



Enjeux et conséquences du changement climatique pour la production rizicole en Camargue

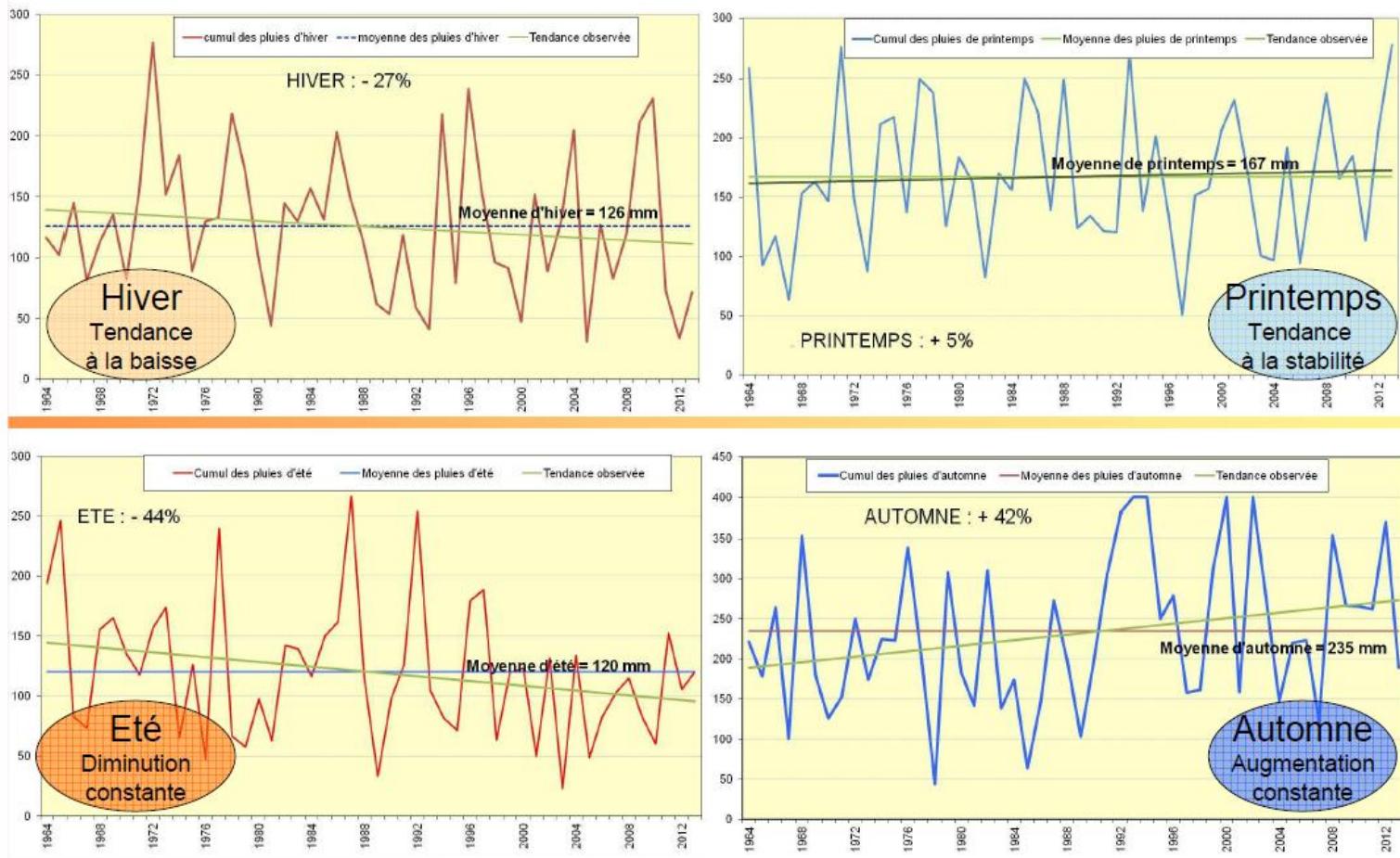


L'évolution du climat

Changements constatés et/ou à prévoir au niveau régional

(source : Présentations CIRAME et INRA - Rencontres Climat - RED PACA - décembre 2013 - Avignon)

- Relative stabilité du cumul annuel de précipitations mais :
 - baisse de la pluviométrie estivale
 - forte augmentation de la pluviométrie automnale

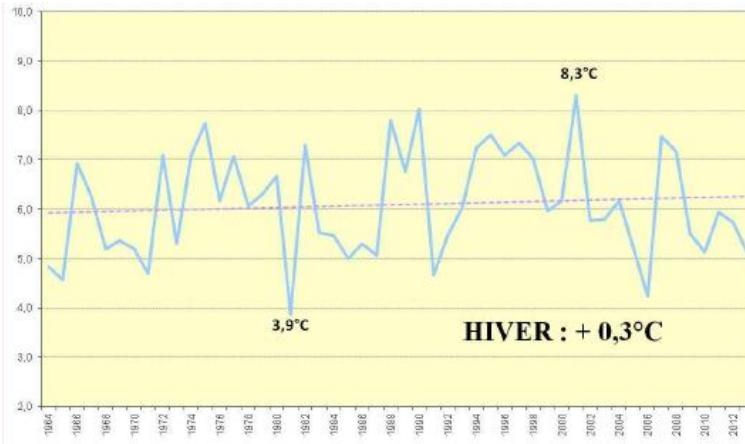


L'évolution du climat

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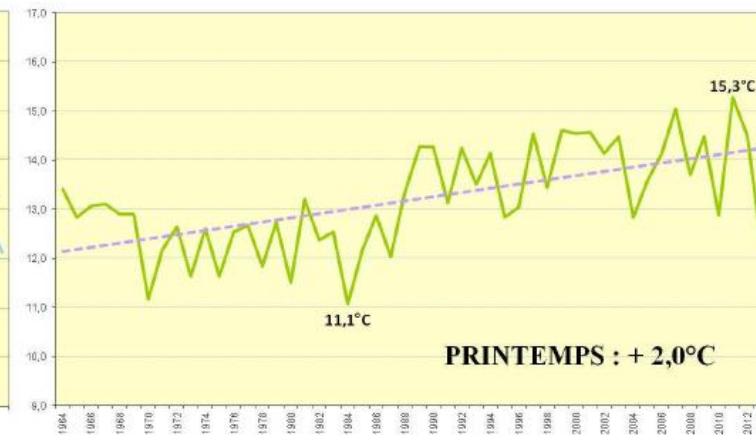
(source : Présentations CIRAME et INRA - Rencontres Climat - RED PACA - décembre 2013 - Avignon)

- Augmentation des températures moyennes en particulier sur la période printemps-été
 - Evaporation en hausse
 - Augmentation du nombre de jours de fortes chaleurs



HIVER : + 0,3°C

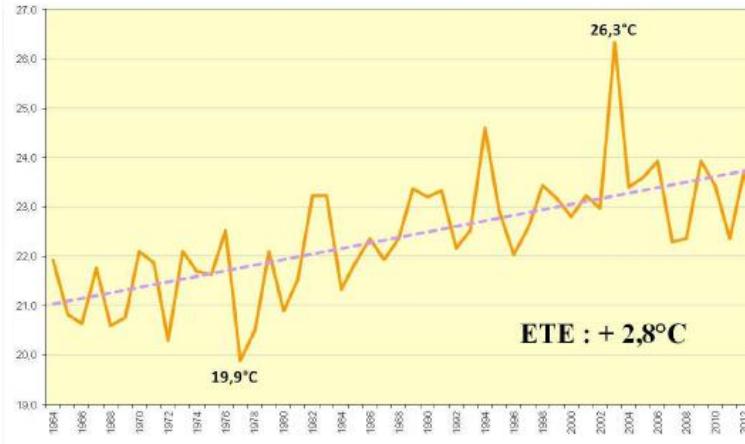
3,9°C



PRINTEMPS : + 2,0°C

11,1°C

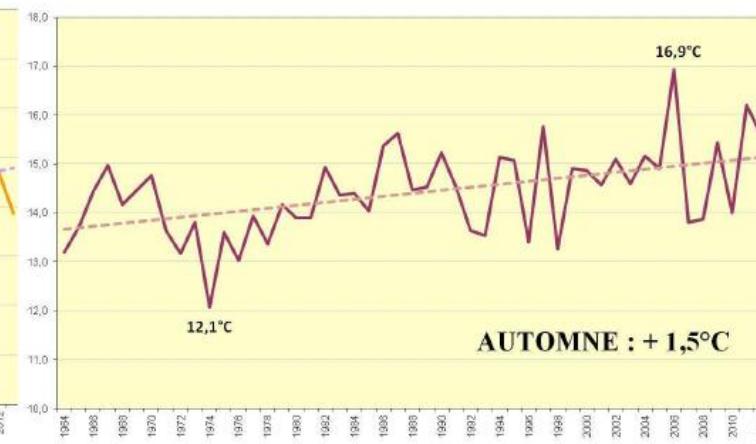
15,3°C



ETE : + 2,8°C

19,9°C

26,3°C



AUTOMNE : + 1,5°C

12,1°C

16,9°C

L'évolution du climat

Changements constatés et/ou à prévoir au niveau régional

(source : Présentations CIRAME et INRA - Rencontres Climat - RED PACA - décembre 2013 - Avignon)

