ALTERNATE WETTING AND DRYING IRRIGATION FOR RICE:
FIRST EXPERIMENTAL ACTIVITIES IN NORTHERN ITALY

Authors

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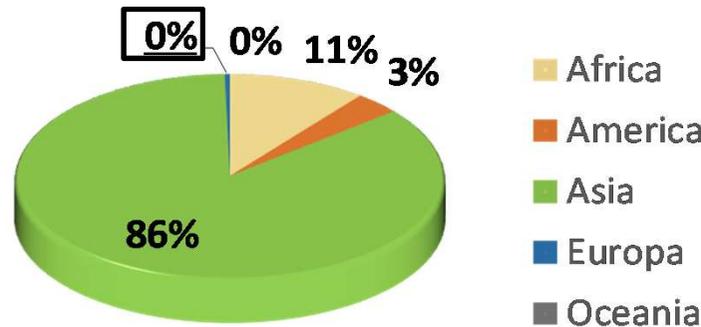
1 Università degli Studi di Milano (Italy), 2 Ente Nazionale Risi (Italy), 3 Università Cattolica del Sacro Cuore (Italy), 4 Aeiforia srl (Italy)

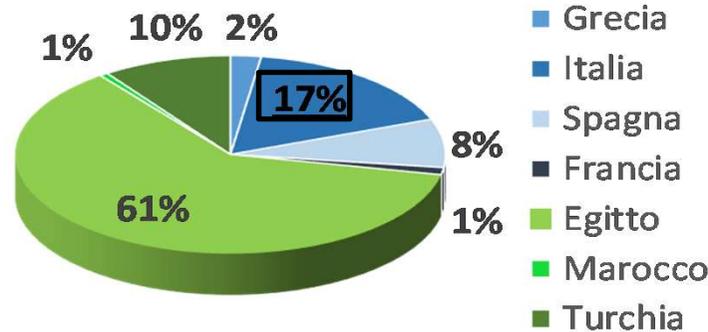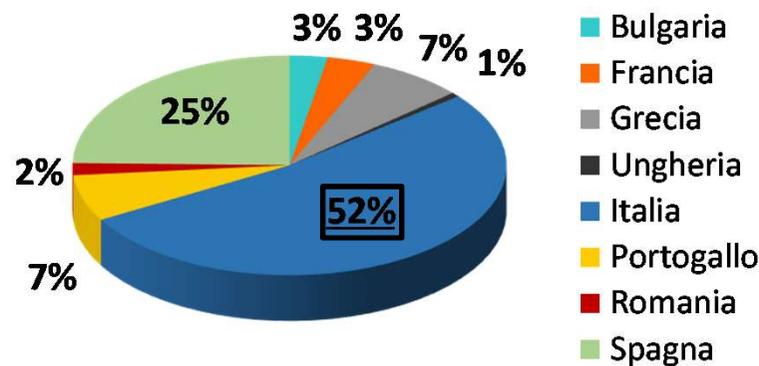# Rice in the World, in the Mediterranean Basin and in Europe

World

0% | 0% | 11% | 3%
86%

Africa
America
Asia
Europa
Oceania

162 milion ha
755 milion tons
(FAOSTAT, 2019)

Mediterranean Basin

1% | 10% | 2%
17%
8%
61%
1%

Grecia
Italia
Spagna
Francia
Egitto
Marocco
Turchia

1,3 milion ha
10,3 milion tons
(FAOSTAT, 2019)

Europe

3% | 3% | 7% | 1%
25%
2%
52%
7%

Bulgaria
Francia
Grecia
Ungheria
Italia
Portogallo
Romania
Spagna

420.000 ha
2,8 milion tons
(FAOSTAT, 2019)
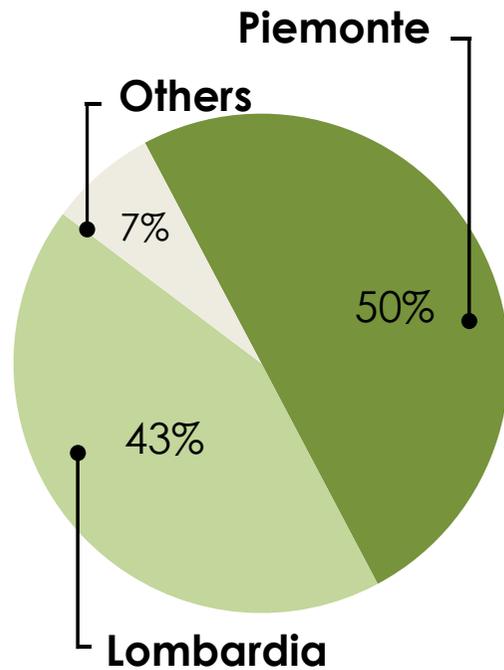
Rice in Italy

220.030 ha

(FAOSTAT, 2019)

1,5 milion tons

(FAOSTAT, 2019)

(ENR, 2018)

Alternative irrigation technique in Italy: "Water saving"

- In Italy, almost the total rice production is concentrated in a large paddy rice area between the Lombardy and Piedmont regions (north-western part of the country). In this area irrigation of rice has been traditionally carried out by wet seeding and continuous flooding (**WFL**), which requires a huge volume of water, since fields are submerged from before sowing to a few weeks before harvest.

