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

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8 VZ in the continental Portugal

4 since 2000-03
2 since 2004
2 since 2005

3,7% of total surface

9,1% of agricultural surface

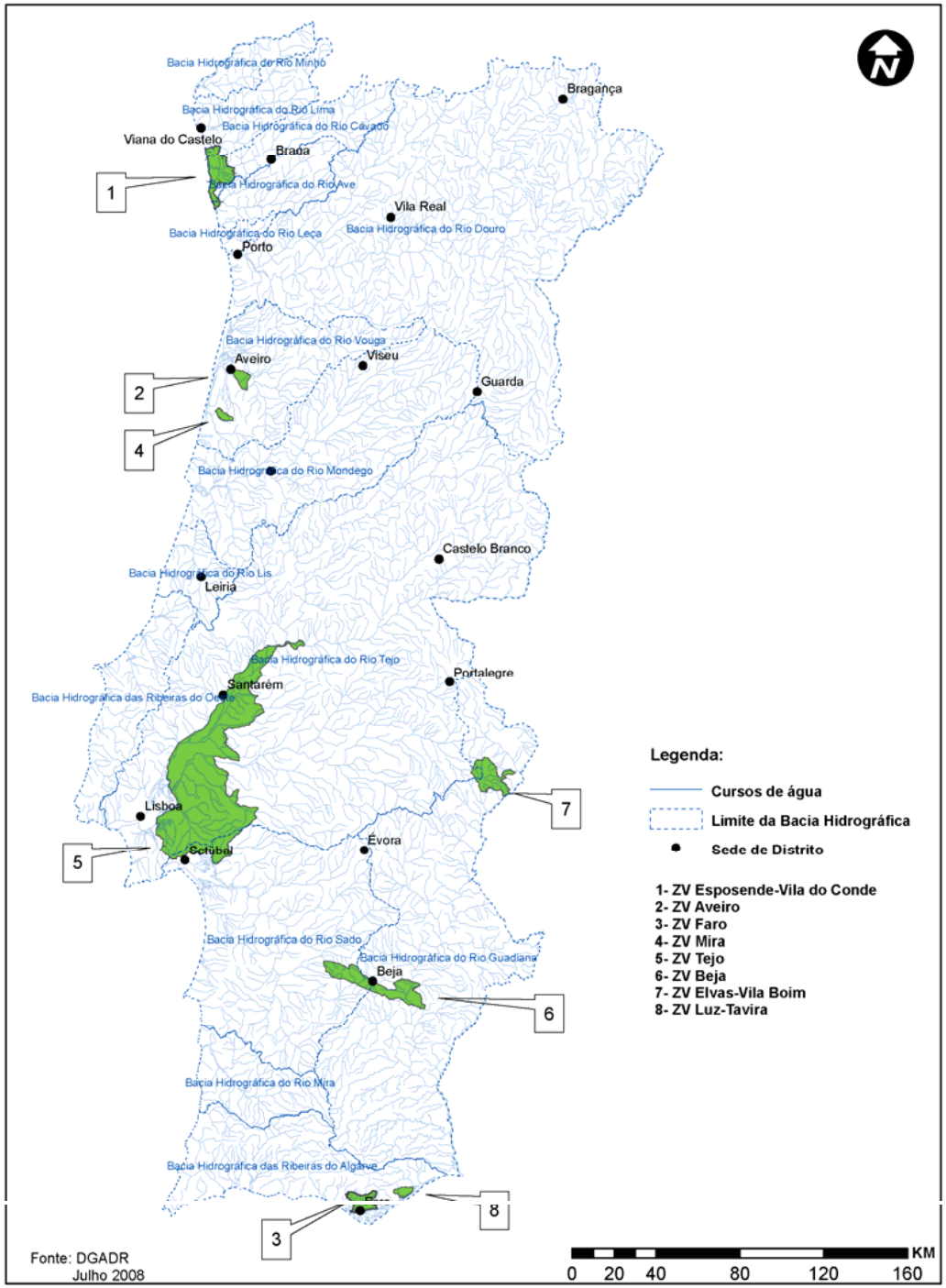
8 VZ in Azores Islands

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.


Bacia Hidrográfica do Rio Minho
Bacia Hidrográfica do Rio Lima
Bacia Hidrográfica do Rio Cavado
Viana do Castelo
Braga
Bacia Hidrográfica do Rio Ave
Bacia Hidrográfica do Rio Leça
Porto
Vila Real
Bacia Hidrográfica do Rio Douro
Bragança
Bacia Hidrográfica do Rio Vouga
Aveiro
Viseu
Guarda
Bacia Hidrográfica do Rio Mondego
Castelo Branco
Bacia Hidrográfica do Rio Lis
Leiria
Bacia Hidrográfica do Rio Tejo
Santarém
Portalegre
Bacia Hidrográfica das Ribeiras do Oeste
Lisboa
Setúbal
Évora
Bacia Hidrográfica do Rio Sado
Bacia Hidrográfica do Rio Guadiana
Beja
Bacia Hidrográfica do Rio Mira
Bacia Hidrográfica das Ribeiras do Algarve
1
2
3
4
5
6
7
8
Legenda:
Cursos de água
Limite da Bacia Hidrográfica
Sede de Distrito
1- ZV Esposende-Vila do Conde
2- ZV Aveiro
3- ZV Faro
4- ZV Mira
5- ZV Tejo
6- ZV Beja
7- ZV Elvas-Vila Boim
8- ZV Luz-Tavira
Fonte: DGADR
Julho 2008
KM
0 20 40 80 120 160

