**7.10** EFFECT OF FUTURE CLIMATIC VARIABILITY ON AGRICULTURE IN A MEDITERRANEAN REGION

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## 1. INTRODUCTION

Recent analysis on changes in climate (IPCC, 1995, 2001) showed that the globally averaged surface temperatures have increased by 0.6±0.2°C over the 20th century. In addition, for the range of scenarios developed in the IPCC Special Report on Emission Scenarios (2000), the globally averaged surface air temperature is projected by models to warm 1.4 to 5.8°C by 2100 relative to 1990. These projections indicate that the warming would vary by region, with increases and decreases in precipitation. The records for Mediterranean areas show similar trends (Rambal and Hoff, 1998), with an increase in the frequency of heat waves and a surface air temperature increase greater than that observed at global scale. Brunetti et al. (2000) and Buffoni et al. (1999) analyzed trends of temperature and rainfall in Italy from mid-1800 to 1996 showing a positive trend for temperature and a decreasing trend for rainfall. This decreasing rainfall trend was confirmed also at a local scale for Sardinia island, Italy, by Delitala at al. (2000).

Environmental variability is the key issue when addressing agricultural production in arid a semi-arid regions. Alternating periods of variable length of relatively dry and wet years are common in these regions. Climate variability, which mainly affects rainfall, is inherently part of the system. Considerable effort has been expended in studies on large-scale and general circulation modeling to assess climatic risk. However, downscaling to the local level to assess climate risk for agricultural areas and crops has proven difficult (Parry and Carter, 1988; Rosenzweig, 1982). In addition, there have been few attempts to account for inter-annual climate variability (van Lanen, 1992; Hudson and Birnie, 1999, Motroni et al., 2002; Duce et al., 2003).

To overcome these deficiencies, a project to incorporate year-to-year climate variability with Land Evaluation was conducted. Land Evaluation models provide qualitative information about land, such as its cropping potential or land vulnerability risk, based on bio-physical and socio-economic characteristics (Rossiter, 1996). In general, land qualities derived from measurements of dynamic variables (e.g. climate data) are converted to static variables (means, medians, etc.) for the purpose of Land Evaluation. A key weakness in using long-term summaries of land qualities is that much of the variability that is an essential property of the lands is removed (Hudson and Birnie, 2000).

In this paper observed and future climate variability data were combined with geographic and soil information from Sardinia island, Italy, using a Land Capability for Agriculture (LCA) classification system, which classifies agricultural land into a range of quality and potential productivity. The aim was to develop a robust and reproducible method for incorporating weather variability into Land Evaluation to make it more relevant to land management problems. In addition, a climatic risk index was developed to enable year-to-year variability in weather to be quantified. Finally, estimates of the actual and future climatic risk index values were mapped using interpolated weather data to show how the risk can be expressed geographically.

## 2. MATERIALS AND METHODS

Sardinian territory was studied in relation to geographic, soil and climatic characteristics using (i) the eco-pedological map of Sardinia derived from an European Union project on producing a georeferenced soil database for Europe, (ii) the Land Use/Land Cover map provided by INEA (National Institute of Agricultural Economics), (iii) daily rainfall and temperature climatic time series for the period 1961-2000, and (iv) future climate scenarios for Sardinia constructed from the recent climate change experiments performed at the Hadley Centre using the HadCM3 model (Gordon et al., 2000).

Using soil and land cover maps, the territory of Sardinia was classified in pedological LCA classes ranging from 1 to 8 with increasing limitations to agriculture. The climatic LCA classes were built using weather data from 54 stations spread all over the island. The reference periods 1961-90 and 1971-2000 were used to derive annual values of maximum potential soil moisture deficit ($PSMD_{max}$) and heat accumulation. Annual $PSMD_{max}$ values were calculated by accumulating the daily moisture deficit between rainfall and evapotranspiration. Annual heat accumulation was determined calculating Growing Degree Days (*GDD*), using the Single Triangle Method and a lower temperature threshold equal to 0°C. A plot of lower quartile of annual *GDD* versus median values of annual $PSMD_{max}$ was used to draw climatic LCA class boundaries for the 54 climate stations. Stations with similar climatic conditions were

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grouped using a cluster analysis method (tree clustering).

The climatic LCA classification was extended to the whole island territory using temperature and precipitation data from about 200 weather stations. The data were interpolated in a 10 km x 10 km grid using a tri-linear interpolation for rainfall and the optimum interpolation technique for temperature (Chessa and Delitala, 1997).