- Baisse marquée des débits estivaux du Rhône (fonte des neiges plus précoce)



Une hausse des températures a priori favorable à la culture du riz

- ✓ Au printemps (phase végétative)
 - ✓ Implantation plus rapide de la culture
 - ✓ Moins de pertes à la levée



- ✓ En été (phase reproductive) :
 - ✓ Floraisons plus précoces
 - ✓ Températures minimales plus favorables à la fécondation



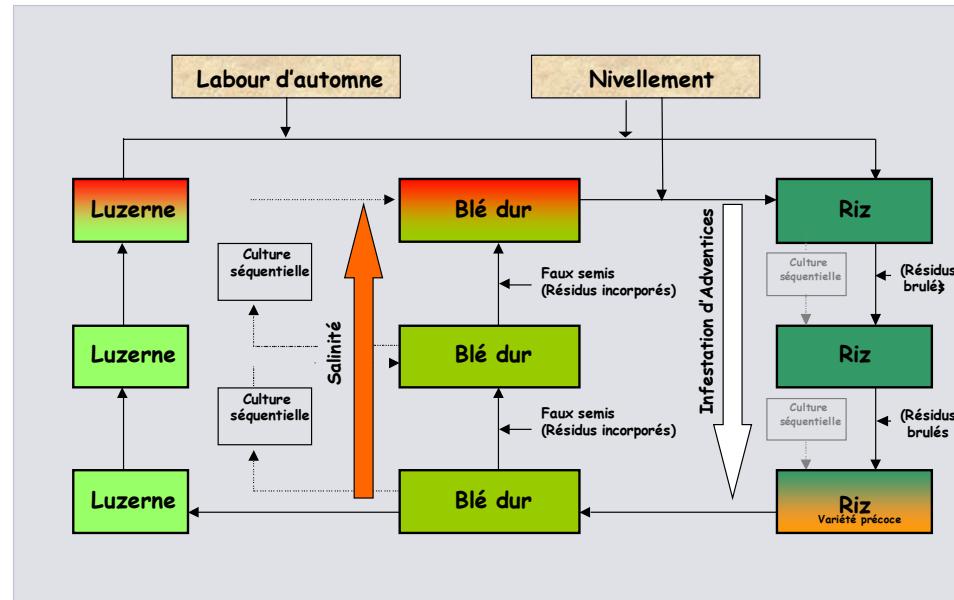
- ✓ Semis plus tardifs et/ou utilisation de variétés à cycle plus tardif possibles

Mais une mise en œuvre plus aléatoire des rotations culturales

A l'automne :

- ✓ Difficultés d'implantation des cultures dans de bonnes conditions (blé dur)

Modèle de Système de Culture à base de Riz et de Blé en culture conventionnelle
(source : INRA - UMR Innovation)



✓ Au printemps :

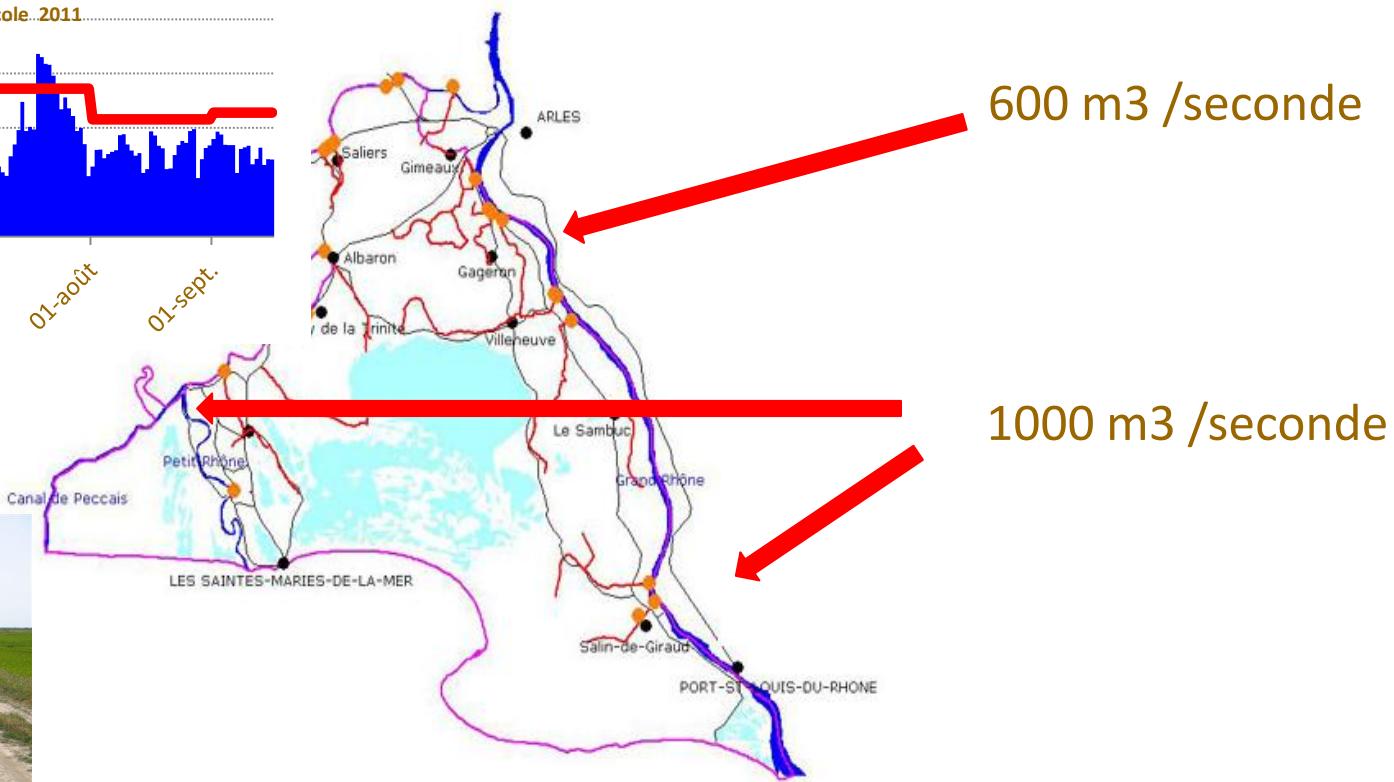
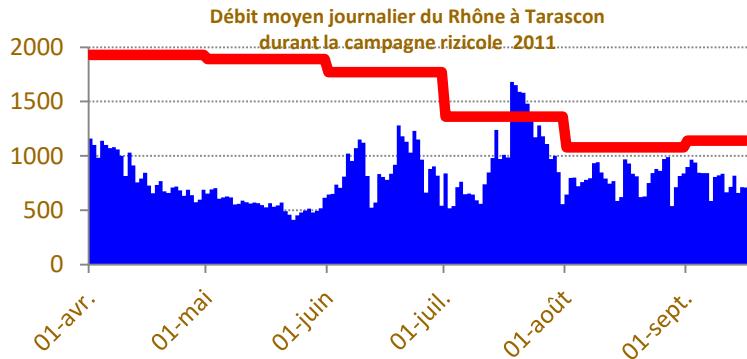
- ✓ Déficit hydrique plus élevé (blé dur et cultures de printemps)
- ✓ Risques accrus de remontées salines (blé dur et cultures de printemps)

Une baisse problématique du débit estival du Rhône

- Remontées d'eau salée jusqu'aux stations de pompage :

- en moyenne quelques jours par an (fin août)
- phénomène exceptionnel en 2011 (400 m³/s en mai)

Position du coin salé en fonction du débit du Rhône



Zones impactées en 2011



Salinité de l'eau
d'irrigation :
jusqu'à 5 grammes/litre
au mois de mai



2.000 ha de riz touchés
600 ha re-semés



L'apparition et le développement possible de nouvelles espèces invasives

Phénomène déjà connu en Camargue ...