Aree risicole

- In recent years, the interest in implementing alternative "water saving" techniques has increased, due to a decreased water availability in many areas and to an increased competition between water uses.
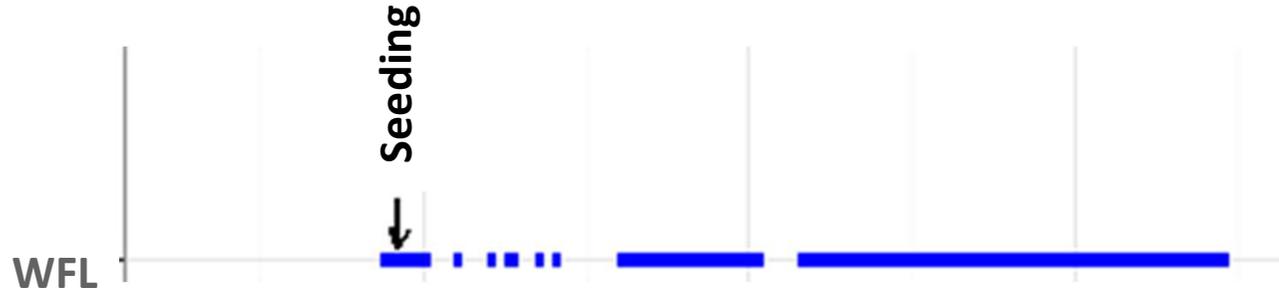In particular: dry seeding and delay flooding (**DFL**) and dry seeding and intermittent irrigation (**IRR**).
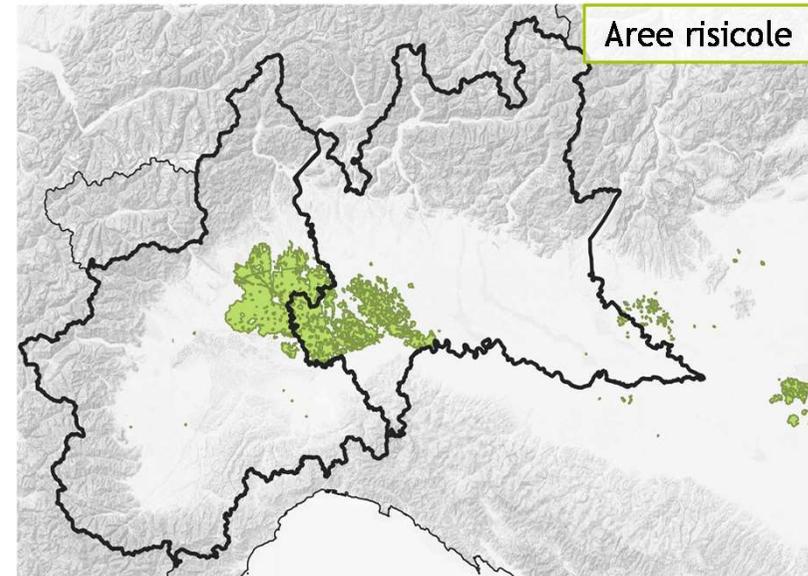
- When adopting a new irrigation strategy, advantages and disadvantages in terms of:
i) water saving,
ii) yield,
iii) environmental impacts
must be assessed.

Rice irrigation systems in Northern Italy

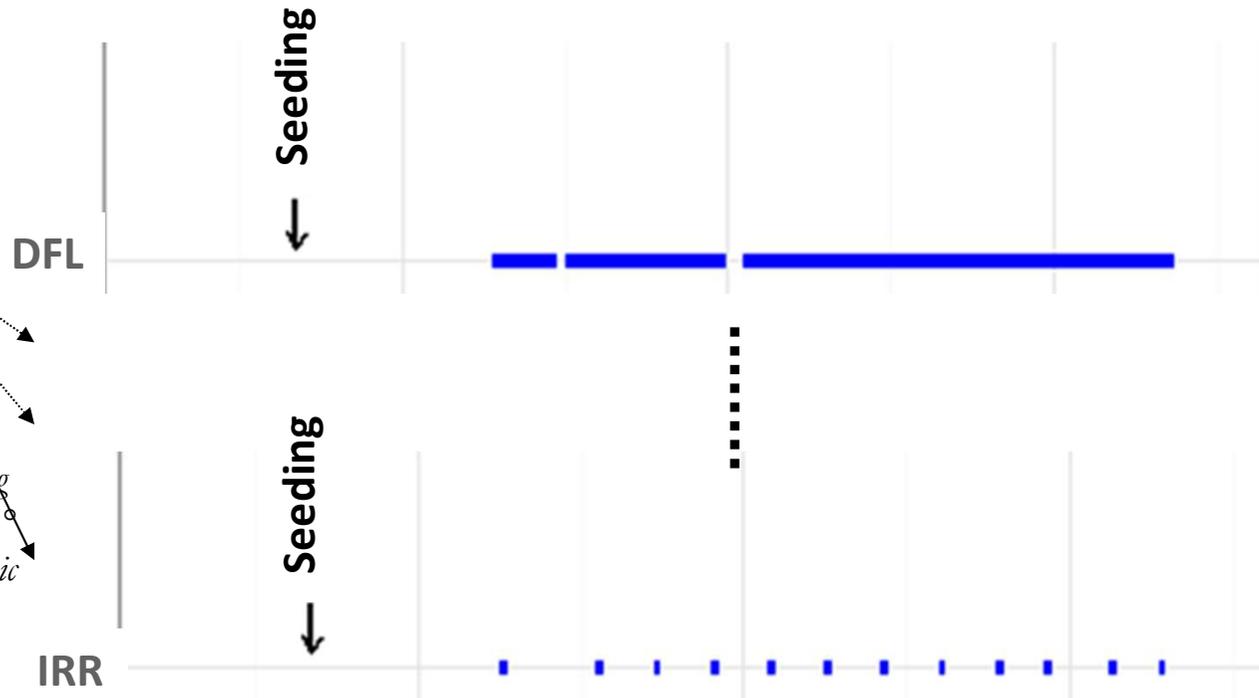**Water seeding**

Dry seeding

(different configurations: from water seeding and continuous flooding starting from the 3°/4° leaf stage, to the aerobic rice under intermittent irrigation)

