Turkey

3.4.1 Antalya

Antalya is situated in the south-west of Turkey on the south coast. It is located at an altitude of 40m and has an annual rainfall of 1057mm, which falls almost entirely in the winter months. No locations in the mediterranean show a climate match above 75% and there is only one location with a climate match of 65%, Vathis, on the island of Samos in Greece.

3.4.2 Adana

Adana is situated on the south coast of Turkey and has a true mediterranean climate with an annual rainfall of 619mm, falling almost entirely in the summer months. However it shows a low similarity to most other Mediterranean locations because of its variation in humidity. This is lower in winter, but higher in summer than more typical Mediterranean locations. The location with the highest climate match was Izmir, at 68%, followed by Patrai in Greece with 60.2%.

3.4.3 Izmir

Izmir is situated on the west coast, with an annual rainfall of 652mm. As described in 3.4.2. it has a very similar climate to Adana, with a slightly higher rainfall and marginally moderated temperatures in summer. The major difference being in their humidity. This small variation in climate increases the number of locations around the Mediterranean, and their percentage similarity, which have a climate match of 65% or greater with Izmir. The greatest similarity is found with Athenai in Greece (72.5%), followed by Patrai. A graph of the climates of Izmir and Patrai is shown in figure 4, where it can be seen that Patrai has a slightly lower relative humidity and marginally less diurnal range.

3.5 Australia

3.5.1 Merredin (Western Australia)

Merredin is situated in the wheatbelt of Western Australia. It is found at an altitude of 315m and has an annual rainfall of 327mm. The climate of Merredin was found to show a high similarity to only a limited number of locations in the Mediterranean, due to the low relative humidity, that is a feature of the mediterranean climate areas of southern Australia. The greatest similarity was found with Amman, Jordan with a climate match of 74.7%, and a graph of these two locations is shown in figure 5. The minimum and maximum temperatures of Merredin and Amman, and the relative humidity are very similar, the main difference being the shorter rain season at Amman.

3.5.2 Katanning (Western Australia)

Katanning is located in the Great Southern region of Western Australia, about 250km south-east of Perth. It is found at an altitude of 130m and has an annual rainfall of 485mm. The

climate of Katanning was also found to correspond to a number of locations in the Mediterranean, with 13 locations revealing a climate match of 65% or greater. Badajoz, Spain was found to show the greatest similarity at 74.6%, followed by Evora, Portugal (70.6%) and Kayseri, Turkey (70%). As at Merredin, it is the low relative humidity in Western Australia that restricts the number of locations in the Mediterranean that show a high climate match.

3.5.3 Turretfield (South Australia)

Turretfield is found at an altitude of 116m and has an annual rainfall of 464mm. It has similar maximum temperatures to the two locations described above, but has lower minimum temperatures throughout the year compared to Merredin. A higher percentage of the rain falls during the summer months. As a result of this the locations in the Mediterranean with which it shows the greatest climatic matches are completely different to Merredin, in particular. The number of locations with a climate match above 65% has decreased in north Africa, and those in Europe have increased (Figure 6). The location which shows the greatest similarity to Turretfield is Badajoz, on the west border of Spain with a climate match of 76%. This is followed by Setif, Algeria and Evora, Portugal with climate matches of 71.2% and 71% respectively. A graph of the climates of Badajoz and Turretfield is shown in figure 6. The main difference between these two sites is the humidity which is noticeably higher at Badajoz, along with increased summer temperatures. Turretfield has more summer rainfall in comparison..

3.5.4 Horsham (Victoria)

Horsham is found in the west of Victoria at an altitude of 141m. It has an annual rainfall of 448mm, and in many respects has a similar to climate to Turretfield in South Australia. A comparison with locations in the Mediterranean shows that Setif, Algeria has the greatest climate match at 74.3%, followed by Badajoz, in Spain and Djelfa in Algeria, with climate matches of 73.9% and 70.3% respectively. All the locations that have a climate match with Horsham of 65% or greater are found in the western Mediterranean countries, apart from Athenai, Greece. This is due to an increase in the relative humidity of Horsham compared to the other Australian sites described above.

4. Discussion

There are two main uses for studies using the programme CLIMEX; in plant collection and in plant breeding/ cultivar selection. Cocks (1993) suggested that determining climatic homologues between southern Australia and the mediterranean would be one step in starting to sort the genepool of the Mediterranean into material that would be of use in the Australian farming system. It would therefore make sense for models such as CLIMEX to be used before a plant collecting mission to determine climatic homologues between targeted areas in Australia and the Mediterranean. The advantage of using such models is that the material collected would be adapted to the climate for which it is targeted. To further increase the success of a collecting mission an ecogeographic survey would be conducted on the homologous areas in the Mediterranean to determine areas which are of particular value in terms of habitat and soil homologues. This is particularly important if specific species or ecotypes are being targeted as it will increase the efficiency of the collecting mission. Maxted *et al.* (1995) outlines the procedures of an ecogeographic survey and Bennett and Maxted (1997) have shown the kind of information that can be obtained from an ecogeographic analysis.