Ravageurs de la culture

- Ecrevisse de Louisiane
- Charançon aquatique du riz (2014)



Flore adventice

- Heteranthera (1985)



- Leptochloa (2011)

... mais risque accru avec le changement climatique ?

- Escargot ampullaire*
- Chenilles défoliatrices (Spodoptera)*

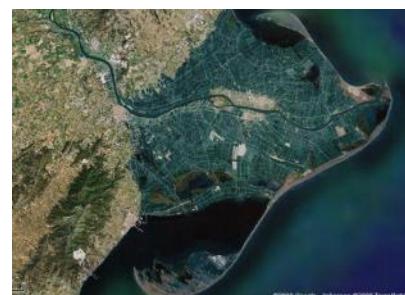
L'alternance d'irrigations et d'assec :
un système permettant de limiter la consommation d'eau et l'émission
des gaz à effet de serre pour les rizicultures tempérées

Le projet GreenRice

Plaine du Pô



Delta de l'Ebre



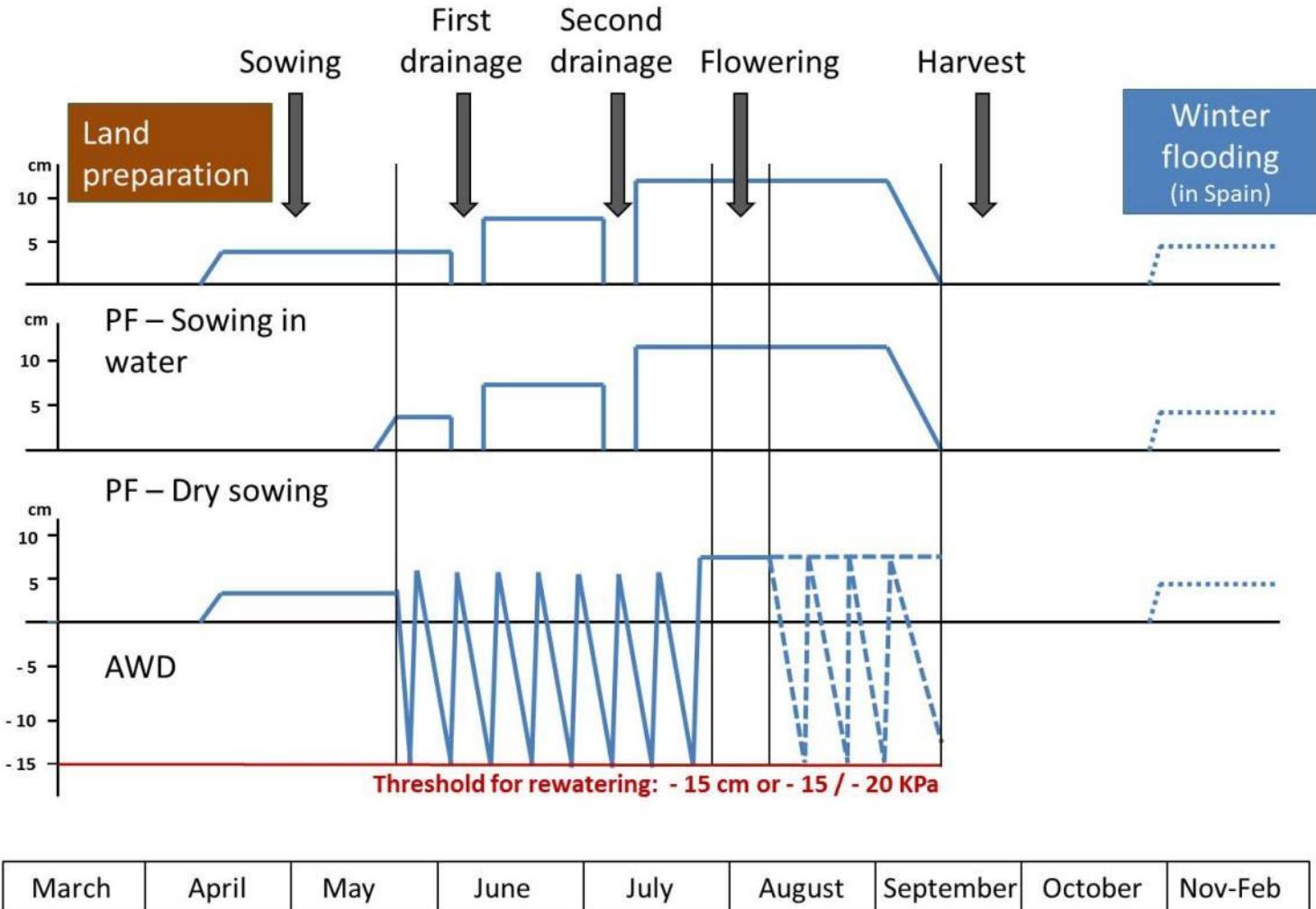
Delta du Rhône



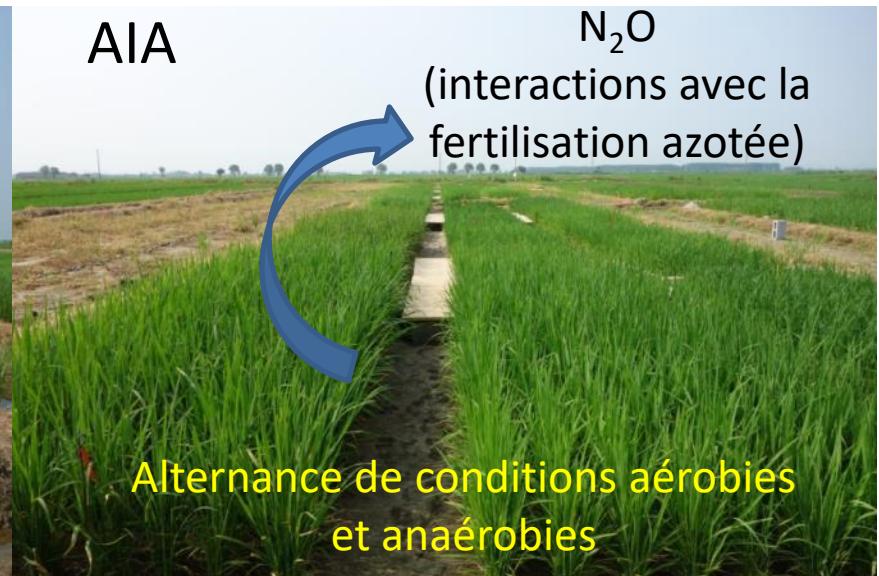
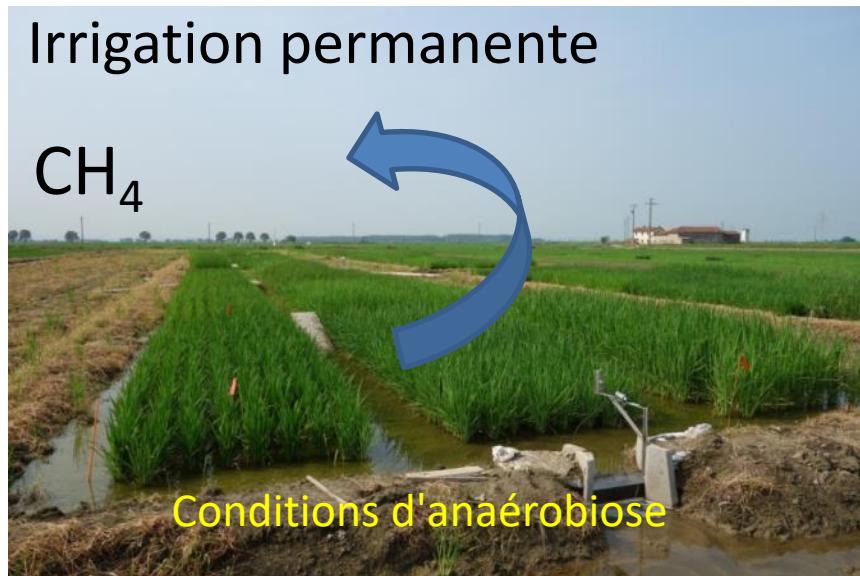
Le système d'alternance d'irrigations et d'assec (SAIA ou "AWDS")

Irrigation permanente (10 cm d'eau durant toute la saison de culture)

AIA: Depuis 3 semaines après semis jusqu'à floraison, alternance d'épisodes secs (jusqu'à -15 / -20 kPa) and humides (2 à 5 cm d'eau)



Avantages du SAIA: économie d'eau; réduction de l'émission de GES et des métaux lourds



