IRRIGATED AGRICULTURE IMPROVEMENTS TO REDUCE AQUIFER POLLUTION: a case study from a Portuguese vulnerable area

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COST Action 869-WG4, Nottwil, June 2009
8 VZ in the continental Portugal

4 since 2000-03 \[3.7\%\] of total surface
2 since 2004
2 since 2005 \[9.1\%\] of agricultural surface

8 VZ in Azores Islands
since 2003
EC Nitrate Directive 91/676/CEE was translated to Portuguese law by act nº 235/97, 3th September; changed by act nº 68/99, 11 March;

Vulnerable zones list should be revised each 4 years;

Since designated as VZ an Action Programme should be design in two years to rescue the region, in accordance with the best agricultural management practices (BAMP);

The farmers receive guidelines and training to implement the BAMP code;

The government should be control the effectiveness of the VZ Action Programme;

The government institutions should be carry out the monitoring of nitrate concentration in the surface and subsurface water, the eutrophication level in the surface water, estuaries and coastal waters;

The coordination of the nitrate directive is under responsibility of:

**Environmental Ministry**: National Institute of Water, Regional Comissions for Development Coordination

**Agriculture Ministry**: Institute of Hydraulics and Rural Development, Regional Agriculture Departments.
VZ 1 (since 2000, enlarged in 2006)

- very high population density, high industry concentration (small and medium, family enterprises)
- 204 km²/ 1040 farmers
- precip. 1400-1500 mm/yr. (74% in fall season), temp. 14,3ºC (20 ºC)
- irrigated crops from pumping wells
- vegetable crops cultivated in “masseiras” and in greenhouses, maize, dairy cattle
- topography is plain (less than 50 m of altitude), shallow water table
- sandy soils (Regossols), enriched with O.M. deposition from the sea (the “sargaço”) and from cattle manure
VZ 2 and 4 (since 2000)

-very high population density, high industry concentration (small and medium enterprises, family enterprises, pulp for paper industry)
-70 km²/980 farmers
-precip. 1000-1200 mm/yr. (77% in fall season), temp. 14,2 ºC (18,6 ºC)
-irrigated crops from pumping wells
-vegetable crops (open land and greenhouses), maize, forages, dairy cattle, forest
-topography is plain (less than 100 m of altitude), shallow water table
-sandy soils (Cambissols), enriched with O.M. deposition from the river estuary (the “moliço”) and from cattle manure
VZ 3 and 8 (since 2003 and 2005)

- low population density (in fall season), very high population density (in Summer), high tourism, low industry concentration
- 130 km²/ 420 farmers
- precip. 500-700 mm/yr. (82% in fall season), temp. 17 °C (23.2 °C)
- irrigated crops from pumping wells
- vegetable crops (open land and greenhouses), orange orchards, greens for golf
- irregular topography
- Aluvissols, limestone Cambissols (Fluvissols and red limestone) and Regossols with low O.M.
- high population density, high industry concentration in the south
- 2417 km²
- irrigated crops from pumping wells and from irrigation perimeter
- precip. 800-1200 mm/yr. (70% in fall season), temp. 18 ºC (25 ºC)
- vineyards, maize for grain, rice, bulls, horses
- topography is plain (less than 100 m of altitude), shallow water table and flooding soils (in the Tejo valley)
- Aluvissols, limestone Cambissols (Fluvissols and Regossols) with low O.M.
VZ 6 and 7 (since 2004 and 2005)

- low population density
- 515 km²
- precip. 400-600 mm/yr. (85% in the fall season), temp. 18ºC (28ºC)
- irrigated crops from irrigation perimeter and from pumping wells
- irrigated crops (maize for grain, sunflower, vineyards), wheat, cork trees
- topography is plain with smooth hills, deep water table
- clay soils with high water holding capacity
- high population density
- 36 km²/ eutrophication of lagoons by high phosphorus concentration
- precip. 1500 - 1800 mm/yr., temp. 18 ºC (22 ºC)
- extensive dairy cattle, grassland and forest
- topography: confined lagoons in valleys bordered by mountains
- volcanic soils
In VZ the technical recommendations for irrigation management is under responsibility of the Regional Departments of Agriculture (RDA).

In its turn, these Departments in partnership with research institutions should apply for the projects funds in order to perform the research needed to carry out the Action Program defined to the region.