The second potential use of CLIMEX is in plant breeding programmes. If a particular trait is required and that trait is associated with a particular climatic trait, for example cold tolerance or early flowering, then using CLIMEX can help to reduce the number of lines from a genebank collection to be tested. There has been much debate on the use and development of core collections which contain all the genetic diversity present within the natural distribution of a species (Frankel, 1984). Brown (1989) also suggests that a collection could also be developed as a subset of the main collection for a specific purpose, such as cold tolerance or acid soil tolerance. The use of 'core collection' should be avoided here, but the advantages of such a subset are obvious. Development of such subsets with climate simulation models will help to rationalise the number of lines needed to identify the required trait.

This study shows the potential of the model CLIMEX to become an integral part of plant genetic resources. However there are at present a number of limitations of the model and these need to be addressed first.

Cocks (1993) postulated the advantages of using climatic homologies to target plant collecting missions. However until missions do take place using this approach combined with ecogeographic surveys, the true value of such an approach can not be accurately determined.

The weightings of the climatic parameters in the study, was limited to only 1.0 and 0.75, of possible values between 1.0 and 0. This was because the authors felt that a drop of more than 0.75, say to 0.5, would severely decrease the influence of that parameter on the model and, at the present level of understanding, it was not known how important each climatic parameter was on plant growth and development. To overcome this limitation the compare location function of CLIMEX described in the Materials and Methods section of this paper (Skarrett *et al.*, 1995) should be calculated for a number of key species. This function requires the specific growth parameters of a species to be calculated, which are correlated to either its natural distribution, or the area where it is currently grown. A simulation is run to determine where else in the world or a specified area it would grow. Climatic simulation studies for mediterranean environments can be refined by obtaining the growth parameters of a number of key species in the Mediterranean and linking them to the climatic similarity index to test the models robustness. For example, flowering time of widespread and widely naturalised legumes such as *Medicago polymorpha*, *Trifolium glomeratum* and *Vicia sativa* ssp. *sativa* could be closely aligned to locations listed in the similarity model.

Finally, it is important to understand that at present the number of locations for which long-term meteorological data is available is limited in the Mediterranean. This may result in poor spatial coverage of areas with high climatic similarities to the area of interest. Ideally, with future versions of the programme, the number of locations with meteorological data will be increased to a coverage similar to that of Australia in the present version. Also spatial extrapolation will be possible from the point meteorological data to produce a map with isolines of percentage climatic match values.

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Merredin	Location	Total*	Total (max. temp.=1)[a]	Total (min. temp.=1)[a]	Total (total rainfall=1)[a]	Total (rainfall pattern=1)[a]	Total (relative humidity=1)[a]	Total (rainfall pattern & relative humidity=1)[a]	Max.temp.[b]	Min.temp.[b]	Total rainfall[b]	Rainfall pattern[b]	Total humidity[b]
Jordan	Amman	75.2	75.5	74.4	75.8	75.7	74.1	74.7	74.1	88.1	91.2	86.2	70.5
Syria	Damascus	74.2	74.6	73.2	73.9	75.2	73.3	74.2	70.9	88.0	81.6	89.4	73.5
Algeria	Tebessa	71.5	70.6	69.4	73.1	72.5	71.0	71.9	62.3	76.1	98.9	87.9	69.3
Libya	Idris	70.8	70.1	68.8	72.2	72.2	69.1	70.5	62.4	78.2	98.2	90.5	59.2
Tunisia	Kairouan	69.9	70.4	69.9	70.5	71.1	66.2	67.6	77.1	84.7	93.0	88.5	43.5
Morocco	Averroes	67.7	67.6	67.8	68.2	69.4		65.6	78.7	75.5	90.5	91.1	40.0
Libya	Nalut	67.3	67.2	67.5	65.8	69.0	65.1	66.8	79.7	75.6	68.4	90.7	60.1
Algeria	Mecheria	66.0	65.0		67.2	67.5		66.0	59.8	71.4	93.2	88.3	57.2
Morocco	Marrakech	65.5	65.9		65.6	67.3			66.2	82.2	84.8	90.9	42.4
Israel	Jerusalem	65.3	66.4	65.4		66.7			73.3	87.6	72.1	86.4	50.5
Tunisia	Gafsa					66.5			73.5	75.5	70.1	90.3	54.0
Algeria	Ain-Sefra					65.9			69.3	66.7	76.8	87.0	63.2
Spain	Badajoz		65.6			66.4			69.0	87.9	82.3	91.1	33.8
Spain	Alicante		65.5		65.4	66.0			75.1	87.4	97.5	89.0	16.7
Tunisia	Tunis					65.7			79.8	79.2	85.0	94.0	22.5
Greece	Athinai					65.3			65.2	70.4	87.7	93.8	37.1
Greece	Khalkis					65.4			76.1	77.7	83.9	96.5	22.1