The climatic variability analysis was based on annual $PSMD_{max}$ values from the reference periods. A climatic risk index was developed analyzing the inter-annual variability of $PSMD_{max}$ values and determining the frequency of occurrence of six classes (from D1 to D6) of $PSMD_{max}$ for each grid cell. An empirical climatic risk coefficient was attributed to each $PSMD_{max}$ class and the climatic risk index was calculated for each grid cell summing the products of each class frequency and climatic risk coefficient over the reference periods (Table 1). The risk index ranges from 0 (no risk) to 1 (high risk).

*Table 1. Boundaries and climatic risk coefficients of the maximum potential soil moisture deficit ($PSMD_{max}$) classes used to analyze inter-annual climatic variability and calculate the climatic risk index.*

| **$PSMD_{max}$ class** | ***Class Boundaries (mm)*** | ***Climatic Risk Coefficient*** |
|---|---|---|
| D1 | D1 ≥ -160 | 0 |
| D2 | -340 ≤ D2 < -160 | 0.05 |
| D3 | -440 ≤ D3 < -340 | 0.50 |
| D4 | -540 ≤ D4 < -440 | 0.75 |
| D5 | -640 ≤ D5 < -540 | 0.90 |
| D6 | D6 < -640 | 1.00 |

Then, the procedure used to determine climatic LCA classification and climatic risk was applied to future climatological time series for the period 2005-2099 obtained from two different emissions scenarios (scenarios A2 and B2).

A Geographic Information System (ArcGIS 8.3) was used to manage, elaborate, and analyze the thematic layers (soil, climate and land use).

## 3. RESULTS

The territory of Sardinia was partitioned in homogeneous pedological areas in relation to LCA classification. Eight classes with increasing limitations to agricultural practices were obtained. In addition, the eight pedological LCA classes were grouped into two broad categories: land suitable for agricultural use, which included the classes ranging from 1 to 4 and land not suitable for agriculture (classes from 5 to 8). Almost 75% of the island showed to be not suitable for agricultural use because of more or less severe orographic and pedological constraints (Figure 1).

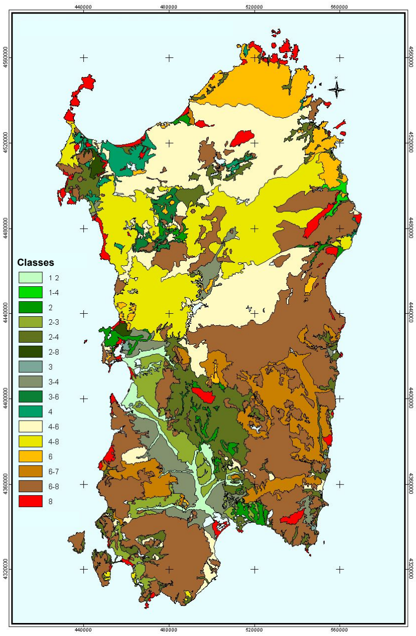


*Figure 1. Pedologic Land Capability for Agriculture map of Sardinia.*

The plot of the median values of $PSMD_{max}$ and the lower quartile of annual *GDD* was used to define seven climatic LCA classes and several subclasses. Water deficit was the key factor in determining the climatic LCA classes. The seven climatic LCA classes were grouped into two categories: *Prime Land* (most suitable for agriculture) and *Non Prime Land* (not suitable for agriculture). Most areas of Sardinia were classified as *Prime Land*, comprising climatic LCA classes 1, $2_1$, $2_2$ and $3_1$, as shown in Figure 2.

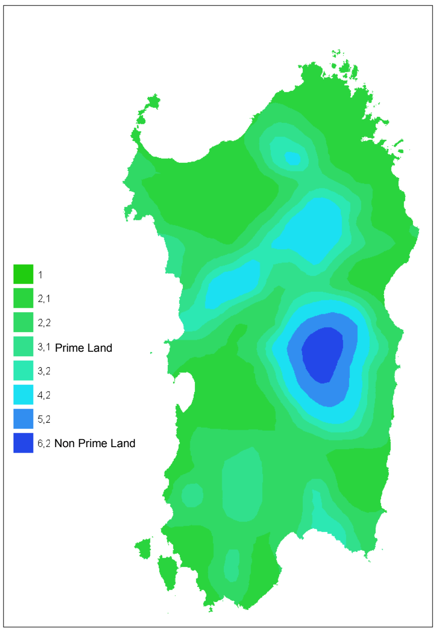


*Figure 2. Climatic Land Capability for Agriculture map of Sardinia for the reference period 1971-2000.*

An overlay between the pedologic and the climatic LCA maps resulted in the pedo-climatic LCA map of Sardinia where the most, moderate, least and not suitable areas of the island for agricultural capability are shown (Figure 3). The pedo-climatic LCA classification was obtained using the criteria reported in Table 2.