- Economie d'eau de 30% sans diminution du rendement
- Réduction de l'émission de CH_4 jusqu'à 48% (si aérations multiples) mais production de N_2O
- Moins de métaux lourds dans les grains



Paramètre importants pour ne pas affecter le rendement

- Intensité du stress hydrique
 - Période du stress
 - Nombre de cycles irrigation/assecs
-
- Suppose de disposer d'un bon contrôle des approvisionnements en eau



UNIVERSITY
OF ABERDEEN



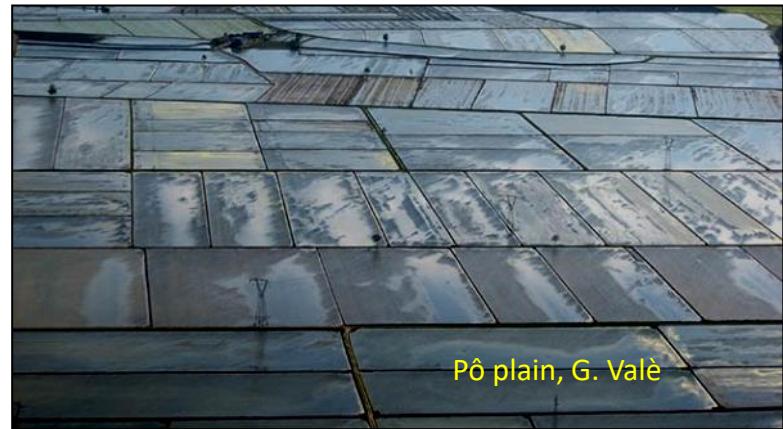
Principaux résultats

Présentation de Brigitte COURTOIS
Coordinatrice du Projet
FACE-JPI meeting, Paris,
22 March 2018



Rice in Europe

- Northern limit of rice cultivation
- Impossible to grow rice without irrigation (low rainfall and high temperatures in summer). Rice is therefore permanently flooded. Irrigation water comes from rivers.
- Rice is grown in flood plains or river deltas. In river deltas (0 to 5 m asl), rice is used to limit soil salinization and enable rotation with other crops (durum wheat, alfalfa, etc.)
- High input systems with high yields (6.5 to 10.0 t/ha)

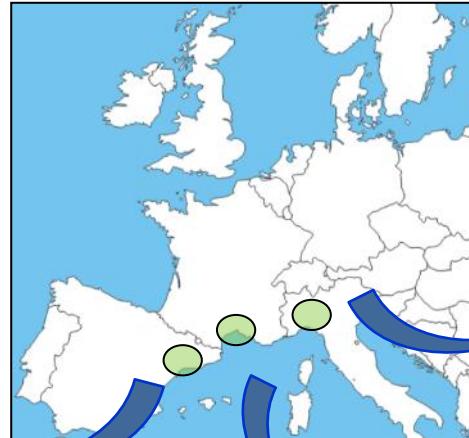




Three sites in Europe for the project: one floodplain and two river deltas



Spain: Ebro delta



Italy: Pô plain (Vercelli)



A. Boisnard

- In the two river deltas , rice interacts with natural parks. Delicate balance between biodiversity, tourism and agriculture: issues of water quantity going through rice fields, release rhythm, water quality (salinity, pesticides,...).

France: Rhône delta



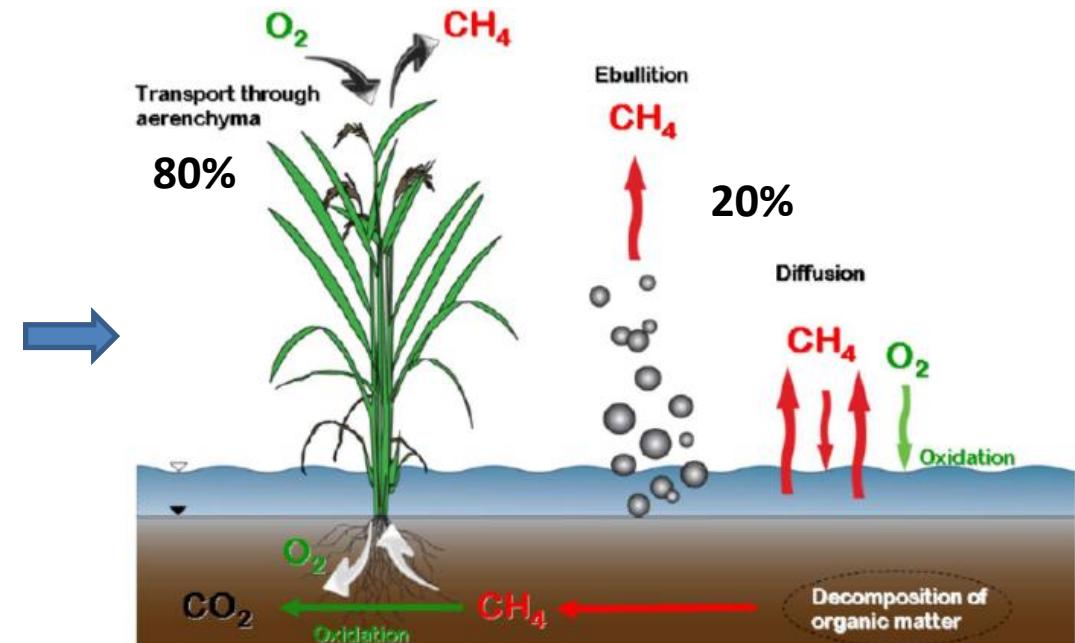
In a context of climate change, environmental issues linked to rice cultivation

1. Water consumption

- 25 000 m³ of water per ha needed, although 50% to 80% of this water goes back in the system (e.g. 400 millions of m³ of irrigation water through rice fields in Camargue; 1 billion of m³ for Pô plain)
- Present threats:
 - Structural: Overall decrease of irrigation water from rivers
 - e.g., Po river flow rate: 1800 m³/s in 1980 and 1400 m³/s in 2010 (-25%)
 - Conjonctural: Increased frequency and severity of drought spells in Mediterranean areas
 - e.g., Rhône river flow rate: 190 m³/s in 2011 against inter-annual average of 620 m³/s (-70%)