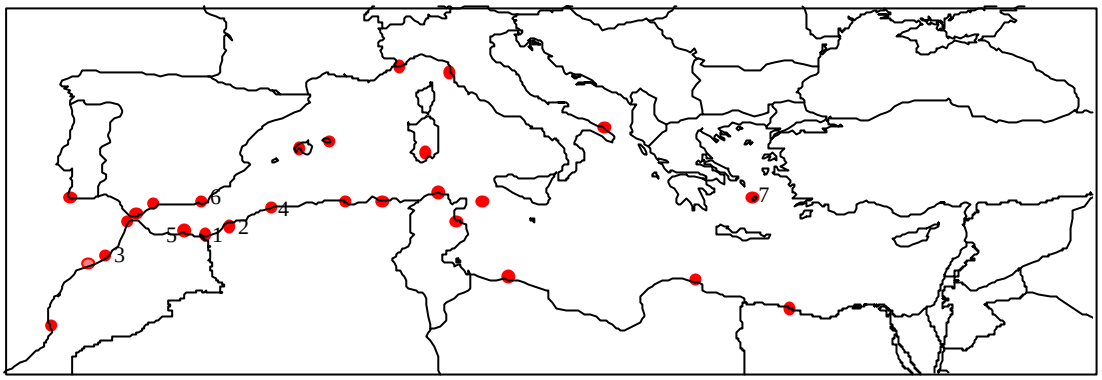
Turretfield	Location	Total*	Total (max. temp.=1)[a]	Total (min. temp.=1)[a]	Total (total rainfall=1)[a]	Total (rainfall pattern=1)[a]	Total (relative humidity=1)[a]	Total (rainfall pattern & relative humidity=1)[a]	Max.temp.[b]	Min.temp.[b]	Total rainfall[b]	Rainfall pattern[b]	Total humidity[b]
Spain	Badajoz	76.7	76.1	75.9	77.5	77.9	74.7	76.0	77.5	80.6	96.6	93.4	62.7
Portugal	Evora	72.2	72.9	72.0	71.3	73.8	69.4	71.0	76.1	88.6	79.0	93.2	56.7
Algeria	Setif	70.6	68.8	68.4	72.2	72.2	69.7	71.2	63.7	68.0	99.1	92.0	65.4
Morocco	Averroes	70.0	70.5	68.1	70.5	71.4	68.3	69.7	58.6	88.6	87.8	89.8	60.7
Israel	Jerusalem	69.7	69.2	69.4	70.8	69.6	69.6	69.5	77.4	73.7	90.7	78.1	74.1
Greece	Athinai	68.9	66.7	68.4	69.9	70.3	67.9	69.2	78.8	58.3	90.7	88.8	65.4
Turkey	Kayseri	67.3	67.7	67.2	67.5	67.7	66.0	66.4	74.2	82.0	82.4	79.7	63.1
Tunisia	Tunis	67.2	66.2	67.4	68.1	68.9		65.5	81.9	65.6	93.5	90.5	41.7
Turkey	Izmir	67.0	66.5	67.0	66.5	68.7		66.6	77.4	71.3	76.6	90.0	57.7
Italy	Foggia	67.0	66.9	66.9	68.4	68.2			75.9	75.9	99.8	86.0	37.7
Algeria	Tebessa	66.5	65.8	65.4	66.6	68.1	65.2	66.7	67.7	71.4	80.4	88.9	62.7
Morocco	Fez	66.3	66.6	65.5	66.9	68.2			66.4	81.1	89.5	91.8	40.7
Greece	Khalkis	66.0		65.9	67.1	67.7			78.7	63.8	94.8	90.0	41.0
Algeria	Constantine	65.6	65.6	65.4	66.3	67.7			73.5	76.6	92.0	93.4	30.6
Libya	Shahhat		65.1						79.9	84.2	81.2	81.4	41.7

Appendix A. Location similarities of Merredin and Turretfield with different weightings on climate parameters

* all parameters are set to 1.0

[a] all other parameters are set to 0.75

[b] the climate match of each parameter individually



	Continent	Country	Location	Total
1	Africa	Algeria	Ghazaouet	86.0
2	Africa	Algeria	Oran	82.2
3	Africa	Morocco	Rabat	79.6
4	Africa	Algeria	Cap Tenes	76.7
5	Africa	Morocco	Melilla	75.9
6	Europe	Spain	Malaga	75.8
7	Europe	Greece	Naxos	75.7
8	Africa	Algeria	Skikda	73.4
9	Europe	Portugal	Lagos	73.2
10	Africa	Tunisia	Sousse	72.2
11	Africa	Morocco	Agadir	71.2
12	Europe	Italy	Cagliari	71.1
13	Europe	Spain	Almeria	71.0
14	Europe	Spain	Palma	71.0
15	Africa	Libya	Darnah	70.8
16	Europe	Italy	Brindisi	69.9
17	Europe	Italy	Livorno	68.4
18	Africa	Morocco	Tanger	68.4
19	Europe	Spain	Mahon	67.2
20	Africa	Tunisia	Bizerte	66.8
21	Europe	Italy	San Remo	66.6
22	Africa	Algeria	Cap Carbon	66.2
23	Africa	Libya	Tarabulus	66.2
24	Europe	Spain	Gibraltar	65.4
25	Europe	Italy	Pantelleria	65.3
26	Africa	Egypt	Marsa Matruh	65.0