VZ 1 (since 2000, enlarged in 2006)

-very high population density, high industry concentration (small and medium, family enterprises)

-204 km^2/ 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 km^2/ 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 km^2/ 420 farmers

-precip. 500-700 mm/yr. (82% in fall season), temp. 17 ºC (23,2 ºC)

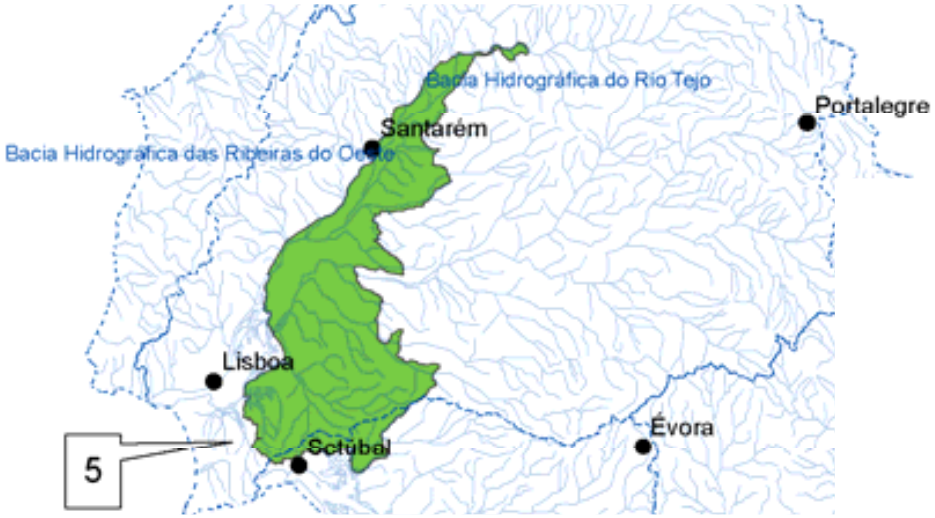
-irrigated crops from pumping wells

-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.

VZ 5 (since 2007)



-high population density, high industry concentration in the south

-2417 km^2

-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 km^2

-precip. 400-600 mm/yr. (85% in the fall season), temp. 18ºC (28ºC)

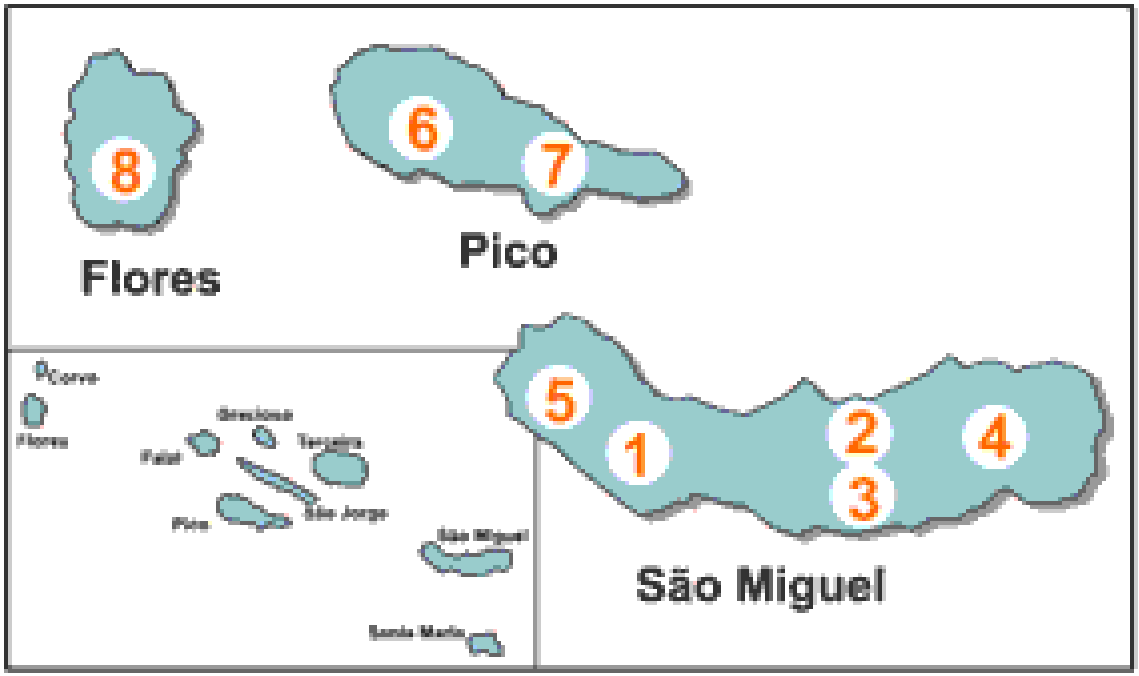
-irrigated crops from irrigation perimeter and from pumping wells

-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

VZ Azores Islands (since 2003)



-high population density

-36 km^2/ 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


Baixaki

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.