Seeding

WFL

Seeding

DFL

Seeding

Seeding

IRR

In northern Italy dry seeding is being replaced by dry seeding

San Giorgio district (Lomellina PV)
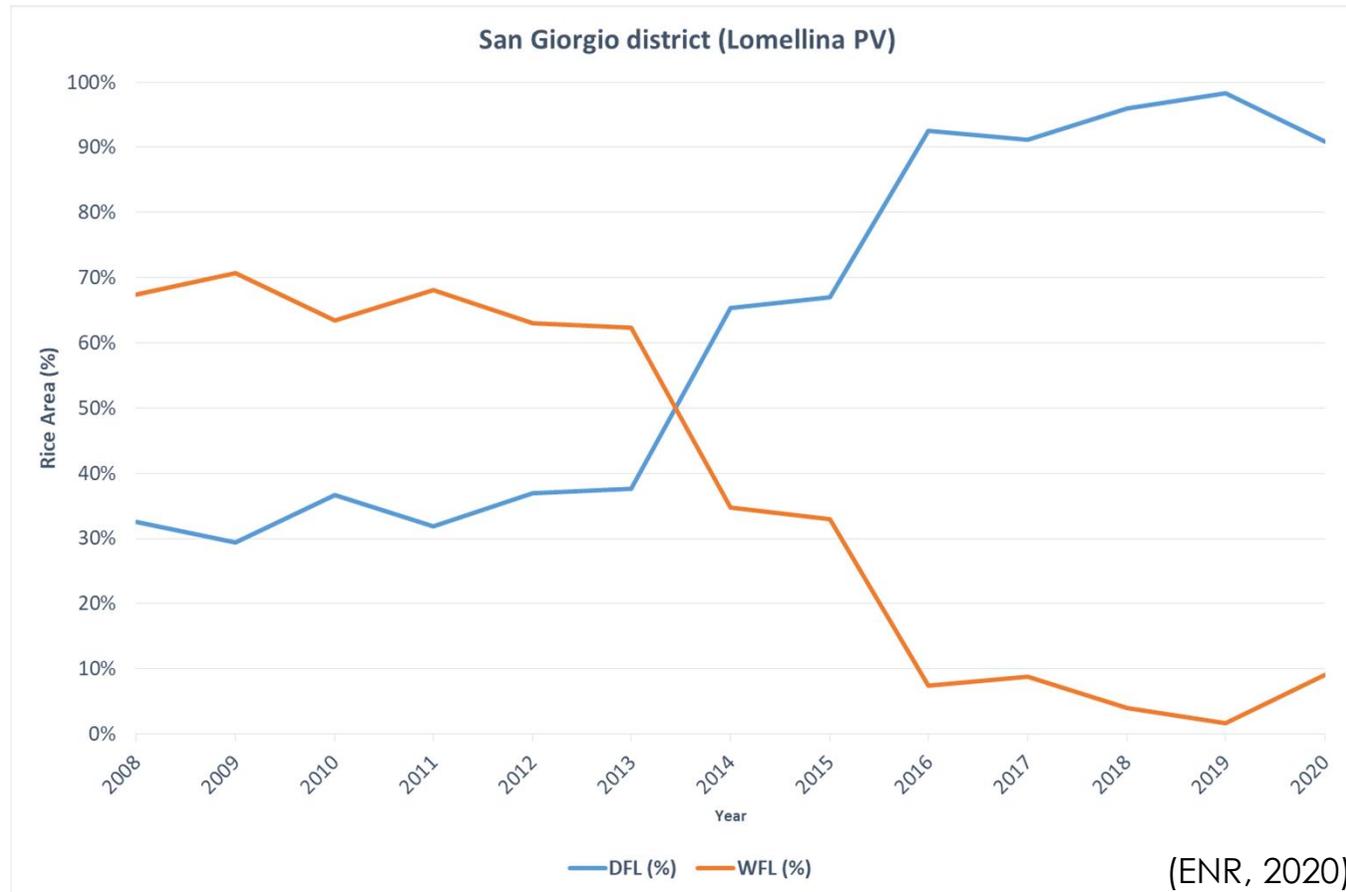
Example of the conversion of rice irrigation methods in the San Giorgio di Lomellina district (1000 ha, PV).
The conversion is taking place, not always with such speed, throughout the Lombardy-Piedmont rice area.

(ENR, 2020)

AWD –Alternate Wetting and Drying

- **As a new rice irrigation strategy in Italy, AWD has being tested in the context of the MEDWATERICE project (agricultural seasons 2019 and 2020).**

- AWD is an irrigation technique based on alternating dry and flooding periods from the tillering stage to the final dry period. Depending on the length of dry periods, AWD assumes more or less severe characteristics.

- AWD has been largely experimented and applied in China and Southeast Asia, as well as in areas with a more temperate climate, such as California and Arkansas, in order to assess: i) water consumption (Song et al., 2019); ii) greenhouse gas emissions (Liao et al 2020); iii) nutrient use efficiency (Chen et al., 2019); and iv) heavy metal content in rice grain (Norton et al., 2017).

- The management of AWD dry and flooding periods must be based on the soil water status. Usually soil water probes, tensiometric sensor or water tubes (WTs) are installed within the fields.

- WT is a perforated tube that can be manufactured with materials such as Polyvinyl Chloride (PVC), bamboo, etc. (Lampayan et al., 2015). The tube allows the measurement of the water level below the soil surface.