In a context of climate change, environmental issues linked to rice cultivation

2. GHG emission



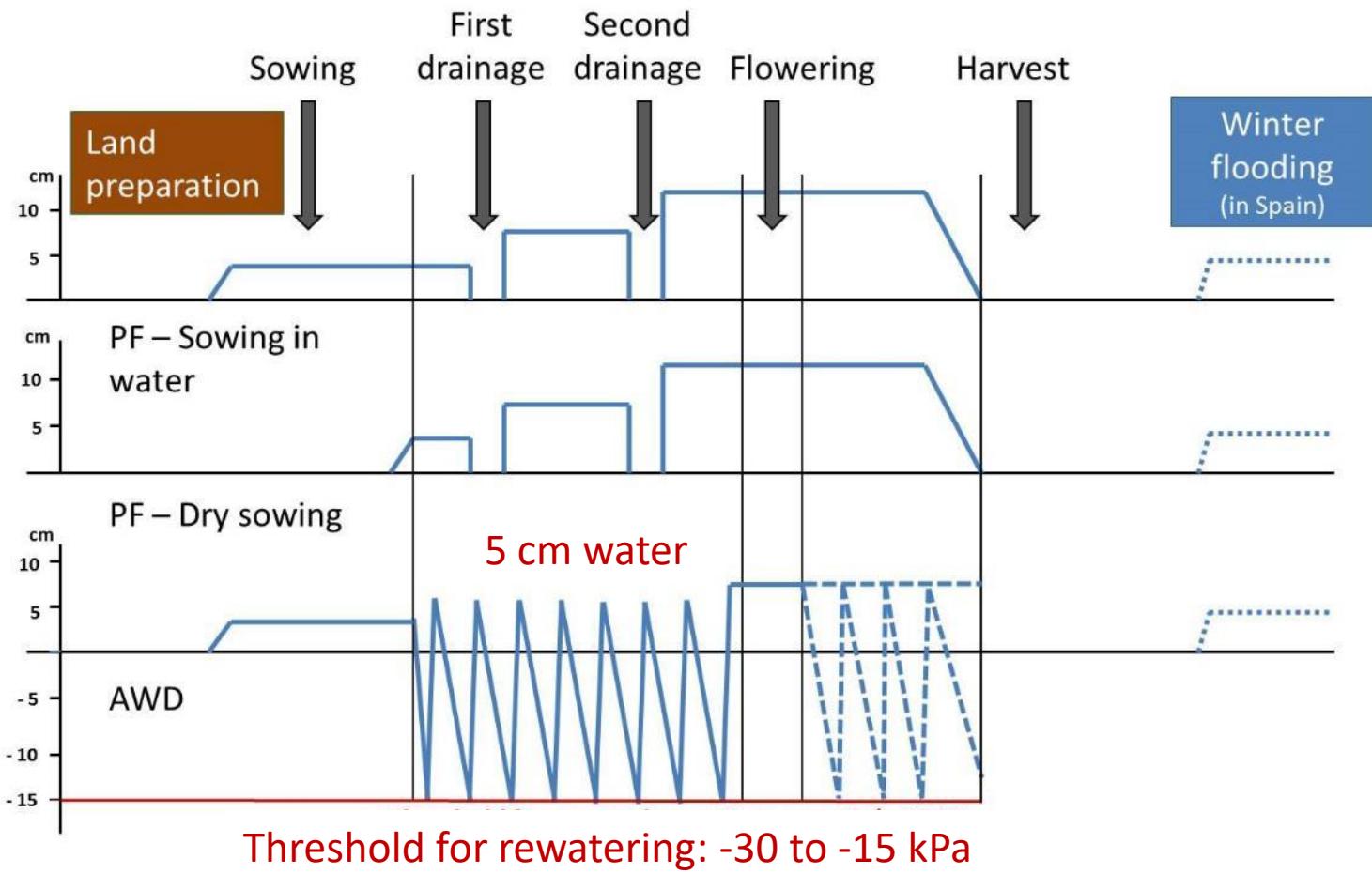
Le Mer et al. 2001

- Anaerobic conditions of the soil + methanogenic bacteria induce methane emission.
- 600 Mt of CO₂ equivalent per year for world irrigated rice; 10-15% of CH₄ emissions from agriculture due to rice.

An option to save water and limit GHG emission: test the "alternate wetting and drying" system (AWD)

Permanently flooded (10 cm of water during almost all cropping season)

AWD: From 3 weeks after sowing up to flowering, alternation of dry and wet periods





GreenRice activities

- **WP1: Consequences of a shift from PF to AWD on rice environment and productivity**
- WP2: Identify varieties productive under AWD:
 - Genome-wide association study on performance in AWD
 - Genomic selection
- WP3: Investigate plant traits determining adaptation to AWD:
 - Root traits
 - Tolerance to salinity
 - Resistance to nematode
 - Colonization by arbuscular micorrhizal fungi (AMF)
 - AMF x blast interaction
- **WP4: Dissemination of the project results to the stakeholders**

WP1: Consequences of a shift from PF to AWD on rice environment and productivity



- 2 years of trials in Italy (2015 and 2017), Spain and France (2016 and 2017) comparing PF and AWD
- Monitoring:
 - Environment parameters
 - Water consumption
 - GHG emission
 - Soil salinity, moisture and chemistry
 - Plant performance
 - Yield of accessions
 - Root colonization by MAF
 - Heavy metal accumulation in grains...



GHG measurement cages





On-station experiments comparing PF and AWD

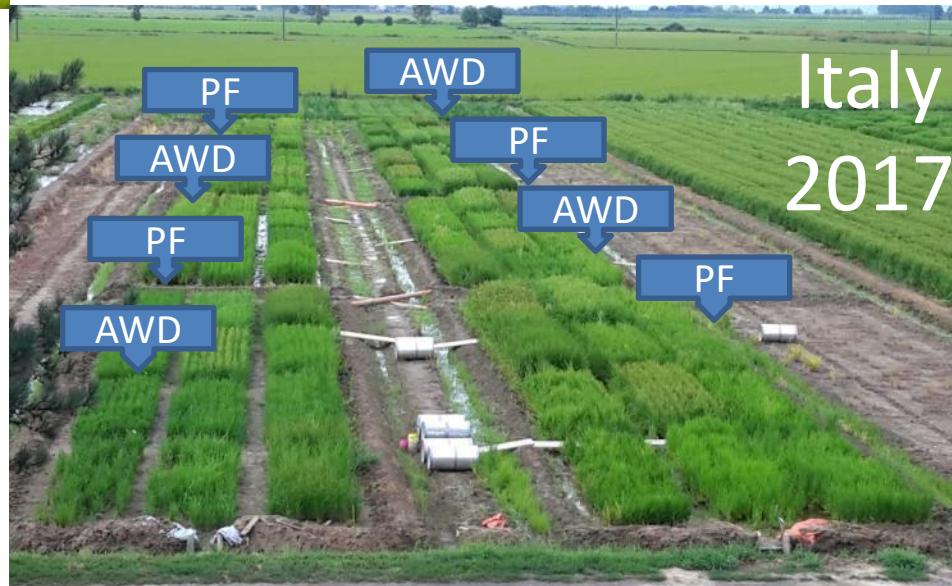


Monitoring tensiometers (20 cm) during AWD cycles



2 treatments: PF and AWD
12 varieties
4 replications
8 to 20 m² plots

Decision to irrigate again based on
tensiometers: -30 to -20 kPa at 15-20 cm



Agronomic results of the seven experiments

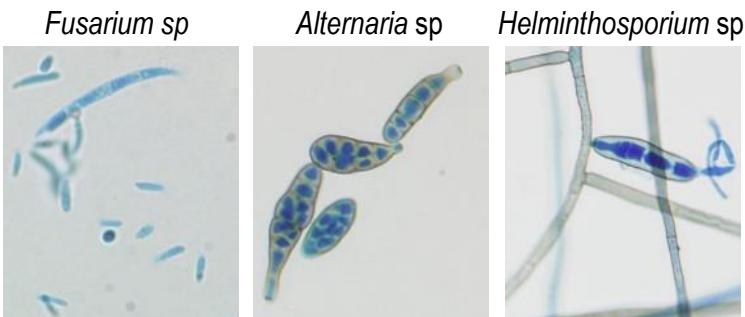
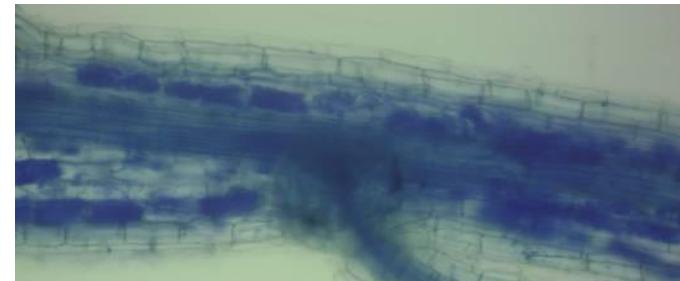
	Italy		Spain		France		
	2015	2017	2016	2017	2016	2017	2017
Water saving during AWD	43%	50%	na	85%	29%	35%	na
Threshold SWP for irrigation	-20 kPa	-20 kPa	-30 kPa	-20 kPa	-30 to -20 kPa	-20 kPa	-15 kPa
Mean effect AWD on yield	-4.8%	-7.5%	-16.0%	-5.0%	-35.0%	-20.0%	-1.1%
Arelate	+4.7%	-13.0%	-22.7%	+5.2%	-50.0%	-21%	+2.0%
Baldo	-16.7%	-21.4%					
Centauro	+6.5%	3.7%					
Gageron	-7.7%	3.6%	-20.2%	-4.1%	-27.0%	-7%	+0.3%
Gines	-6.0%	-3.4%	-27.3%	-10.1%	-23.0%	-20%	-2.5%
Gleva	+3.9%	-9.5%	-24.6%	-14.9%	-68.0%	-32%	
Jsendra	-15.9%	6.8%	-23.9%	-11.1%	-40.0%	-12%	
Loto	-6.9%	-11.5%	-0.3%	+1.1%	-76.0%	-31%	
Prometeo	+28.1%	-15.4%			-76.0%		
Puntal	-11.2%	-21.2%	-36.6%	+2.6%	-15.0%	-4%	
Selenio	+6.7%	-17.5%	-20.5%	-0.1%	-47.0%		
Vialone nano	-23.5%	9.3%	+30.0%	-13.5%	-12.0%	-10%	



- Large water savings during the AWD period; less over the crop whole cycle.
- Effect of AWD on yield linked to water management and soil type
- Yield decreases with the stress intensity:
 - 30 kPa threshold too severe in most conditions but particularly when light filtrating soils
- No significant yield difference between AWD and PF under the best conditions
- No variety particularly well adapted to AWD

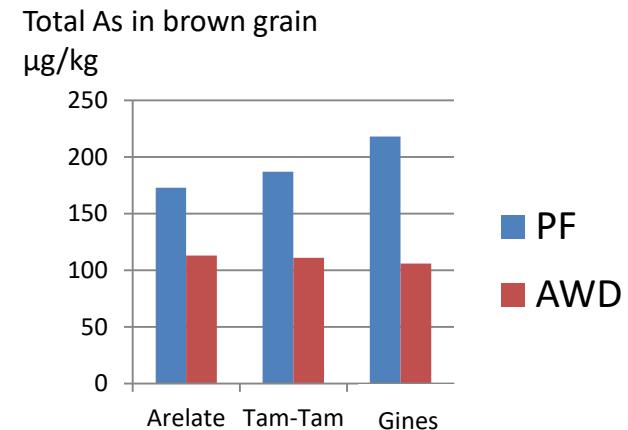
Other elements analyzed in the trials that could be affected by AWD:

- **Arbuscular mycorrhiza fungi:** no colonization under PF but good root colonization by native AMF under AWD.