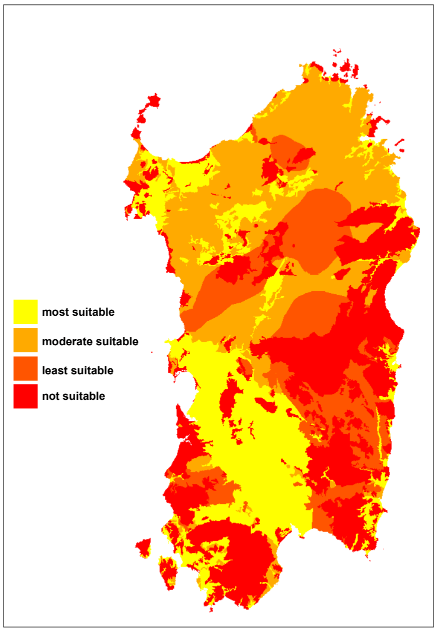


*Figure 3. Pedo-climatic Land Capability for Agriculture map of Sardinia for the reference period 1971-2000.*

*Table 2. Criteria used to define the pedo-climatic LCA classes and resulting percentage surface area of each class.*

| **Pedo-climatic LCA classes** | **Pedologic LCA classes** | **Climatic LCA classes** | **Surface area relative to the total area (%)** |
|---|---|---|---|
| most suitable | 1-4 | $1_1$, $2_1$, $2_2$, $3_1$ | 23.7 |
| moderate suitable | 4-6, 4-8, 6 | $1_1$, $2_1$, $2_2$, $3_1$ | 27.7 |
| least suitable | 6-7, 6-8 | Prime and $3_1$, $4_1$, $4_2$ | 17.4 |
| not suitable | 8 | - | 31.2 |

To obtain an estimate of the climatic risk for the reference period 1971-2000, the climatic risk index was calculated from the frequency of occurrence of each $PSMD_{max}$ class and empirical climatic risk coefficients. The results are shown in Figure 4. The areas characterized by moderate and high climatic risk are located in the southern and north-western portions of Sardinia which represent the most important agricultural areas of the island.

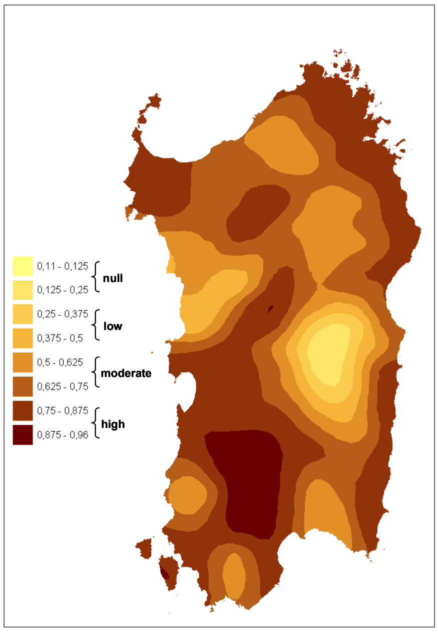


*Figure 4. Climatic risk map of Sardinia for the reference period 1971-2000.*

The future climatological time series for Sardinia from the HadCM3 model were analyzed to determine rainfall and temperature trends and were used to obtain a projection of the pedo-climatic LCA and climatic risk maps for the 21$^{st}$ century

The scenarios A2 and B2 showed an increase of the annual mean temperature ranging from 1 to 5°C and a decrease of the annual mean rainfall of about 100 mm (approximately 15% of the annual mean rainfall of Sardinia) by the end of this century. Figure 5 shows an example of the analysis conducted using the future climatological time series.

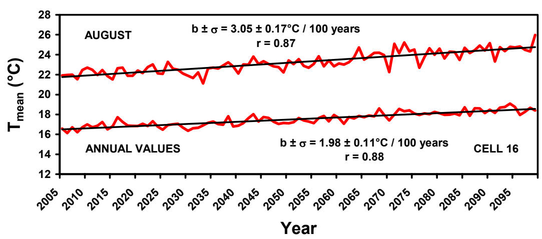


*Figure 5. August and yearly mean temperature trends for grid cell 16 (north-west Sardinia) for the period 2005-2099 from scenarios B2. The linear regression coefficient (b), the associated error ($\sigma_b$) and the linear correlation coefficient (r) values are reported.*

The pedo-climatic LCA and climatic risk maps for different future 30-year periods were obtained by applying to future climatic time series an identical procedure used for observed climatology. Figures 6 and 7 show results obtained for the period 2070-2099.