Water tube
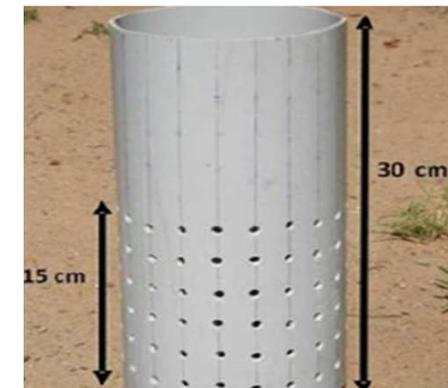
30 cm

15 cm

MEDWATERICE: Towards a sustainable water use in Mediterranean rice-based agro-ecosystems

- **Objectives**: MEDWATERICE aims to explore sustainability of innovative irrigation methods, to reduce rice water consumption and environmental impacts, and to extend rice cultivation outside of traditional paddy areas to meet the escalating demand.

- **Section and call:** PRIMA Section 2 – Multi-topic 2018.

- **Topic: 1.1.3:** Irrigation technologies and practices.

- **Starting date:** 1st April 2019; Duration: 36 months (Ending date: 31st March 2022.

- **Participants:**

  Università degli Studi di Milano (**UMIL**), Ente Nazionale Risi, Centro Ricerche sul Riso (**ENR-CRR**), Università Cattolica del Sacro Cuore di Piacenza (**UNICATT**), **ITALY**

  Rice Research and Training Centre, Agricultural Research Centre (**ARC**), **EGYPT**

  Universitat de Girona (**UdG**), Instituto de Agricultura Sostenible, Agencia Estatal Consejo Superior de Investigaciones Científicas (**CSIC**), TEPRO Consultores Agrícolas S.L (**TEPRO**), **SPAIN**

  NETAFIM Irrigation Solutions (**NETAFIM**), **ISRAEL**

  Instituto Politécnico de Coimbra (**IPC**), University of Coimbra (**UC**), **PORTUGAL**

  Black Sea Agricultural Research Institute (**BSARI**), **TURKEY**

www.medwaterice.org

MEDWATERICE — Towards a sustainable water use in Mediterranean rice-based agro-ecosystems

PRIMA — PARTNERSHIP FOR RESEARCH AND INNOVATION IN THE MEDITERRANEAN AREA

MEDWATERICE:
Case Study 1 - Lomellina, Italy

In Italy, the MEDWATERICE experimental activity was carried out at the ENR - Rice Research Centre's experimental farm located in Castello d'Agogna (Pavia, Italy), within a traditional rice cultivated area.

In the 2019 and 2020 agricultural seasons the experimentation was conducted in six plots of about 20 m x 70 m each with two replicates for each of the three following water irrigation techniques:

1) Water seeded rice and continuous flooding (**WFL**);

2) Dry-seeded rice followed by a delayed continuous flooding from around the 3-leaf stage (**DFL**);

3) Water seeded rice followed by an Alternate Wetting and Drying regime from tillering stage (**AWD**). In particular, a "SAFE" AWD was implemented, and the field was re-flooded to an irrigation depth of 9-10 cm depth when the water level in the WT (water tube) dropped below the -7 cm from the soil surface, and the soil water potential measured by a tensiometer installed at -10 cm from the soil surface below – 5 kPa.

MATERIALS AND METHODS

Field-scale experimental site (Castello D'Agogna, PV) 2019

Experimental setup (Centauro variety 150 kg/ha) in 2019

WFL		AWD		DFL	
FIELD 1	**FIELD 2**	**FIELD 3**	**FIELD 4**	**FIELD 5**	**FIELD 6**
Water seeding + flooding		Water seeding + AWD		Dry seeding + flooding 3°-4° leaf	
Sirtaki (0.5 L/ha)		Sirtaki (0.5 L/ha)		Sirtaki (0.5 L/ha)	
Tripion E (0.8 L/ha)		Tripion E (0.8 L/ha)		Tripion E (0.8 L/ha)	
N (% PRE-TILL-PD): 40-30-30		N (% PRE-TILL-PD): 40-30-30		N (% PRE-TILL-PD): 0-70-30	
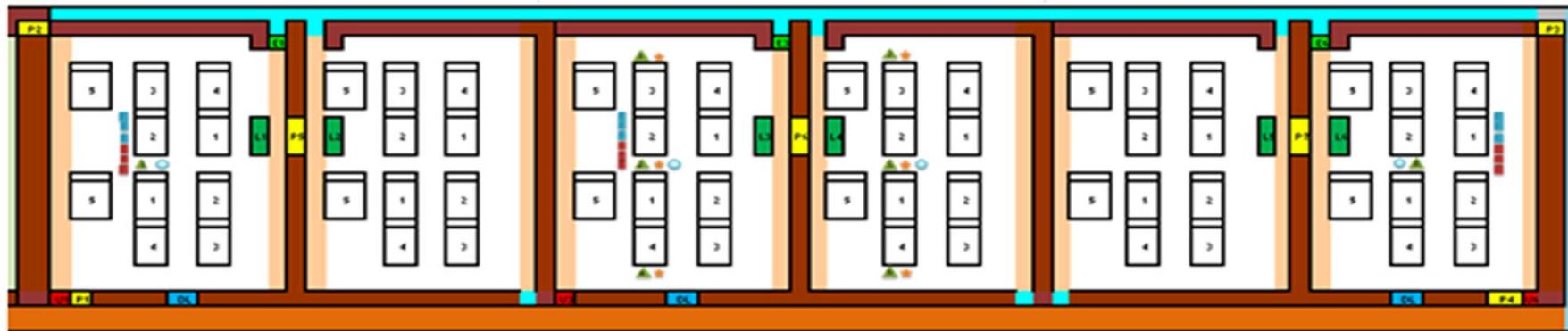
Sub-plots	
1	0 N
2	100 N
3	160 N
4	160 N NO FUNGICIDE
5	160 N NO HERBICIDE

P1	PIEZOMETRIC WELLS
E1	FLOW METER AT INLET
U1	FLOW METER AT OUTLET
L1	WATER LEVEL SENSOR
DL	DATA LOGGER

- POROUS CUPS AT 20 CM
- POROUS CUPS AT 70 CM
- FIELD WATER TUBES
- pH and Mv ELECTRODES
- TENSIOMETERS

Monitoring activities

- Measurement of water balance components: one out of the two plots irrigated with each specific irrigation option was instrumented with: water inflow and outflow meters; set of piezometers and tensiometers and set of water tubes (only in the AWD plots, for the management of the intermittent irrigation).