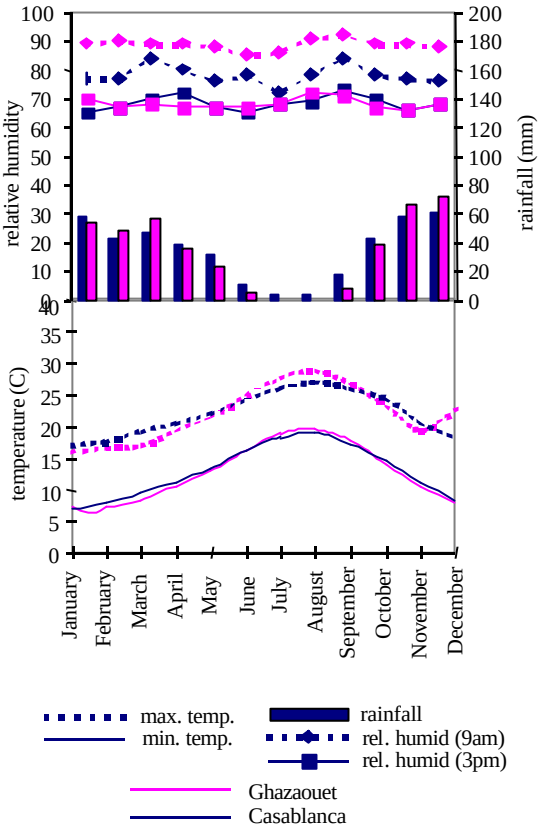
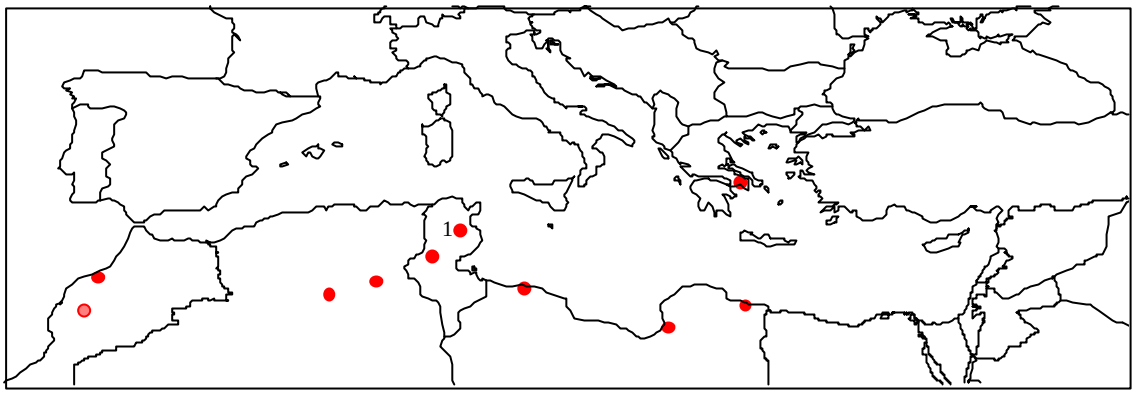


Figure 1: Map showing locations with a climate match of 65% and above to Casablanca, Morocco. Labelled locations show a similarity of 75% and above.
Comparison of the annual climate of Casablanca and Ghazaouet, Algeria are shown.

Bennett et al. Agriculture, Ecosystems and Environment. 1998; 70, 129-143.



	Continent	Country	Location	Total
1	Africa	Tunisia	Kairouan	79.0
2	Africa	Morocco	Averroes	74.0
3	Africa	Tunisia	Gafsa	71.2
4	Africa	Algeria	Ghardaia	71.1
5	Africa	Libya	Idris	68.8
6	Africa	Libya	Ajdabiyah	68.0
7	Africa	Libya	Al Adam	67.0
8	Africa	Algeria	Touggourt	66.8
9	Europe	Greece	Athinai	66.1