- VZ 1: RDA with High Institute of Agronomy (Lisbon)
- VZ 2,4: RDA with High Agricultural School (Coimbra)
- VZ 3,8: RDA with Agronomy College (Algarve)
- VZ 5: Farmers Association with High Institute of Agronomy
- VZ 6,7: Irrigation Research Center

In some cases, especially when the VZ is located in an organized irrigation perimeter, the farmers associations pay the private technicians to make the nitrate monitoring and irrigation management.
The study case – VZ 2

- vulnerable zone settled upon a quaternary aquifer in the central coast of Portugal;
- family agriculture in a full or part time regime;
- main agriculture activities: intensive dairy cattle, forage and maize for animal feed (64%), vegetable crop rotation (23%);
- very high yields resulting in high nitrate concentration level in the soil and water table.

Results from two water monitoring campaigns (154 wells, fountains and small water stream samples):

- 16% $[\text{NO}_3] < 50$ ppm
- 42% $50 < [\text{NO}_3] < 100$ ppm
- 42% $[\text{NO}_3] > 100$ ppm

Medium to high VZ index
monitoring points for water nitrate concentrations

experimental plots
**Vegetable Crop Rotations (VC)**

**rotations:** lettuce x cabbage, potato x cabbage

**N fertilization:** 2000 kg/ha organic fertilizer (1.8% N)
+ 100-200 kg of mineral N

270-470 kg N/ha.year

**irrigation:** daily rate, sprinkler, non-regulated water depth, low irrigation efficiencies

**Forages and Maize (FM)**

**Soil occupation:** maize (spring-summer) x forages (fall season)

**N fertilization:** 20-25 ton/ha.year of cattle manure (0.60-0.65%) + 10-20 m³/ha of cattle sewage sludge (0.05-0.1% of N) + 300-400 kg N/ha in mineral fertilization (on maize crop)
320-550 kg N/ha.year

irrigation: sprinkler (high pressure), 1 irrig./year of 100 mm, low water irrigation efficiencies
| **Soil** | Cambissols, well drained with some gravel materials and a medium to rough texture. Slopes less than 1%.  
| High O.M. content and large water holding capacity.  
| Shallow water table (1.5-2 m), with no drainage system regulation.  
| Low soil cation exchange capacity. |
| **Climate** | High precipitation during fall season (1000 mm – 1200 mm)  
| Good temperatures for mineralization during Spring/Summer (monthly average 15-25 °C) |
Soil hydrodynamic and macroporosity

• 3 replications of undisturbed soil samples (100 cm$^3$) at the 0-20 cm, 20-40 cm and 40-60 cm depths for bulk density and for water characteristic curves (pF 0.3, 1, 1.5, 2, 2.5, 3, 4.2).

• *in situ* tension infiltrometer readings for macroporosity and hydraulic conductivity curve assessment.

macroporosity according to Watson and Luxmoore (1986)

hydraulic conductivity curves according to Wooding approach (1968) and Gardner (1958) function
Results

1) Macroporosity

**Effective porosity** = volume occupied by the porous hydraulically actives, excluding any isolated or dead-end porous.
A water table contribution around 30% of maize ET corresponds to a contribution of about 13-17 kg N/ha
3) Validation of RZWQM (Root Zone Water Quality Model)

- Calibration was validated by comparison of TDR soil moisture readings with the simulated ones;

- Simulations were performed considering the contribution of macroporosity in the movement of water into the soil (*two domain approach* for preferential flow prediction);

- Simulated results are considered very satisfactory when $\text{REMQ} \leq \text{SDo}$ and $\text{EFM} \geq 0$

- Soil nitrate leaching was validated by comparison of simulated results with samples of buried lysimeters at 50 cm depth in VC plots

- As the model does not predict the use of *slow release fertilizers*, the validation was performed only with nitrate-ammonium fertilizer treatments
3.1) Water content

### Depth vs. Water Content

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>EFM</th>
<th>REMQ</th>
<th>SDo</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>0.50</td>
<td>0.083</td>
<td>0.084</td>
</tr>
<tr>
<td>20</td>
<td>0.63</td>
<td>0.057</td>
<td>0.062</td>
</tr>
<tr>
<td>40</td>
<td>0.45</td>
<td>0.023</td>
<td>0.024</td>
</tr>
<tr>
<td>60</td>
<td>0.72</td>
<td>0.023</td>
<td>0.023</td>
</tr>
<tr>
<td>100</td>
<td>0.39</td>
<td>0.018</td>
<td>0.019</td>
</tr>
</tbody>
</table>
3.2) Nitrate leaching

**Table:**

<table>
<thead>
<tr>
<th>Treatment</th>
<th>EFM</th>
<th>REMQ</th>
<th>SDo</th>
</tr>
</thead>
<tbody>
<tr>
<td>E1+N0</td>
<td>0.27</td>
<td>1.91</td>
<td>2.09</td>
</tr>
<tr>
<td>E1+N2</td>
<td>0</td>
<td>3.40</td>
<td>3.72</td>
</tr>
<tr>
<td>E1+nitra4</td>
<td>0.56</td>
<td>4.57</td>
<td>7.56</td>
</tr>
</tbody>
</table>