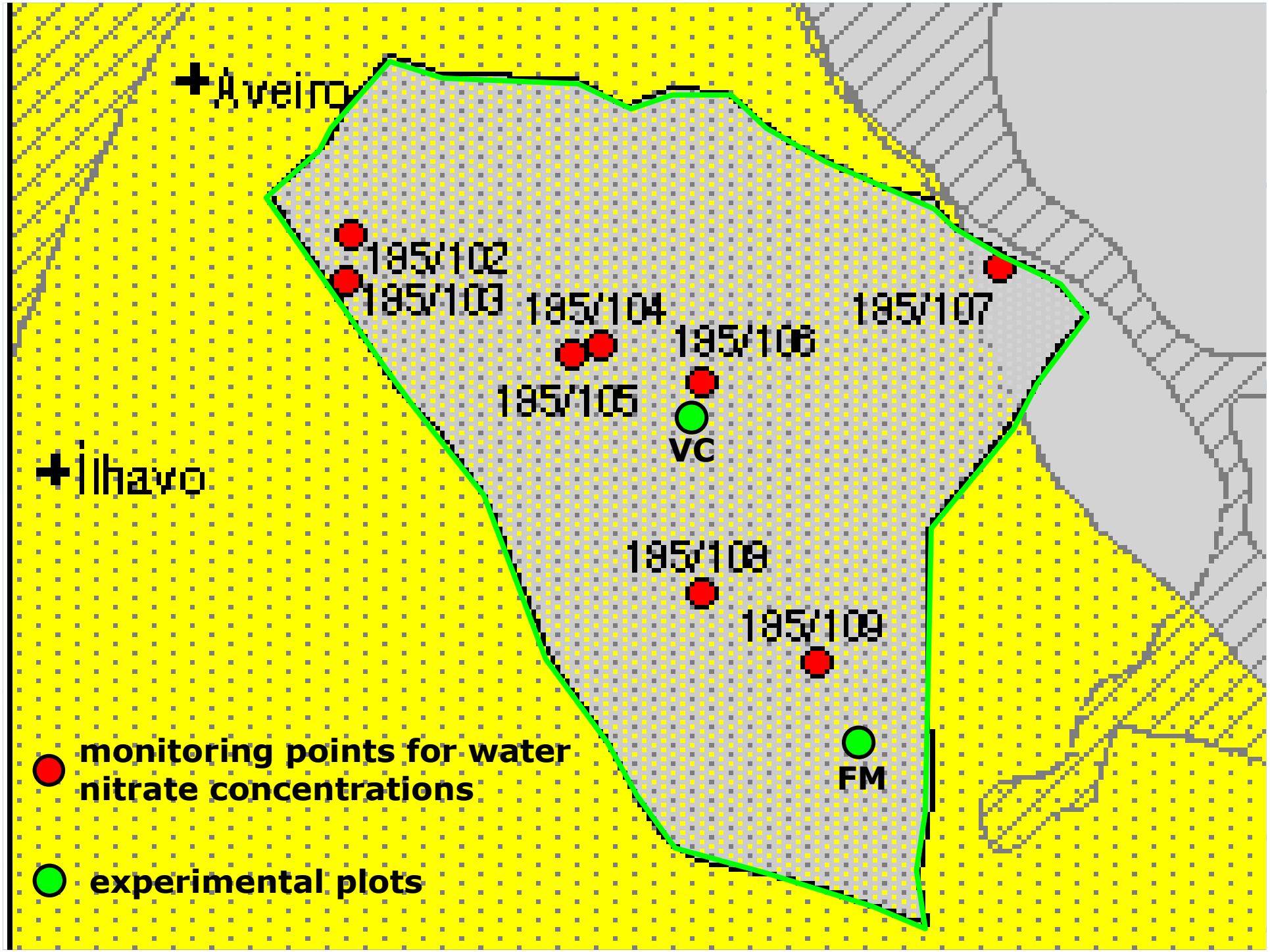
results from two water monitoring campaigns (154 wells, fountains and small water stream samples)

16% $[NO_3] < 50$ ppm

42% $50 < [NO_3] < 100$ ppm

42% $[NO_3] > 100$ ppm

Medium to **high** VZ index


Aveiro
Ílhavo
185/102
185/103
185/104
185/105
185/106
185/107
185/108
185/109
VC
FM
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 m^3/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 ºC)

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).