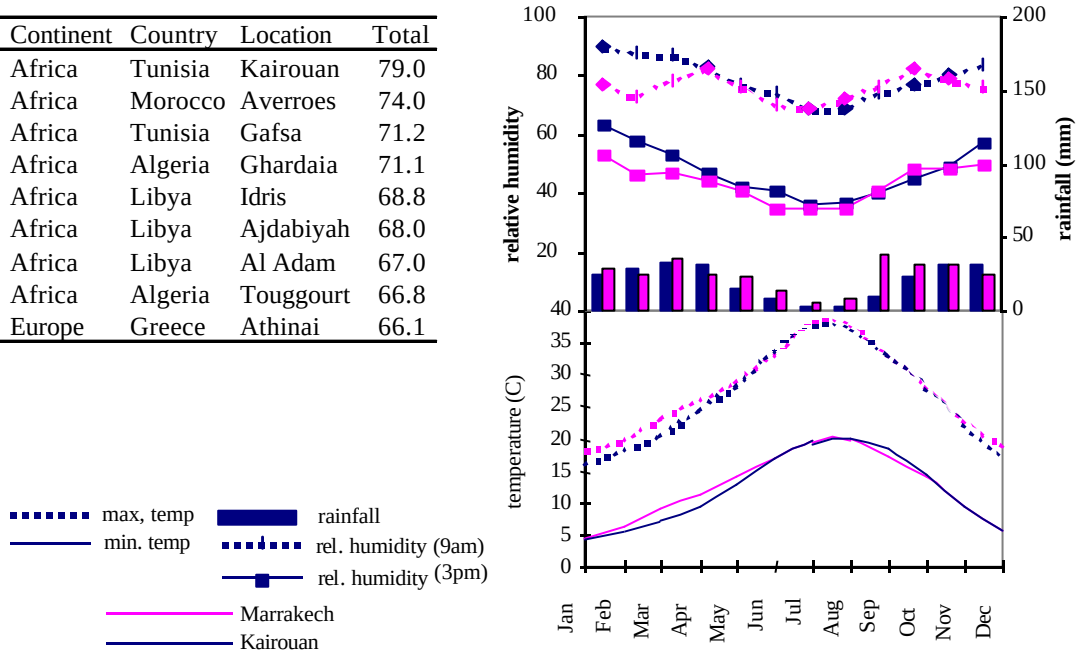
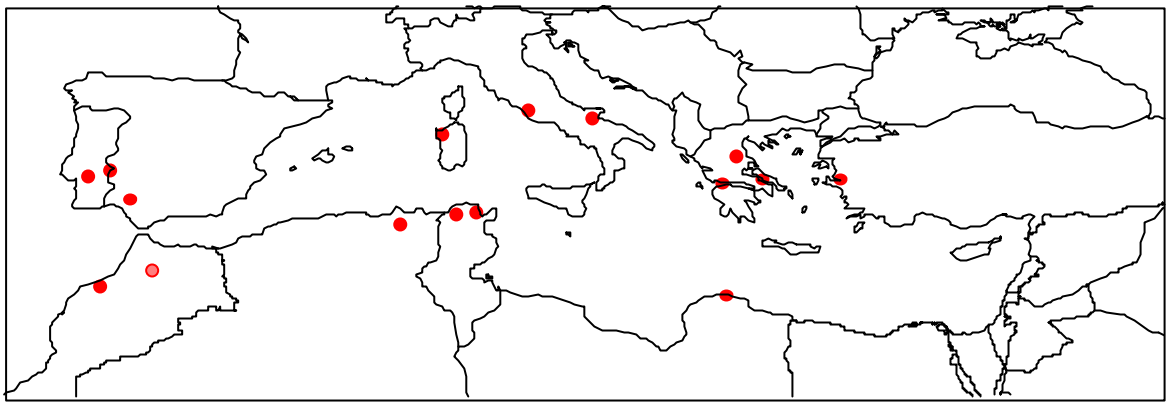


Figure 2: Map showing locations with a climate match of 65% and above to Marrekech, Morocco. Labelled locations show a similarity of 75% and above. Comparison of the annual climate of Marrekech and Kairouan, Tunisia are shown.

Bennett et al. Agriculture, Ecosystems and Environment. 1998; 70, 129-143.



	Continent	Country	Location	Total
1	Africa	Algeria	Constantine	73.5
2	Africa	Tunisia	Tunis	72.1
3	Europe	Greece	Khalkis	72.0
4	Europe	Spain	Badajoz	70.9
5	Africa	Tunisia	Beja	70.9
6	Asia	Turkey	Izmir	70.7
7	Europe	Portugal	Evora	69.2
8	Europe	Spain	Sevilla	68.6
9	Africa	Morocco	Averroes	68.3
10	Europe	Greece	Patrai	68.0
11	Europe	Italy	Roma	67.7
12	Europe	Italy	Foggia	67.4
13	Europe	Greece	Larissa	66.3
14	Europe	Italy	Sassari (Sardinia)	65.5
15	Africa	Libya	Shahhat	65.2

