Economic modelling of climate change scenarios and adaptation of Mediterranean agriculture

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Objectives

- Define a possible strategy to integrate climate change aspects into mathematical models
  - using Discrete Stochastic Programming (DSP)

- Evaluate the economic impact of climate change on the agricultural sector
  - of the study area (but transferable to other cases)
Study area: CBI Oristanese

WUA facilities
36,000 ha

Rain-fed area
18,000 ha

- **Pasture**: 5%
- **Silage corn**: 14%
- **Forage**: 27%
- **Wheat**: 18%
- **Rice**: 8%
- **Vegetables**: 17%
- **Other**: 11%

- **Pasture**: 50%
- **Clover**: 30%
- **Wheat**: 10%
- **Barley-oat**: 5%
- **Vegetables**: 2%
- **Other**: 3%
Two sides of agriculture

- **Irrigated area**
  - Intensive production and relevant economic dimension (dairy, citrus, vegetables)

- **Rain-fed area**
  - Cereals and dairy sheep sectors, important to prevent land abandonment
## Territorial structure – Farm types

<table>
<thead>
<tr>
<th>WUA facilities</th>
<th>Farms (n)</th>
<th>Land (ha)</th>
<th>Net Income (€ 000)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rice</td>
<td>24</td>
<td>115.3</td>
<td>139.5</td>
</tr>
<tr>
<td>Citrus</td>
<td>68</td>
<td>12.6</td>
<td>45.7</td>
</tr>
<tr>
<td>Cattle A</td>
<td>130</td>
<td>30.9</td>
<td>199.2</td>
</tr>
<tr>
<td>Cattle B</td>
<td>40</td>
<td>31.9</td>
<td>112.7</td>
</tr>
<tr>
<td>Greenhouse</td>
<td>46</td>
<td>12.9</td>
<td>29.7</td>
</tr>
<tr>
<td>Vegetables - Cereals</td>
<td>562</td>
<td>22.2</td>
<td>34.2</td>
</tr>
<tr>
<td>Cereals - Forages</td>
<td>55</td>
<td>146.4</td>
<td>126.3</td>
</tr>
<tr>
<td>Tree and arable crops</td>
<td>100</td>
<td>5.8</td>
<td>11.8</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Rain-fed</th>
<th>Farms (n)</th>
<th>Land (ha)</th>
<th>Net Income (€ 000)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vegetables - Fruit</td>
<td>100</td>
<td>4.1</td>
<td>18.2</td>
</tr>
<tr>
<td>Cereals - Forages</td>
<td>94</td>
<td>24.5</td>
<td>16.9</td>
</tr>
<tr>
<td>Sheep A</td>
<td>45</td>
<td>86.9</td>
<td>43.6</td>
</tr>
<tr>
<td>Sheep B</td>
<td>188</td>
<td>41.2</td>
<td>16.1</td>
</tr>
<tr>
<td>Sheep C</td>
<td>129</td>
<td>62.4</td>
<td>42.5</td>
</tr>
</tbody>
</table>
Climate Model and Scenarios

- The numerical model for future climate scenarios downscaling is the Regional Atmospheric Modelling System - RAMS (www.atmet.com).

- RAMS is forced from a global simulation model, from surface temperatures of the sea coming from the ocean model coupled with the atmosphere.

- The global climate change is simulated by ECHAM 5.4 developed and used by the Euro - Mediterranean Centre for Climate Change (CMCC - www.cmcc.it).

- The greenhouse gas emissions scenario is A1B.

- Two scenarios:
  - Near future climate o Future (2020 - 2030)

- Estimation of probability distributions of agro-climatic events
Evapotranspiration
Spring Hay yield from rain-fed crops
DSP: Choices under uncertainty

- Farmer’s annual decision making under uncertain agro-climatic events:
  - formulating hypotheses about the pdfs of uncertain parameters, and discretize them (states)
  - partial correction of wrong decisions during the year

- Farmer minimizes the possible impact of sub-optimality by choosing the state with the highest expected income, once corrective actions are undertaken
  - resulting income lower than optimal solution under certainty (cost)

- The cost can increase if CC alters representative values or probability of states of nature
DSP: tree decision

DSP Choice Process:
eg 3 stages with uncertainty on 2 uncertainty events
DSP: Mathematical formulation