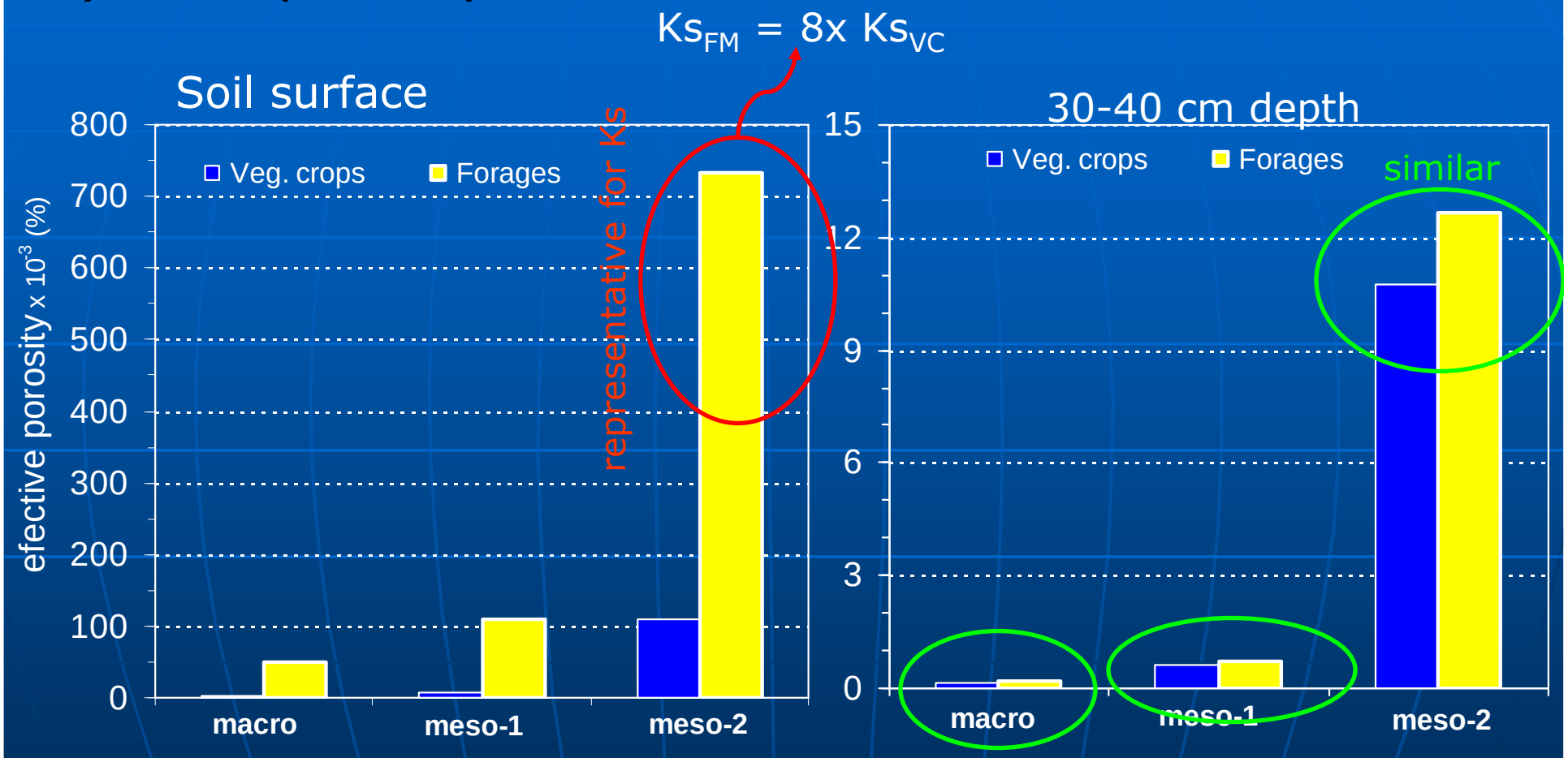
- *in situ* tension infiltrometer readings for macro-porosity and hydraulic conductivity curve assessment.

macroporosity according to Watson and Luxmoore (1986)