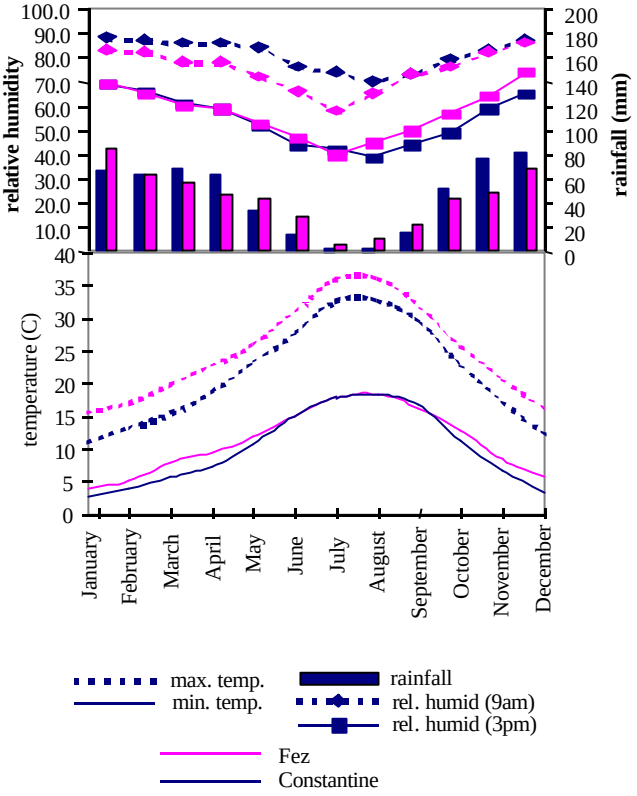
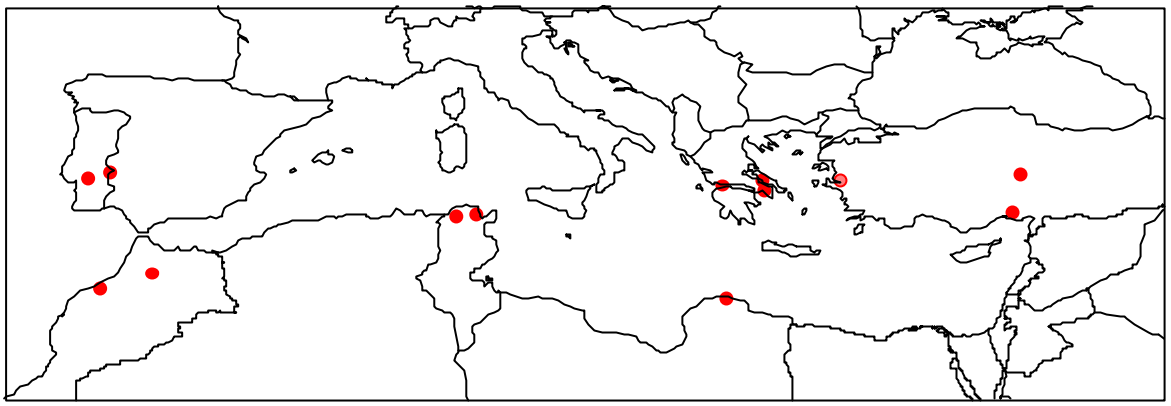


Figure 3: Map showing locations with a climate match of 65% and above to Fez, Morocco. Labelled locations show a similarity of 75% and above. Comparison of the annual climate of Fez and Constantine, Algeria are shown.

Bennett et al. Agriculture, Ecosystems and Environment. 1998; 70, 129-143.



	Continent	Country	Location	Total
1	Europe	Greece	Athinai	72.5
2	Europe	Greece	Patrai	72.1
3	Europe	Greece	Khalkis	71.2
4	Europe	Portugal	Evora	71.1
5	Asia	Turkey	Kayseri	70.8
6	Africa	Morocco	Fez	69.9
7	Africa	Morocco	Averroes	69.3
8	Africa	Libya	Shahhat	69.1
9	Europe	Spain	Badajoz	69.0
10	Asia	Turkey	Adana	67.9
11	Africa	Tunisia	Tunis	67.3
12	Africa	Tunisia	Beja	66.6