- Conduction of a soil survey before the agricultural season (EMI sensor and physico-chemical analysis of soil samples, for all the plots in the platform.

- Periodic measurements of crop biometric parameters (LAI, crop height, crop rooting depth).

- Analysis of rice grain yields, rice grain and straw nitrogen uptake, and arsenic and cadmium rice grain content, for all the plots in the platform.

- Periodic measurement of two widely used pesticides (Clomazone, MCPA) and nutrients in irrigation water (inflow and outflow), porous cups installed at two soil depths (20 and 70 cm, above and below the plough pan) and groundwater.

Water balance components

- Groundwater levels: piezometric wells equipped with pressure transducers (Keller, Switzerland).

- Surface water fluxes: irrigation inflow and outflow measurement devices, RBC long throated flumes (selfmade) equipped with sensors to measure the water level (pressure transducer by Keller, Switzerland).

- Surface water storage: field water level gauge, equipped with pressure transducers (Keller, Switzerland) positioned in small windowed tubes measuring ponding water level in the field.

- Data storage and transmission: piezometers, water flow measurement devices and water level gauges were connected by cable to dataloggers, acquiring and storing data at 5 minutes time step. Dataloggers wireless were connected to a PC placed in a ENR office. Data can be accessed remotely from UMIL offices.

CR1000 datalogger (Campbell Sci., USA)

- Soil water status:

  ✓ Tensiometers to measure soil water potential at a depth of 10 cm (to monitor soil water status for computing water balances)

  ✓ Field water tubes (selfmade) to assess the water table depth (to manage irrigation in the AWD fields).
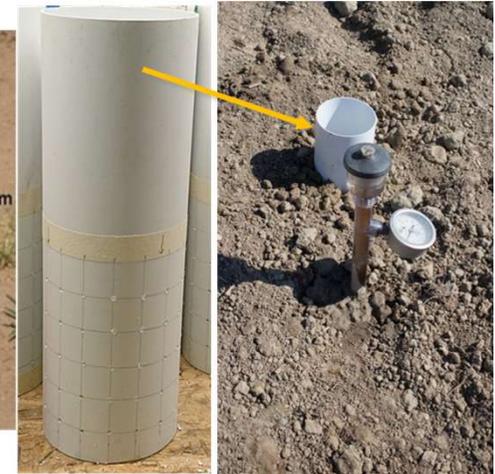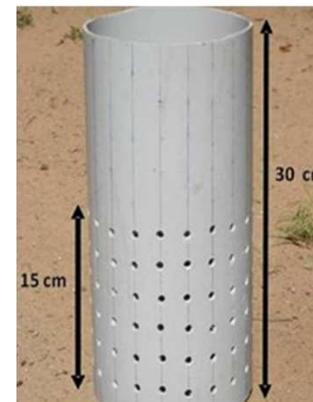
RESULTS

Water balance → **2019 in this presentation**

- Relative Water Supply (RWS), Water Productivity (WP)

Agronomic sustainability → **2019 and 2020 in this presentation**

- Yield and rice grain quality

Environmental sustainability → **2019 in this presentation**

- Pesticides potential pollution
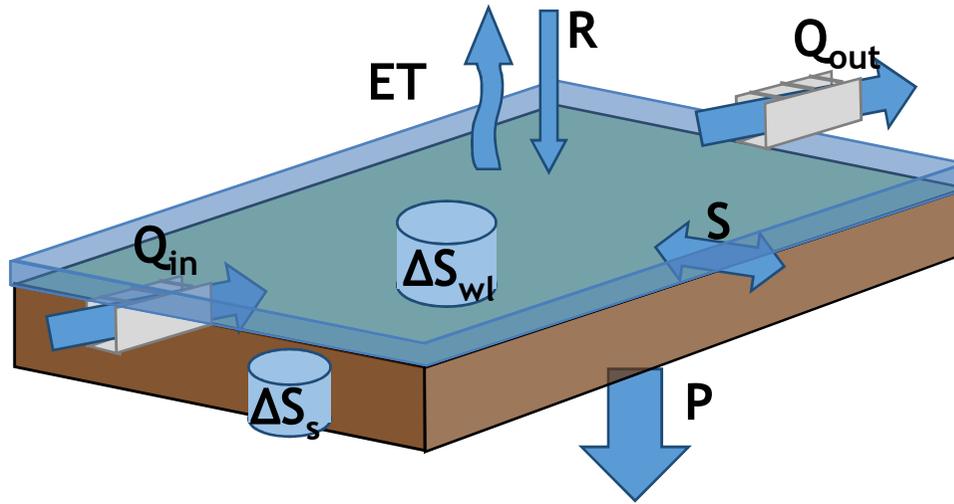- Nutrient potential loss

Water balance components
(Daily time step)

$$\Delta S_s + \Delta S_{wl} = Qin - Qout + R - ET + SP$$

Measured (red box)

Estimated (green box)