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

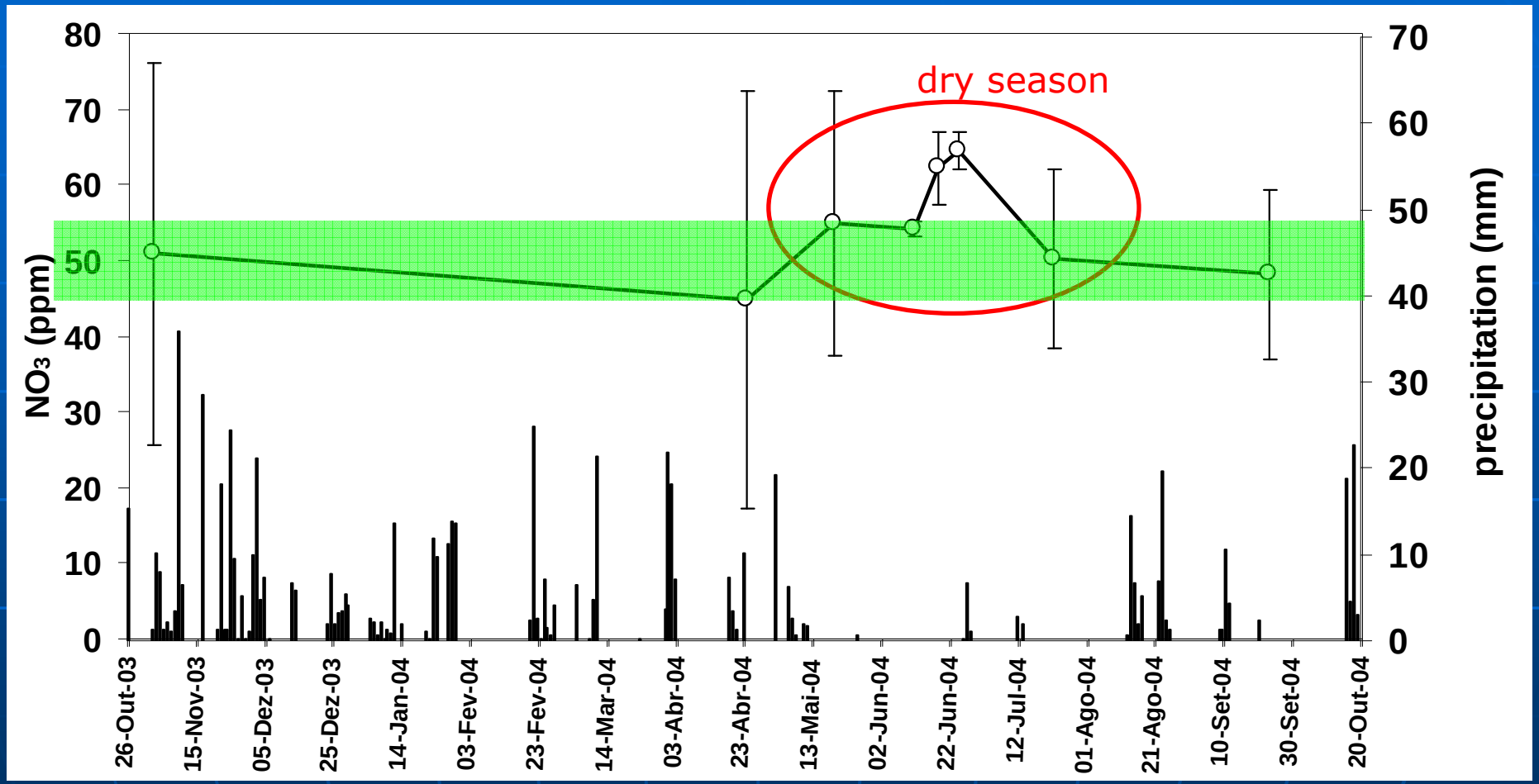
Results

1) Macroporosity



effective porosity = volume occupied by the porous hydraulically actives, excluding any isolated or dead-end porous