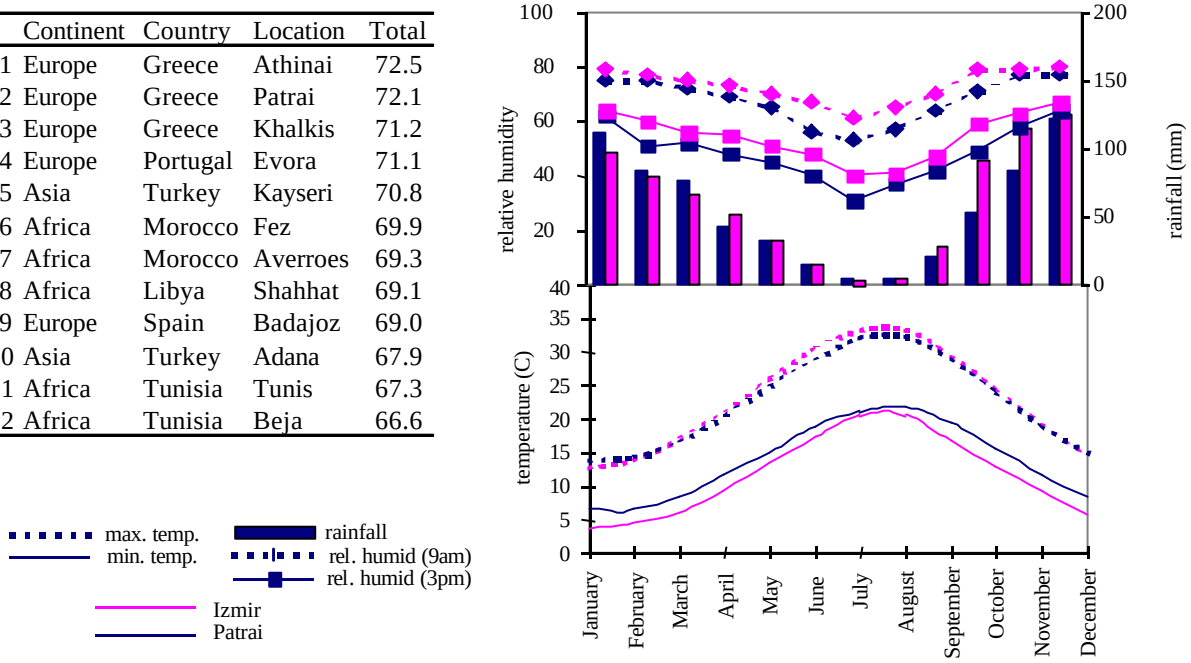
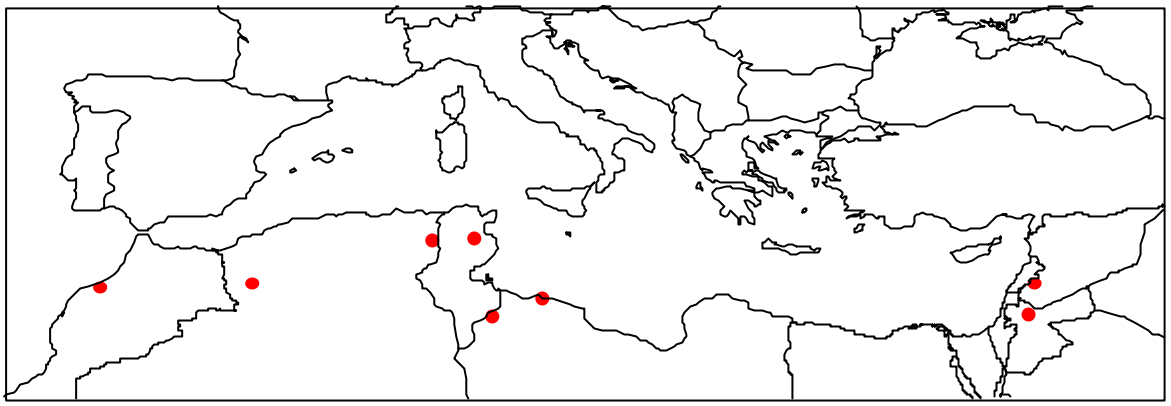
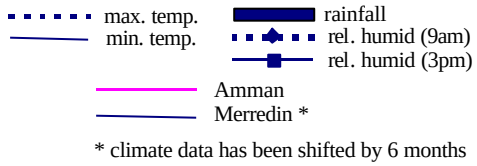


Figure 4: Map showing locations with a climate match of 65% and above to Izmir, Turkey. Labelled locations show a similarity of 75% and above. Comparison of the annual climate of Izmir and Patrai, Greece are shown.



	Continent	Country	Location	Total
1	Asia	Jordan	Amman	74.7
2	Asia	Syria	Damascus	74.2
3	Africa	Algeria	Tebessa	71.9
4	Africa	Libya	Idris	70.5
5	Africa	Tunisia	Kairouan	67.6
6	Africa	Libya	Nalut	66.8
7	Africa	Algeria	Mecheria	66.0
8	Africa	Morocco	Averroes	65.6