\[
\begin{align*}
\max_{\substack{x_{n_s}, c_{r_n_s}, c_{a_n_s}}} \quad & z = \sum_s P_s \times (G_{I_s} \times x_{n_s} - C_{cr} \times c_{r_n_s} - C_{ca} \times c_{a_n_s}) \\
\text{subject to} \quad & A_s \times x_{n_s} \leq B_s + c_{r_n_s} \quad \forall s \\
& x_{n_s} = x_{n+1_s} \quad \forall s \\
& N_s \times Y_s \times x_{n_s} + c_{a_n_s} \geq R_s \quad \forall s \\
& x_{n_s} \geq 0, c_{r_n_s} \geq 0 \text{ and } c_{a_n_s} \geq 0 \quad \forall s
\end{align*}
\]
<table>
<thead>
<tr>
<th>Management Issues</th>
<th>Uncertain Parameter</th>
<th>DSP Stages</th>
<th>Corrective Actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meet nutritional needs of flocks, given uncertainties on yields of pastures in Fall and Spring, and on hay production.</td>
<td>Autumn grazing yields of pasture</td>
<td>I: land allocation, uncertainty on Autumn and Spring grazing yields, and Spring hay yields</td>
<td>Use stocks of hay and buy feed in Autumn, at additional costs, when lowest yields of grazing prevent meeting nutritional needs of flocks.</td>
</tr>
<tr>
<td></td>
<td>Autumn grazing yields of hay-crop</td>
<td>II: known Autumn grazing yield</td>
<td>Use residual stocks of hay and buy feed in Spring/Summer, at additional costs, when lowest yields of grazing prevent meeting nutritional needs of flocks.</td>
</tr>
<tr>
<td></td>
<td>Spring grazing yields of pasture</td>
<td>III: known Spring yield of grazing and hay</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Spring yields of hay-crop</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Allocate water of dam with uncertain irrigation needs of crops</td>
<td>Irrigation needs of ryegrass in April-May</td>
<td>I: land allocation, uncertainty on irrigation needs of ryegrass and Summer crops</td>
<td>Take groundwater, at additional costs, when higher irrigation requirements generate scarcity of water dam</td>
</tr>
<tr>
<td></td>
<td>Irrigation needs of Summer crops in June-August</td>
<td>II: known irrigation need of ryegrass</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Yields of ryegrass, connected to its irrigation needs</td>
<td>III: known irrigation need of Summer crops</td>
<td></td>
</tr>
<tr>
<td>Meet nutritional needs of dairy cattle with uncertain yields of farm’s fodder</td>
<td>Yields of corn silage and alfalfa, connected to their irrigation needs</td>
<td></td>
<td>Buy feed, at additional costs, when lowest yields of farm’s fodder prevent meeting nutritional needs of the livestock</td>
</tr>
<tr>
<td></td>
<td>Yields of corn silage and alfalfa, connected to their irrigation needs</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Economic results for the present climatic scenario, absolute values (000 €), and future climatic scenario, [percentage changes of future over current (%Δ)] for the total case study area, the irrigated sub-zone served by WUA facilities and the rainfed sub-zone

<table>
<thead>
<tr>
<th></th>
<th>Current scenario (000 €)</th>
<th>Future scenario (%Δ)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total</td>
<td>WUA</td>
</tr>
<tr>
<td>Total revenues</td>
<td>204,730</td>
<td>179,050</td>
</tr>
<tr>
<td>Animal</td>
<td>89,806</td>
<td>75,278</td>
</tr>
<tr>
<td>Variable costs</td>
<td>130,010</td>
<td>114,024</td>
</tr>
<tr>
<td>Technical means</td>
<td>67,796</td>
<td>61,798</td>
</tr>
<tr>
<td>Feed</td>
<td>23,067</td>
<td>19,008</td>
</tr>
<tr>
<td>Extra-farm labor</td>
<td>7,738</td>
<td>5,707</td>
</tr>
<tr>
<td>Payments to the WUA</td>
<td>2,144</td>
<td>2,107</td>
</tr>
<tr>
<td>Water pumping from farm wells</td>
<td>278</td>
<td>121</td>
</tr>
<tr>
<td>Gross margin</td>
<td>106,365</td>
<td>89,095</td>
</tr>
<tr>
<td>Net income</td>
<td>78,078</td>
<td>65,945</td>
</tr>
</tbody>
</table>
### Net Income per typology and farm: present climate scenario [absolute values (000 €)] and future climate scenario [percentage changes of future over current (%Δ)]

<table>
<thead>
<tr>
<th>Typology</th>
<th>Representative farm</th>
<th>Current scenario (000 €)</th>
<th>Future scenario (%Δ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rice</td>
<td>4,097</td>
<td>170.7</td>
<td>9.9</td>
</tr>
<tr>
<td>Citrus</td>
<td>2,670</td>
<td>39.3</td>
<td>-0.01</td>
</tr>
<tr>
<td>Cattle A</td>
<td>26,355</td>
<td>202.7</td>
<td>-5.1</td>
</tr>
<tr>
<td>Cattle B</td>
<td>6,825</td>
<td>170.6</td>
<td>-5.9</td>
</tr>
<tr>
<td>Greenhouse</td>
<td>1,231</td>
<td>26.8</td>
<td>0.4</td>
</tr>
<tr>
<td>Vegetables - Cereals</td>
<td>18,656</td>
<td>33.2</td>
<td>-0.8</td>
</tr>
<tr>
<td>Cereals – Forages</td>
<td>4,902</td>
<td>89.1</td>
<td>2.2</td>
</tr>
<tr>
<td>Tree and arable crops</td>
<td>1,209</td>
<td>12.1</td>
<td>0.04</td>
</tr>
<tr>
<td>Vegetables – Fruit</td>
<td>1,014</td>
<td>10.1</td>
<td>-0.04</td>
</tr>
<tr>
<td>Cereals - Forages</td>
<td>2,691</td>
<td>28.6</td>
<td>0.01</td>
</tr>
<tr>
<td>Sheep A</td>
<td>2,461</td>
<td>54.7</td>
<td>-5.3</td>
</tr>
<tr>
<td>Sheep B</td>
<td>1,984</td>
<td>10.5</td>
<td>-11.8</td>
</tr>
<tr>
<td>Sheep C</td>
<td>3,984</td>
<td>30.9</td>
<td>-7.4</td>
</tr>
</tbody>
</table>
Conclusions

- Water availability is strategic for adaptation of agriculture to future climatic scenarios.

- Water accumulation is to be considered for dealing with the changing variability of CC.

- Rain-fed agriculture must be sustained also for the prevention of land abandonment.

- The economic impacts on milk production is relevant.

- This approach is transferable to other cases.
Next steps

- The economic impacts on milk production matter
  - livestock integration needs improvements

- Simulation of AgMip-CAPRI scenarios

- Impact of climate on weeds and pests spread

- ...

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