2) Nitrate leaching towards to water table

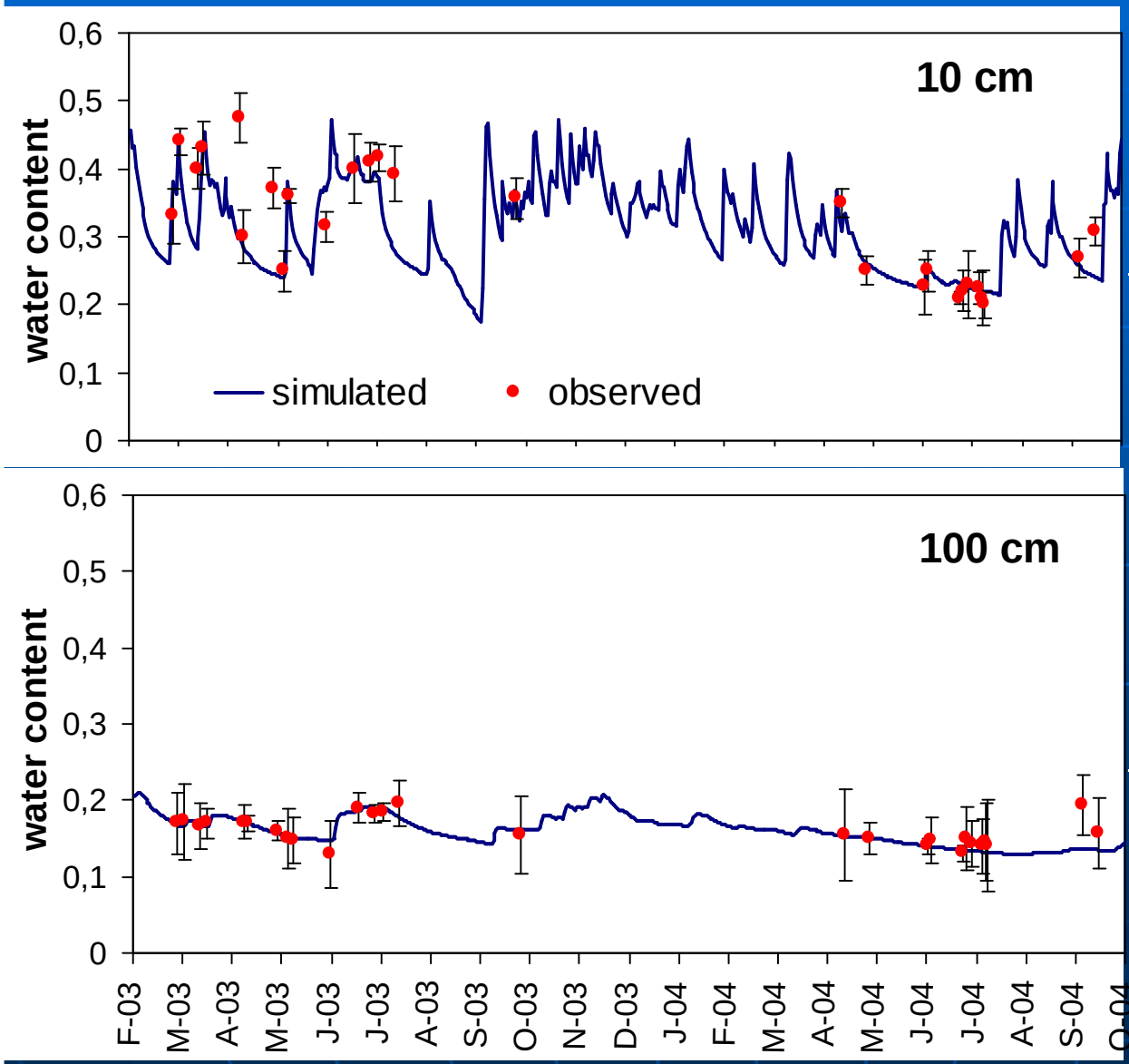


A water table contribution around 30% of maize ET corresponds to a contribution of about **13-17** kg N/ha

3) Validation of RZWQM (Root Zone Water Quality Model)

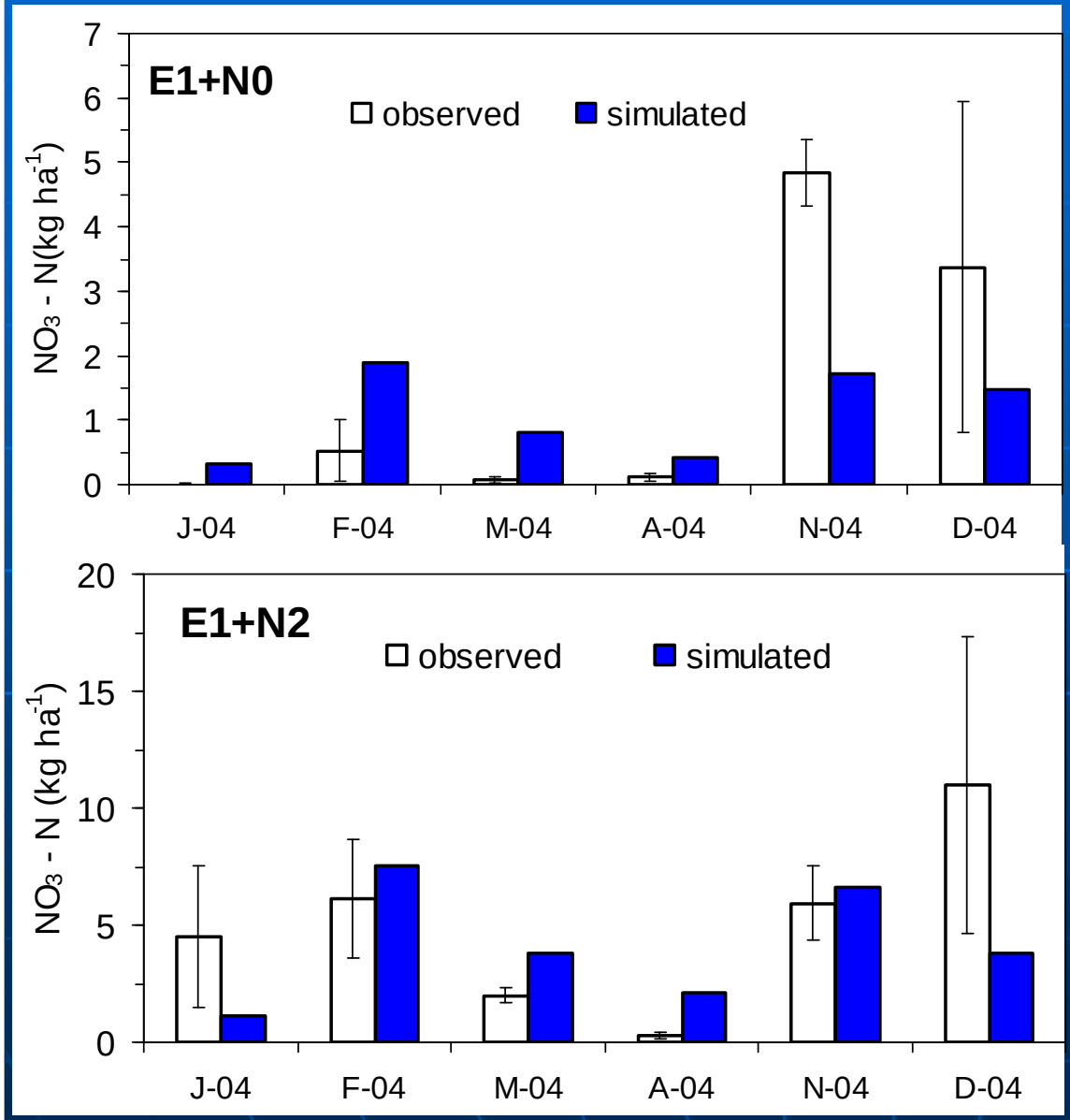
- calibration was validated by comparison of TDR soil moisture readings with the simulated ones;
- simulations were performed considering the contribution of macroporosity in the movement of water into the soil (*two domain approach* for preferential flow prediction);
- simulated results are considered very satisfactory when REMQ $\leq$ SDo and 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