ΔS_s (mm) = Soil water storage variation → soil water status sensors

ΔS_{wl} (mm) = Water level variation → field water level sensor

Q_{in} (mm) = Irrigation inflow → flow meter

Q_{out} (mm) = Irrigation outflow → flow meter

R (mm) = Rainfall → agro-meteorological station (already installed at ENR-CRR)

ET (mm) = Evapotranspiration → FAO-56, Kc for rice measured in previous experiments

SP (mm) = Seepage and Percolation → residual term of the water balance

Water balance components, RWS, WP (2019)

	WFL	DFL	AWD
Rainfall (R, mm)	185	200	185
Net surface irrigation (Q_{IN}-Q_{OUT}, mm)	2941	2647	2389
Evapotranspiration (ETc, mm)	654	635	653
Residual term (SP, mm)	2462	2231	1938
Relative Water supply RWS (-)	4.78	4.48	3.94
Water Productivity (kg/m³)	0.36	0.39	0.44
Average water table depth (m) over the season [and period 01/07 – 31/08]	-0.80 [-0.16]	-0.86 [-0.16]	-0.80 [-0.16]

- Due to the **high soil variability** in the platform (shown in **the following slide**), the difference in measured water balance terms could not be totally explained by the irrigation strategy adopted.

- To generalize the results, **a Darcy-type hydrological model** was developed, calibrated using the measured data 2019, and used to compute the water balance terms by **considering soil properties observed in the WFL plot**.

Soil variability
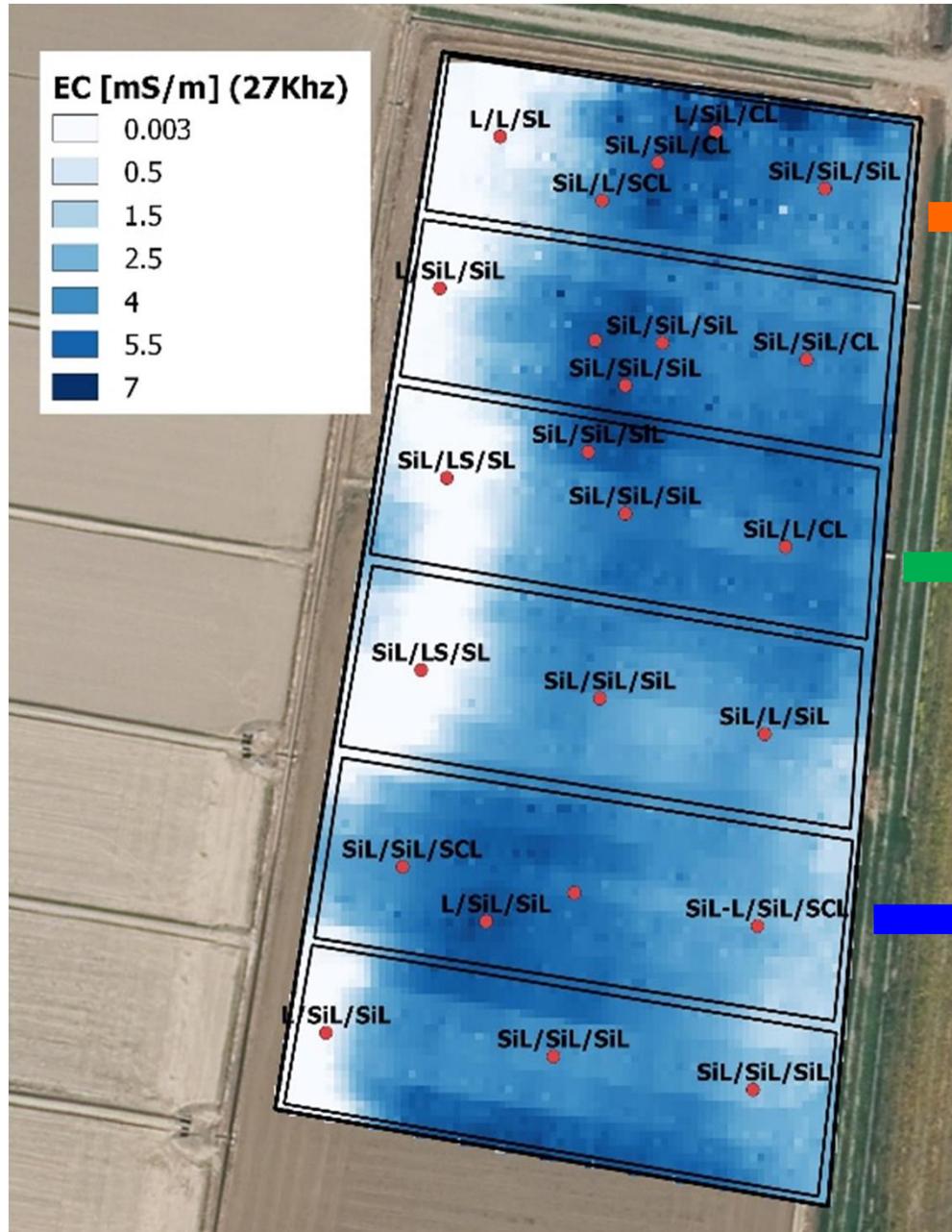
EC soil electrical conductivity map (mS/m) from measurements acquired at 64 kHz and soil textures measured at three depths (20, 40, 60 cm)

Yield components 2019-2020

Water management	Final plant (plants/m^2) Mean	Bonf.	Spikeles/panicle (n°) Mean	Bonf.	Sterility (%) Mean	Bonf.	1000 seeds (g) Mean	Bonf.
WFL	672	a	91	b	11.1	b	29.0	b
AWD	694	a	98	a	13.5	a	28.5	c
DFL	557	b	95	ab	11.6	b	29.8	a
		***		*		**		***
N application (kg/ha)	Mean	Bonf.	Mean	Bonf.	Mean	Bonf.	Mean	Bonf.
0 N	538	b	91	b	8.63	c	29.7	a
100 N	674	a	94	ab	12.5	b	29.1	b
160 N	711	a	99	a	15.1	a	28.4	c
		***		**		***		***

n.s. = not significant   *=p<0.05; **=p<0.01; ***=p<0.001. ANOVA analysis with Bonferroni (post-hoc)

Final plant density, number of spikelets per panicle, sterility and 1000-seeds weight resulted to be statistically different among the water strategies during the two years.