- **Toxigenic seed fungi:** No significant difference in the incidence of toxigenic fungi in seeds harvested from plants grown in PF and AWD.

- **Grain arsenic content:** a substantial reduction in grain arsenic content was observed in AWD (-33% in 2015).



Monitoring GHG emission on the same experiments

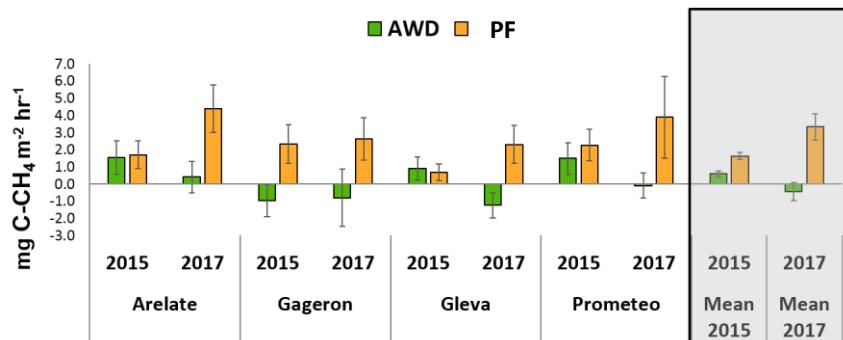
- Weekly measurements of CH₄, N₂O and CO₂; several time points per date and per cage
- All 12 varieties (2015) then selected ones.
- Some variability:
 - Large raise at T0 when putting the cages (focus on fluxes)
 - Frequent outliers probably due to bubbles
 - Negative values for CH₄: presence of methanotrophic bacteria



Strong reduction of CH₄ emissions under AWD during the monitoring period

	Italy		Spain		France	
	2015	2017	2016	2017	2016	2017
Methane emission	-63%	-113%	-80%	-95%	-98%	na

Mean CH₄ fluxes - Italy

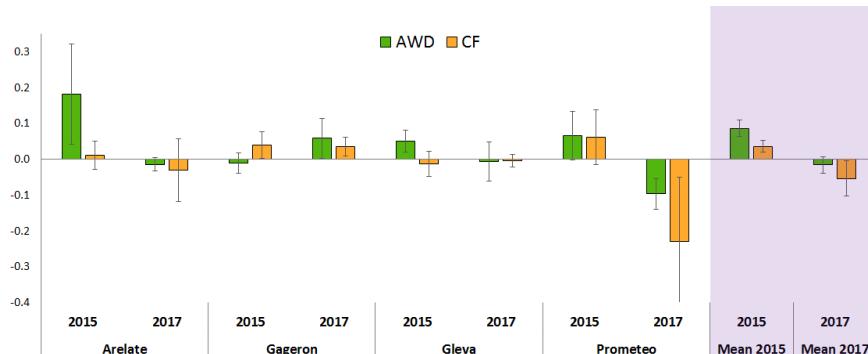


- In all field trials, AWD reduced methane emissions by at least 2/3 compared to PF.
- Higher reduction in more stressful conditions
- Limited variation due to varieties.
- Factors of variation of emission intensity: soil moisture, growth stage.

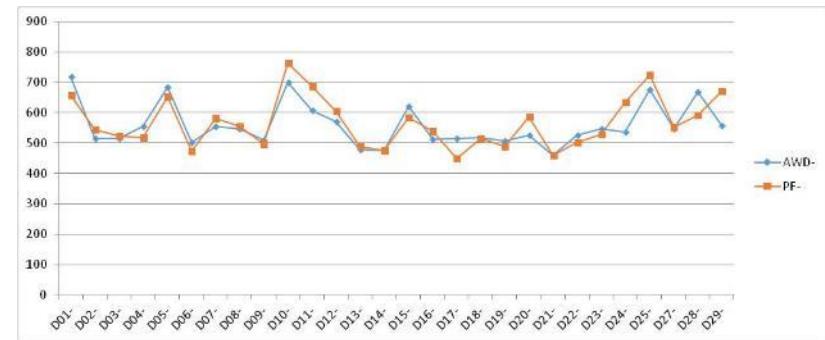


Limited differences between AWD and PF fluxes for N₂O and CO₂

Mean N₂O fluxes, Italy



CO₂ concentrations - France, 2016

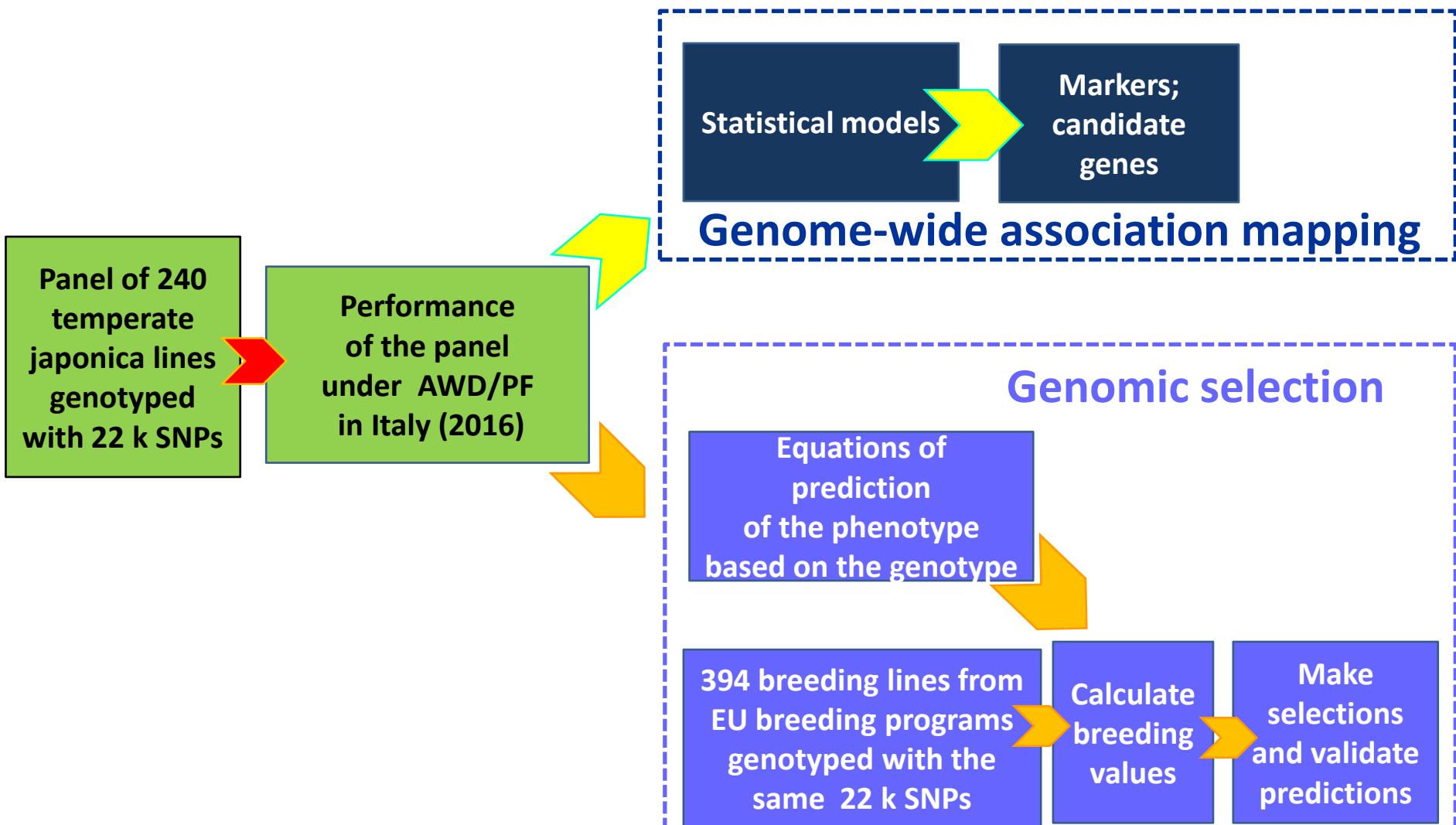


Summary of AWD effect on GHG emissions

	Italy		Spain		France	
	2015	2017	2016	2017	2016	2017
Methane emission	-63%	-113%	-80%	-95%	-98%	na
N ₂ O emission	+65%	+75%	+45%	+38%	~ 0%	na
CO ₂ emission	na	na	-65%	-3%	~ 0%	na
Gobal warming potential	na	na	-59%	-53%	na	na

- N₂O emission higher in AWD but low in absolute.
- No significant difference in soil CO₂ fluxes between the two treatments.
- C uptake in the system (from plant respiration, not from OM decomposition) but no significant AWD effect on C dynamics in Italy (soil with low OM).