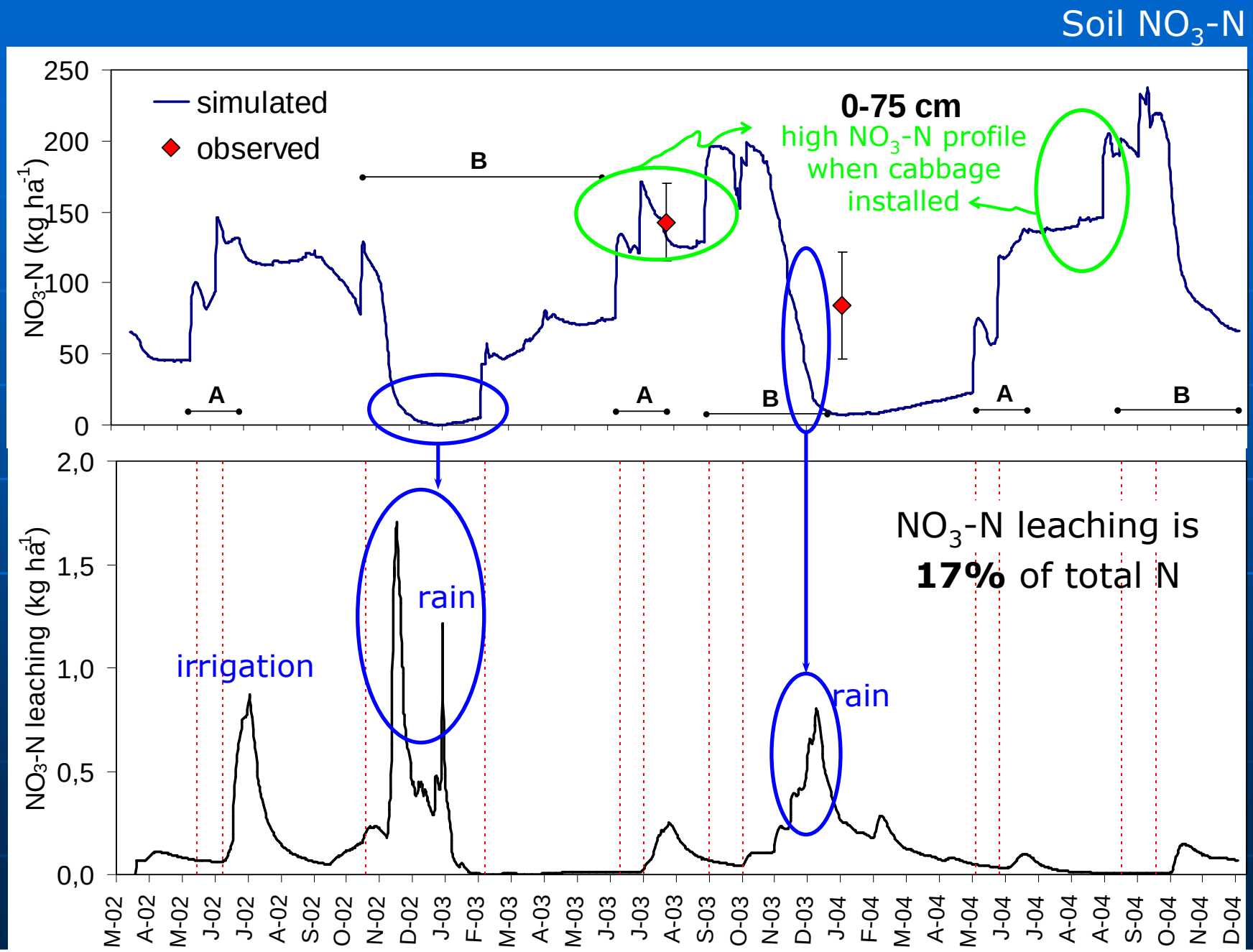
depth (cm)	EFM	REMQ	SDo
10	0,50	0,083	0,084
20	0,63	0,057	0,062
40	0,45	0,023	0,024
60	0,72	0,023	0,023
100	0,39	0,018	0,019