Although values were tolerable, grain sterility was statistically affected by AWD strategy.

Rice quality 2019-2020

	Milled rice yield (%)		Head rice yield (%)		Chalkiness kernels (%)		Damaged kernels (%)	
Water management	Mean	Bonf.	Mean	Bonf.	Mean	Bonf.	Mean	Bonf.
WFL	72.3	a	64.7		2.61		1.16	
AWD	71.1	b	63.3		2.77		1.17	
DFL	71.9	b	62.3		2.14		1.15	
		***		n.s.		n.s.		n.s.
N application (kg/ha)	Mean	Bonf.	Mean	Bonf.	Mean	Bonf.	Mean	Bonf.
0 N	72.1		60.5	b	1.62	b	0.8	b
100 N	71.9		65.4	a	2.77	a	1.1	ab
160 N	71.9		66.1	a	3.13	a	1.5	a
		n.s.		***		**		*

Milled rice yield was strongly affected by the water management.

Inorganic As values were under 0.20 mg/kg threshold (EU Commission Regulation 2015).

	As(III)+As(V) mg kg^{-1}		DMA(V) mg kg^{-1}		Cd (Tot) mg kg^{-1}	
Water management	Mean	Bonf.	Mean	Bonf.	Mean	Bonf.
WFL	0.16		0.07	b	0.01	ab
AWD	0.16		0.06	b	0.02	a
DFL	0.17		0.09	a	0.01	b
		n.s.		**		**

n.s. = not significant; *=p<0.05; **=p<0.01; ***=p<0.001. ANOVA analysis with Bonferroni (post-hoc)

Weed composition 2019

160 N without herbicide application sub-plot
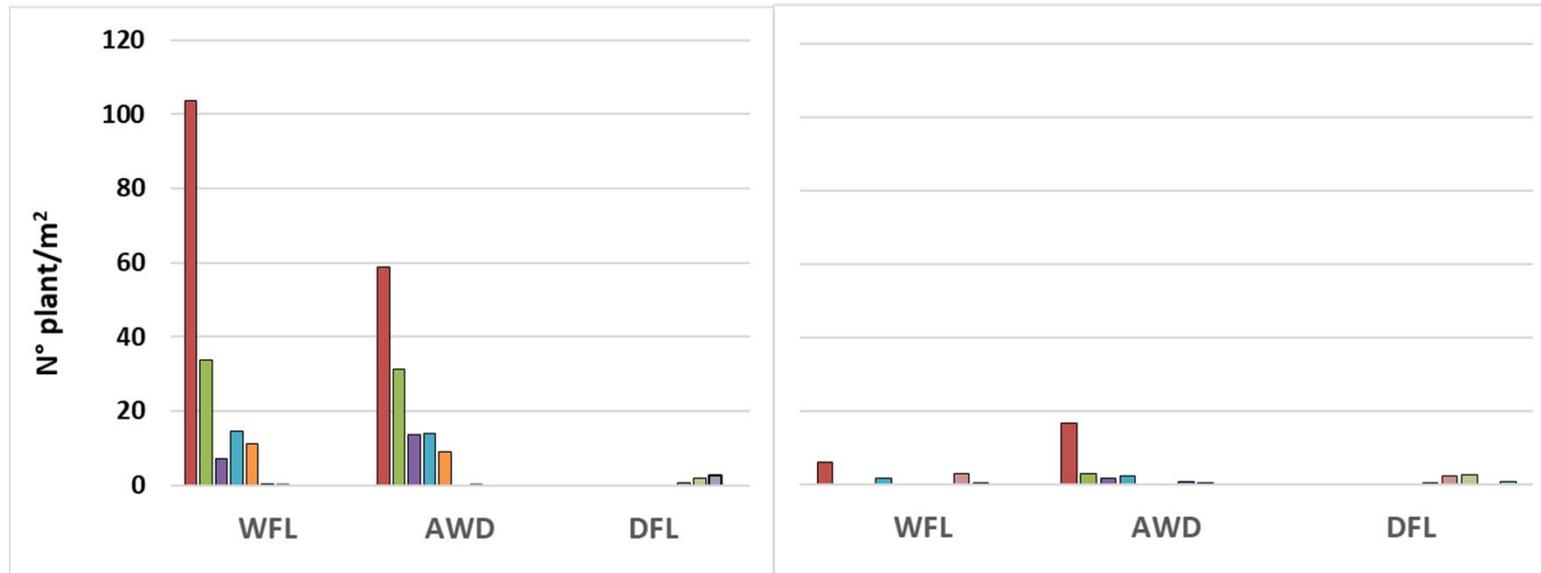
The AWD irrigation strategy in 2019 showed the highest number of weed species, but the number of individuals was similar to the other two strategies.