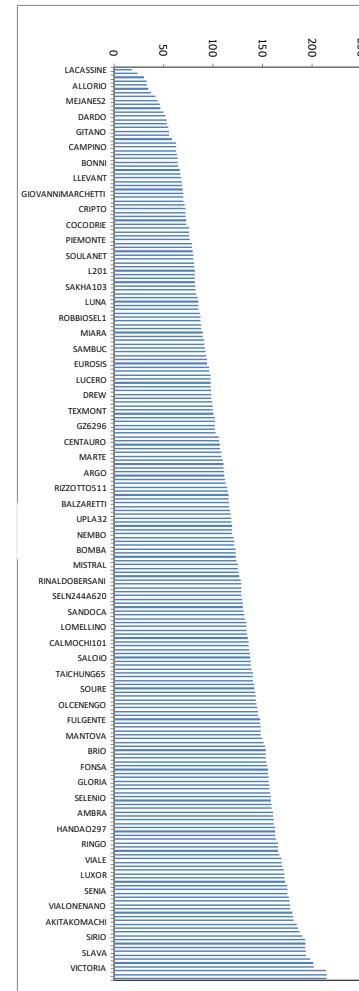
WP2 : Identify varieties productive under AWD; assess the possibility to breed for this trait





Genome-wide association study results for performance under AWDS

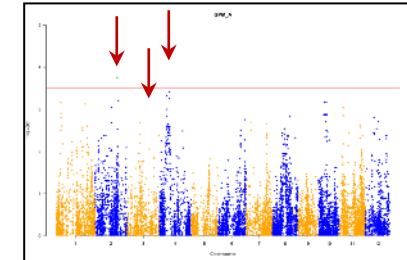
- Some variability within the panel.
- GWAS model taking structure and kinship into account
- 83 significant MTAs:
 - 1/3 MTAs specific to AWD
 - 1/3 MTAs specific to PF
 - 1/3 common to both
- Some significant MTAs for yield but with small effect; no major genes
- Identification of interesting genes among the candidates underlying the MTAs but not for yield.



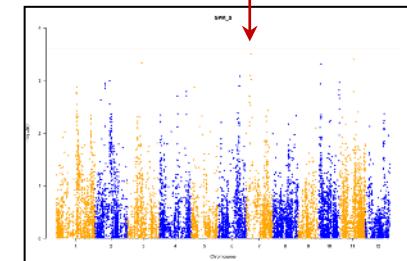
Ranking of the varieties of the panel based on AWD/PF yield index

GWAS Manhattan plots
red arrow= significant markers

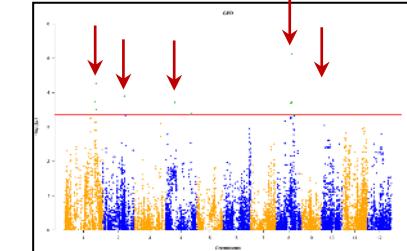
AWD - Yield



PF - Yield

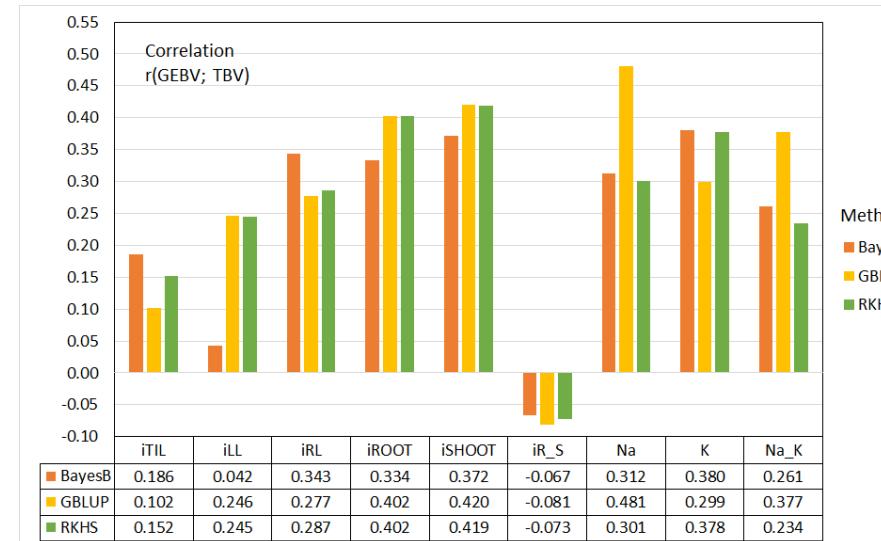


AWD/PF - Yield index



Interest of genomic selection in GreenRice context ? Case study on salinity tolerance

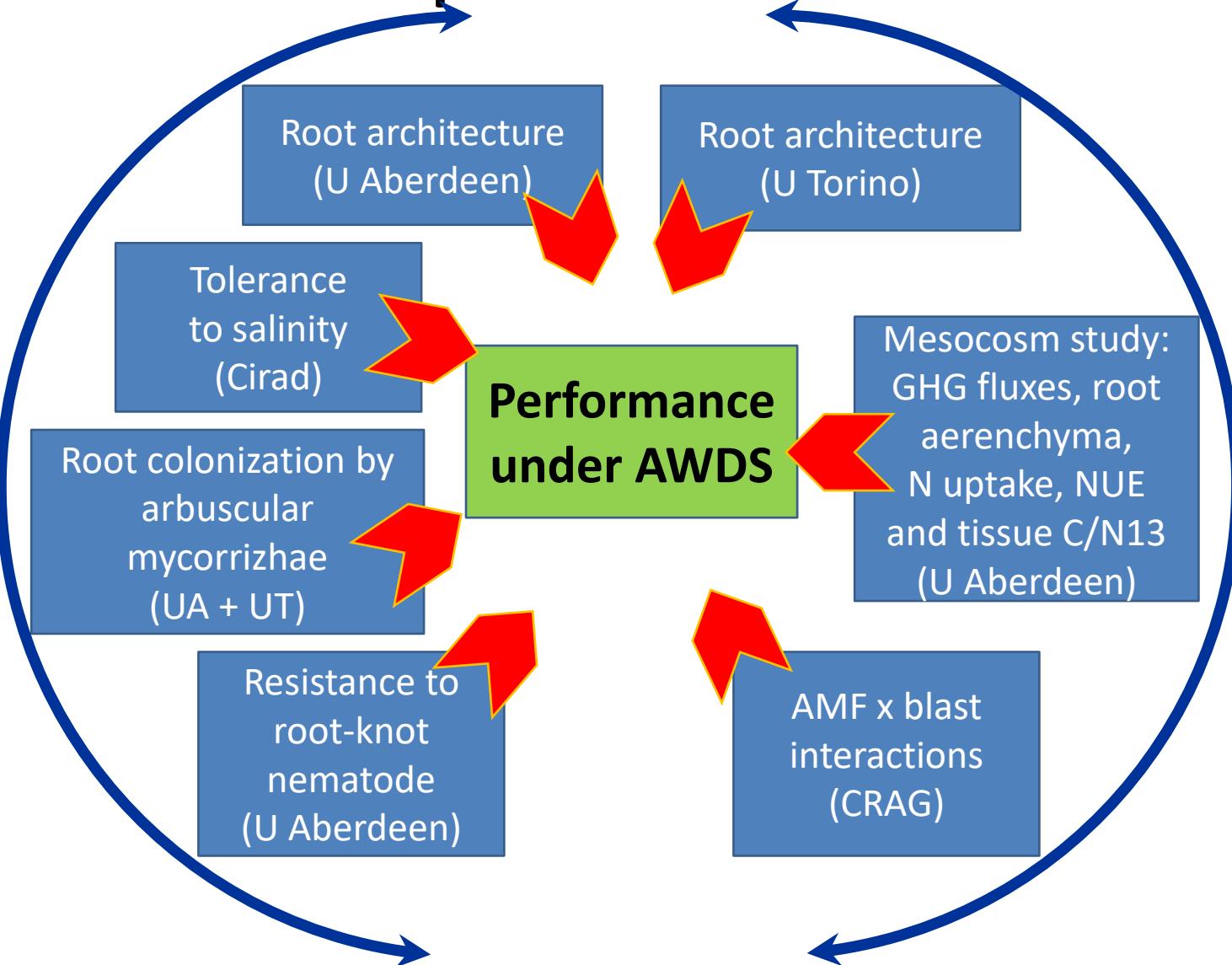
- Several models (single and multi-environments) and several prediction methods (GBLUP, RKHS, Bayes B) tested.
- Accuracy of the prediction = simple correlation (predicted; observed)
- Not so good prediction for salinity traits: accuracy varying from 0.0 to 0.48.
- Strong variation depending on trait.
- Little effect of model or prediction method.
- Still to conduct the same analysis with AWD/PF yield index.