A comparison of pedo-climatic LCA classifications

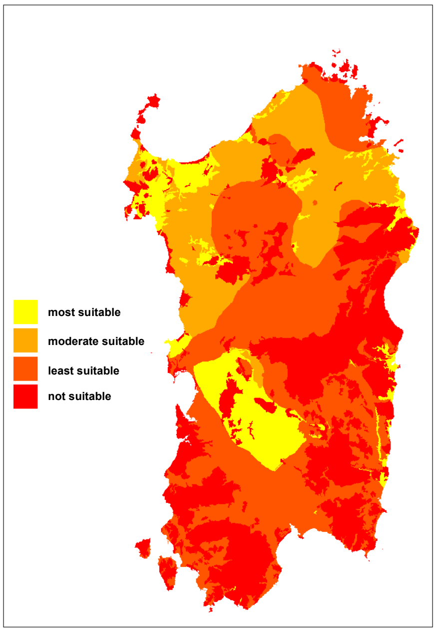


*Figure 6. Pedo-climatic Land Capability for Agriculture map of Sardinia for the period 2070-2099 (scenario A2).*

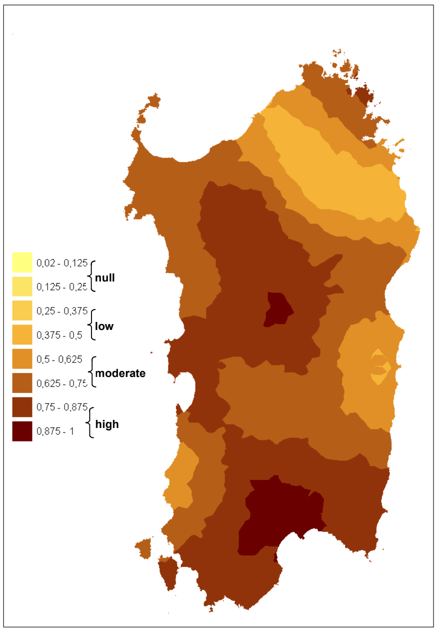


*Figure 7. Climatic risk map of Sardinia for the period 2070-2099 (scenario B2).*

obtained from the climate scenarios against results from the reference period 1961-2000 (Table 3) shows a clear reduction of the areas classified as most and moderate suitable for agricultural activities. The percentage of the most and moderate suitable areas relative to the total surface would represent the 29.8% and 33.7% for scenarios A2 and B2 respectively against the 51.4% observed during the reference period. Whereas the least suitable areas would double moving from 17.4% (1961-2000) to 38.4% (scenario A2) and 35.4% (scenario B2). The change in the agro-climatic characteristics of the island would concern mainly the southern portion of Sardinia where the economic and social relevance of agricultural activities is more important.

*Table 3. Percentage surface area of each pedo-climatic LCA class for the reference period 1961-2000 and climatic scenarios A2 and B2 (2070-2099).*

| **Pedo-climatic LCA classes** | **Surface area relative to the total area (%)** | | |
|---|---|---|---|
| | **1961-2000** | **Scenario A2** | **Scenario B2** |
| most suitable | 23.7 | 10.5 | 14.0 |
| moderate suitable | 27.7 | 19.3 | 19.7 |
| least suitable | 17.4 | 38.4 | 35.4 |
| not suitable | 31.2 | 31.8 | 30.9 |

The analysis of the climatic risk for the period 2070-2099 showed that future temperature and rainfall regimes could cause a significant increase in climatic risk for both climatic scenarios in most of the agricultural areas of Sardinia.

## 4. CONCLUSIONS

This study presents a LCA methodology developed to assess climatic risk for agriculture in a Mediterranean region and to provide qualitative and quantitative evidence on climate change impacts for supporting both policy and practice decisions in agriculture. LCA methodology allows to include weather variability into Land Evaluation models and to assess climatic risk vulnerability of agriculture at a local scale.

The results showed that LCA classification is sensitive to weather variability and that the determination of actual and future climatic risk for agriculture requires climatic variability to be included into Land Evaluation models. In addition, an adequate network of meteorological stations and a sufficiently long run of climatic data are essential to develop spatial estimates of climatic risk. The accuracy of the results depended mainly on the spatial resolution of input data and approximations derived from some empirical analysis. Future work will be addressed to test the procedures in a wider range of climatic conditions and to investigate temporal variations in other land qualities.

## 5. ACKNOWLEDGEMENTS

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