* climate data has been shifted by 6 months

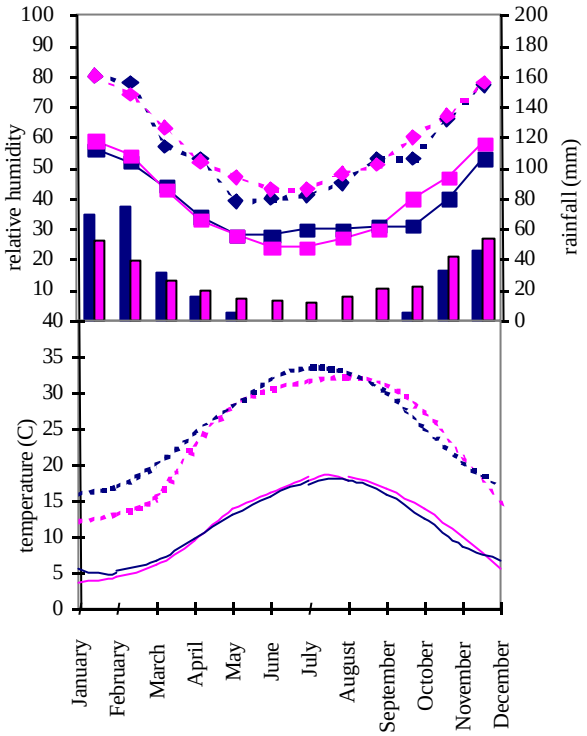
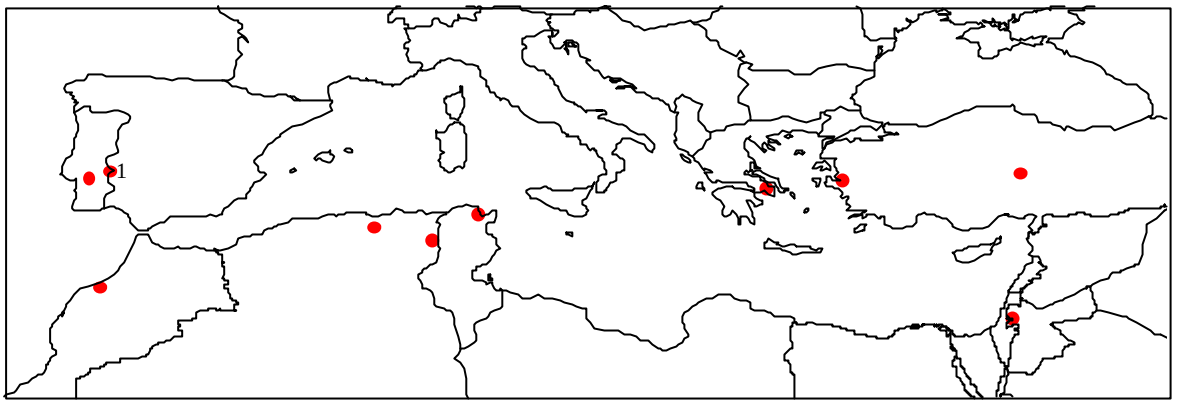
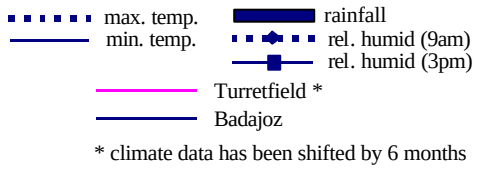


Figure 5: Map showing locations with a climate match of 65% and above to Merredin, Australia. Labelled locations show a similarity of 75% and above. Comparison of the annual climate of Merredin and Amman, Jordan are shown.

Bennett et al. Agriculture, Ecosystems and Environment. 1998; 70, 129-143.



	Continent	Country	Location	Total
1	Europe	Spain	Badajoz	76.0
2	Africa	Algeria	Setif	71.2
3	Europe	Portugal	Evora	71.0
4	Africa	Morocco	Averroes	69.7
5	Asia	Israel	Jerusalem	69.5
6	Europe	Greece	Athinai	69.2
7	Africa	Algeria	Tebessa	66.7
8	Asia	Turkey	Izmir	66.6
9	Asia	Turkey	Kayseri	66.4
10	Africa	Tunisia	Tunis	65.5



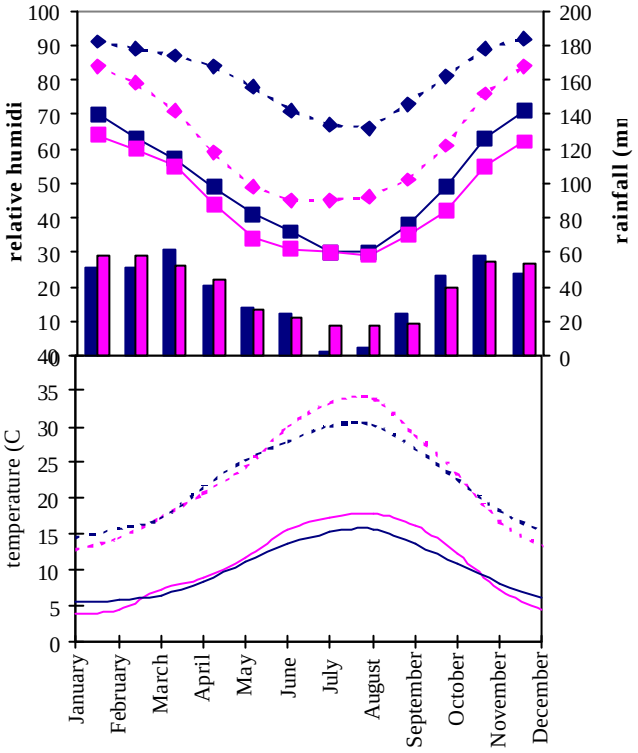


Figure 6: Map showing locations with a climate match of 65% and above to Turretfield, Australia. Labelled locations show a similarity of 75% and above.
Comparison of the annual climate of Turretfield and Badajoz, Spain are shown.

Bennett et al. Agriculture, Ecosystems and Environment. 1998; 70, 129-143.