**Graphs:**

- **E1+N0**
  - Observed vs. Simulated values for NO$_3$-N (kg ha$^{-1}$)
  - Data points for J-04 to D-04

- **E1+N2**
  - Observed vs. Simulated values for NO$_3$-N (kg ha$^{-1}$)
  - Data points for J-04 to D-04
3.3) Vegetable crop rotations

Soil NO₃-N

NO₃-N leaching (kg ha⁻¹) is 17% of total N.
3.4) Forages and maize

NO$_3$-N leaching is 7% of total N

with catch crop

irrigation season

irrigation season

0-100 cm

300 kg N/ha

150 kg N/ha

NO$_3$-N leaching is 7% of total N

Soil NO$_3$-N

0-100 cm

0

100

200

300

400

500

NO$_3$-N (kg ha$^{-1}$)

NO$_3$-N leaching (kg ha$^{-1}$)

irrigation season

irrigation season

300 kg N/ha

150 kg N/ha

NO$_3$-N (kg ha$^{-1}$)
Nitrate leaching is unmeaning in FM plots during irrigation season when compared with the VC plots. One of the reasons is the great volume occupied by roots of maize providing a better opportunity of nitrate uptake, reducing its mobility beyond the root depth.

3.5) Simulated scenarios with RZWQM

Scenarios were designed considering different agriculture management practices concerned with water and N applications.

It was considered the appropriated water irrigation depths to satisfy the ET needs during the crop season, avoiding water excess in the root zone, preventing the nitrate leaching towards the water table.
3.5.1) Forages and Maize

Reference is 100 mm/1 irrigation

<table>
<thead>
<tr>
<th>water irrigation depth</th>
<th>Treatment 150 kg N/ha</th>
<th>Treatment 300 kg N/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Δ Yield</td>
<td>Δ Leaching</td>
</tr>
<tr>
<td>100 mm/ 4 irrig. a)</td>
<td>+ 11,2 %</td>
<td>+ 24 %</td>
</tr>
<tr>
<td>170 mm/ 4 irrig. b)</td>
<td>+ 10,7 %</td>
<td>+ 35 %</td>
</tr>
<tr>
<td>240 mm/ 4 irrig. c)</td>
<td>+ 11,4 %</td>
<td>+ 58%</td>
</tr>
</tbody>
</table>

The total leaching is not reduced with more partitioning of water irrigation depths because the dryness-moisturizing process stimulates the nitrification during spring-summer, leading to accumulation of high nitrate concentrations in the soil profile after harvesting to be leached in the next rainfall season.

Nevertheless, a better water comfort along the crop cycle improves the yield.
### 3.5.2) Vegetable crop rotations

<table>
<thead>
<tr>
<th>Scenarios</th>
<th>lettuce x cabbage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>110 kg N/ha</td>
</tr>
<tr>
<td>165 mm (3 days frequency)</td>
<td>-16.1 %</td>
</tr>
<tr>
<td>suppressed N-fertilization before cabbage installation</td>
<td>-55.4 %</td>
</tr>
<tr>
<td>2 broadcast N-fertilization</td>
<td>-23.0 %</td>
</tr>
</tbody>
</table>

Nitrate leaching is reduced to a half when N-fertilization before fall crop (cabbage) is suppressed.

Important reduction in nitrate leaching with N-fertilizer splitting and when the irrigation management is more appropriate to crop needs, since it improved the water and N uptake by roots.
Conclusions

- In both agricultural systems is imperious the installation of a *catch crop* during fall/winter season to prevent the most part of nitrate leaching by rain;

- The reduction of residual nitrate in the soil profile is only effective if there is no N-fertilization when the fall season crop installation, since the nitrate profile left by precedent spring/summer crop is high;

- The macroporosity could be important for a preferential flow of solutes up to 40 cm depth. Therefore, the appropriate water irrigation management is crucial to avoid leaching in the VC plots during spring/summer but not so relevant in the FM plots;

- Despite of the yield increments in FM, irrigation splitting seems favorable to nitrification, increasing the nitrate soil profile before rainfall season and as a consequence, increases the nitrate leaching towards the water table;
The farmers within this VZ were trained and advised about how to perform the appropriate irrigation according to the crop needs as well as how to manage the manure and splitting of N-fertilizer;

The farmers have been encouraged to use slow release N-fertilizers.
Thank for your attention!

Obrigada pela vossa atenção!

COST Action 869-WG4, Nottwil, June 2009