3.2) Nitrate leaching



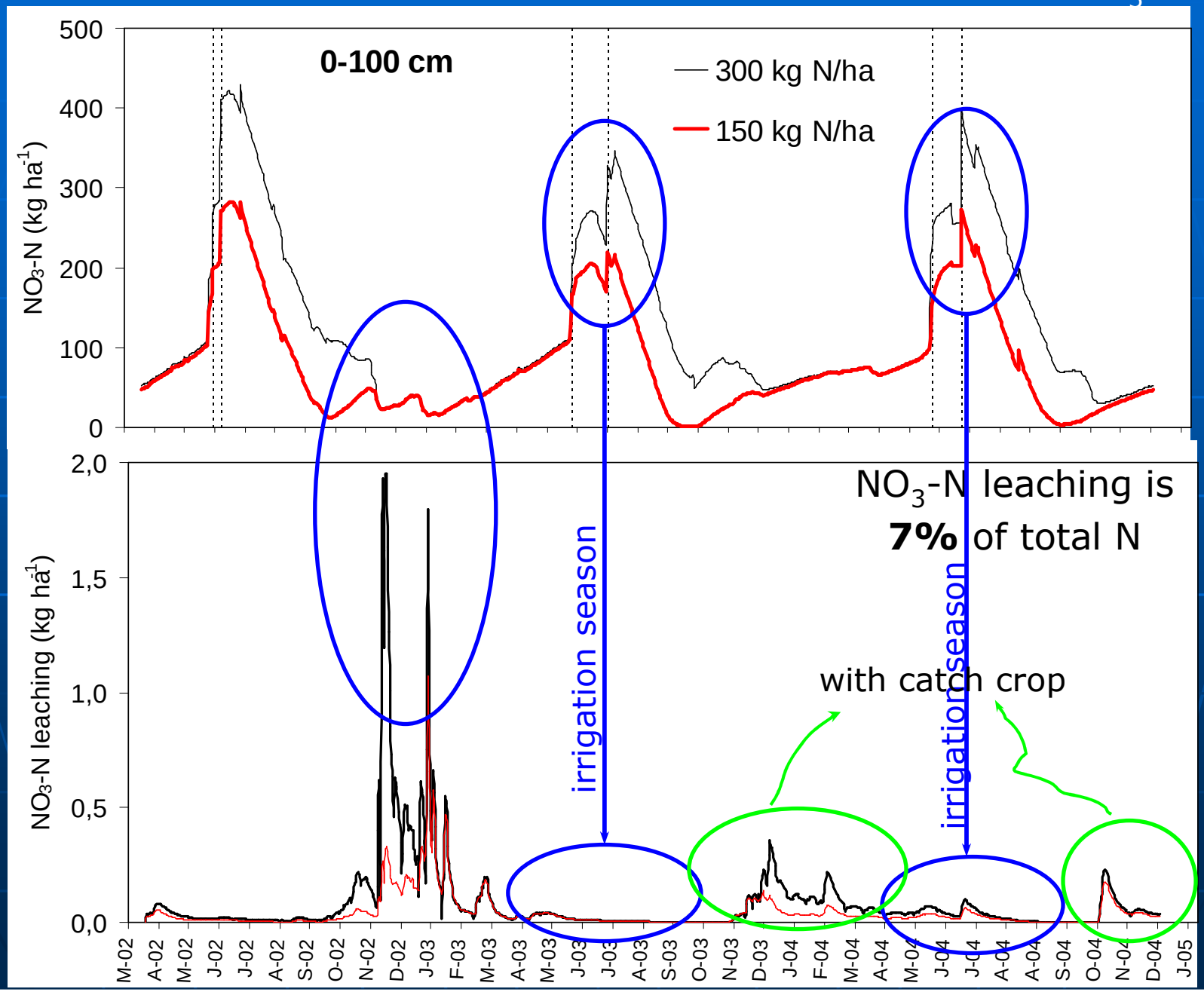
	EFM	REMQ	SDo
E1+N0	0,27	1,91	2,09
E1+N2	0	3,40	3,72
E1+nitra4	0,56	4,57	7,56

3.3) Vegetable crop rotations



3.4) Forages and maize

Soil NO_3-N



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

	Treatment 150 kg N/ha		Treatment 300 kg N/ha	
water irrigation depth	Δ Yield	Δ Leaching	Δ Yield	Δ Leaching
100 mm/ 4 irrig. [a)]	+ 11,2 %	+ 24 %	+ 11,6 %	+ 13,9 %
170 mm/ 4 irrig. [b)]	+ 10,7 %	+ 35 %	+ 10,9 %	+ 29,1 %
240 mm/ 4 irrig. [c)]	+ 11,4 %	+ 58%	+ 11,1 %	+ 49,7 %

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

Scenarios	lettuce x cabbage	
	110 kg N/ha	220 kg N/ha
165 mm (3 days frequency)	-16,1 %	-9,9 %
suppressed N-fertilization before cabbage installation	-55,4 %	-53,6 %
2 broadcast N-fertilization	-23,0 %	-15,0 %

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!

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