WP3: Investigate plant traits determining adaptation to AWDS

Panel of
240 lines:
GWAS +
genomic
selection

Limited
number
of
accessions



Key trait-based findings

- Roots:

Changes in root architecture: Increased root branching under AWD treatment, mostly involving the large lateral roots.

Changes in metabolism: a P transporter (OsPT6) highly upregulated in AWD plants.

- Nematode resistance:

Mapping of a major gene for complete nematode (*Meloidogyne graminicola*) resistance to chr 11 using a population derived from a cross between resistant LD24 with susceptible Vialone nano.

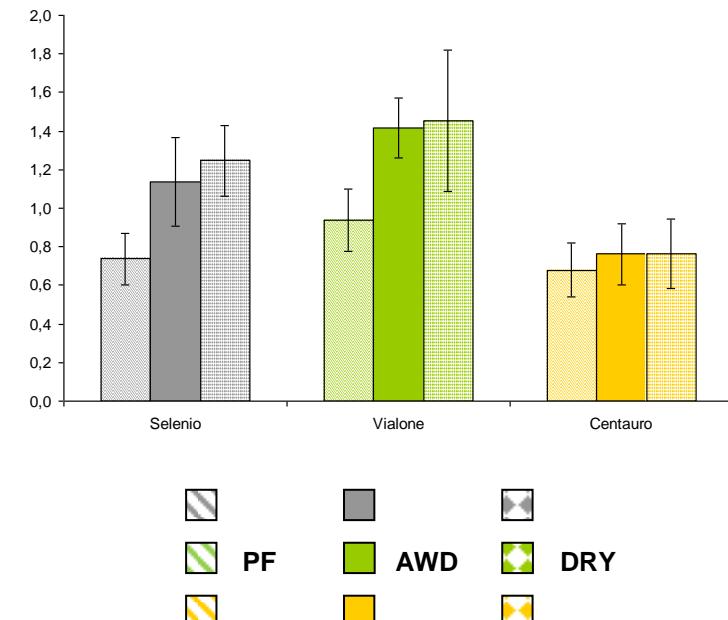
- AMF colonization; salinity tolerance; nematode resistance:

Characterization of the panel of 240 European accessions for these traits; genome-wide association mapping on these traits.

- AMF x blast:

Under controlled conditions, AMF-induced protection against blast infection dependent on host genotype.

Number large lateral roots per cm crown root



WP4: Dissemination of the project results to the stakeholders

- Leaflet in 5 languages
- Web site: <http://www.greenrice.eu/>
- Twitter account [@greenriceEU](https://twitter.com/greenriceEU)
- Farmers' field days in France, Italy and Spain in 2015, 2016 and 2017:
~ 50 to 100 participants per day



Conference by Dr A. Price
at Aberdeen Climate Week,
15-25 March 2018

RIZICULTURE
Greenrice: vers un système moins émetteur de gaz à effet de serre

cultivar LEADERS

► 1 janvier 2017 - N°72

WP4: Dissemination of the project results to the scientific community

- Publications: 3 papers, 1 book chapter, 4 posters, 9 oral presentations / invited talks.
- Several papers in preparation.

RESEARCH ARTICLE

Tolerance to mild salinity stress in japonica rice: A genome-wide association mapping study highlights calcium signaling and metabolism genes

Julien Frouin^{1*}, Antoine Langellaume¹, Justine Mas¹, Delphine Mieulet¹, Amaud Bolzanardi², Axel Labeyrie¹, Mathilde Bettembourg¹, Charlotte Bureau¹, Eve Lorenzini¹, Muriel Portefax³, Patricia Turquay¹, Aurore Vernet¹, Christophe Pépin¹, Nourollah Ahmadi¹, Brigitte Courtois^{1*}



A Rice GRAS Gene Has an Impact on the Success of Arbuscular Mycorrhizal Colonization

Valentina Fiorilli^{1*}, Veronica Volpe¹, Silvia Zanini¹, Marta Vallino², Simona Abbà², Paola Bonfante^{1*}

American Journal of Plant Sciences, 2015, 6, 1905-1915
Published Online August 2015 in SciRes. <http://www.scirp.org/journal/ajps>
<http://dx.doi.org/10.4236/ajps.2015.612191>

Genome-Wide Analysis of *japonica* Rice Performance under Limited Water and Permanent Flooding Conditions

Andrea Volante^{1*}, Francesca Desiderio^{2*}, Alessandro Tondelli², Rosaria Perrini¹, Gabriele Orasen³, Chiara Biselli², Paolo Riccardi⁴, Alessandra Vattari⁴, Daniela Cavalluzzo¹, Simona Urso², Manel Ben Hassen², Agostino Fricano², Pietro Piffanelli¹, Paolo Cozzi¹, Filippo Biscarin², Gian Attilio Sacchi¹, Luigi Cattivelli² and Giampiero Vale^{1*}



ORIGINAL RESEARCH
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1.14



EFFECT OF ALTERNATE WETTING AND DRYING (AWD) GROWING CONDITIONS ON THE FIELD PERFORMANCE OF DIFFERENT EUROPEAN RICE VARIETIES

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Valorisation opportunities

- With AWD, possibility to reduce water inputs without jeopardizing yield, provided very careful water management:
 - Relies on reliable supply of irrigation water. Changes in water governance mechanisms?
 - Impact difficult to forecast without an economic study:
 - Depending on water and rice costs, higher water productivity may not be economically interesting for a farmer.
 - Farmers pay pumping costs and irrigation costs per ha but do not pay for the quantity of water (m^3) they use.
 - Situations where AWD should be avoided/risky: sandy soils; salt-prone areas; cold periods; heat waves.
- With AWD, reduction in methane emissions:
 - No incentive in Europe to adopt practices to reduce GHG emissions (such incentives exist in USA for irrigated rice). Agri-environmental measures?
 - Require to look at the whole year, and not only the cropping season, notably management of the straws and the water during winter (70% yearly CH_4 emissions emitted post-harvest):
 - Incentives to maintain water in rice fields during winter in Ebro delta.
 - Project to look at the GHG emissions of natural wet areas (IRTA + CFR + Tour du Valat).
- With AWD, reduction of grain As: strong interest for organic farmers
 - Limited management options to reduce As uptake presently.



Future prospects

- Finish to exploit data. Run multi-site/multi-year analysis. Key papers still to be published.
- Collective interest for a "GreenRice 2":
 - Part of the activities in farmers' field: normal scale (rice farmer's field = 0.5 to 1.0 ha) + water management adapted to the phenology of a unique variety (flowering time) + method for irrigation decision to be simplified (piezometers instead of tensiometers, etc.)?
 - Part of the activities in station: unsolved issues
 - Testing other water management options (just two mid-season drainages? Extending AWD to maturation phase?)
 - Landscape modelling for prediction on how AWD will perform on a plot basis: need more data
 - Analyze the effect of AWD on weeds
 - Role of N
 - AMF: Metagenomics to analyze the change in species abundance due to AWD.
 - ?
 - Part: a socio-economic study of irrigation systems/costs
 - New project involving Egypt (Prima call)?
 - Collaborations with a Swedish team, which published a paper on rice ideotypes for low methane emission?



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Thank you for your attention



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