Weed composition 2020

160 N without herbicide application sub-plot
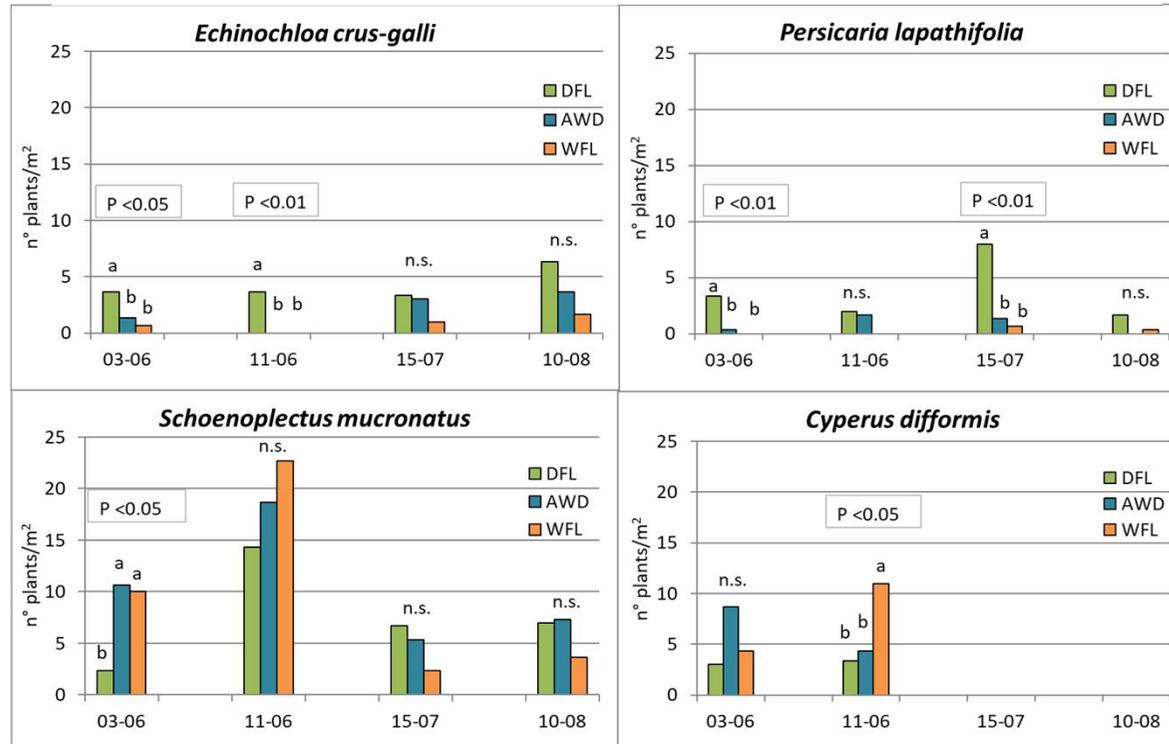
ANOVA analisys with LSD (post-hoc)

In 2020, no statistical differences were found between AWD and WFL for *Echinochloa crus-galli* and *Persicaria lapathifolia*.

AWD and WFL showed a higher number of *Schoenoplectus mucronatus* and *Cyperus difformis* (aquatic plants) compared to DFL.

Disease incidence 2019-2020

	Blast		Brown spot	
	IRRI Scale (0-9)		*IRRI Scale (0-9)*	
Water management	Mean	Bonf.	Mean	Bonf.
WFL	0.16		0.08	
AWD	0.34		0.11	
DFL	0.22		0.01	
		n.s.		n.s.
Fungicide	Mean	Bonf.	Mean	Bonf.
With fungicide	0.16		0.05	
Without fungicide	0.32		0.08	
		n.s.		n.s.

n.s. = not significant; *=p<0.05; **=p<0.01; ***=p<0.001. ANOVA analysis with Bonferroni (post-hoc)

The irrigation strategy did not affect the blast and brown spot incidence for both years (2019 and 2020).

Although no statistical difference was found, blast affected more AWD than the other water management strategies.
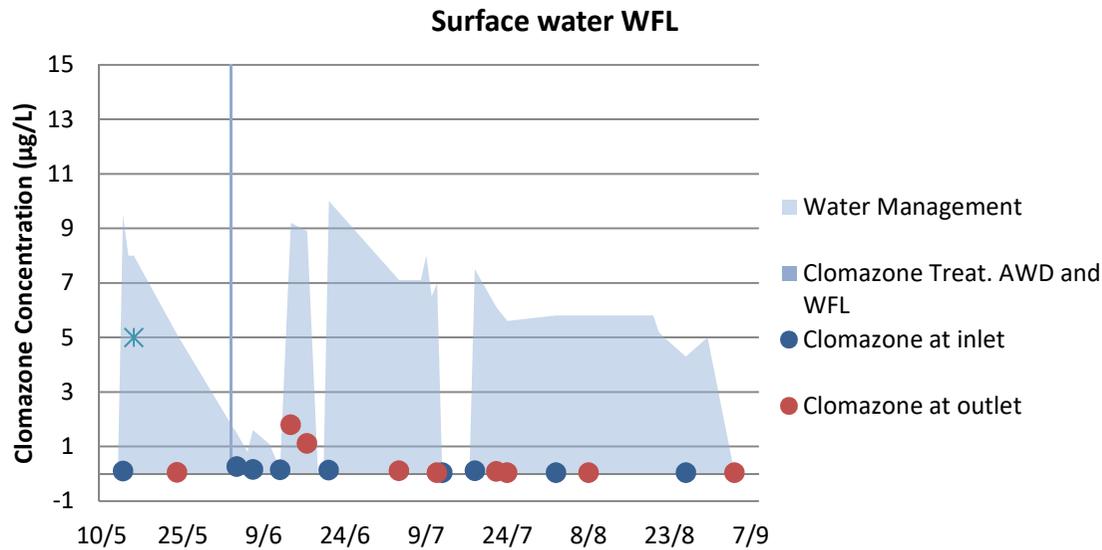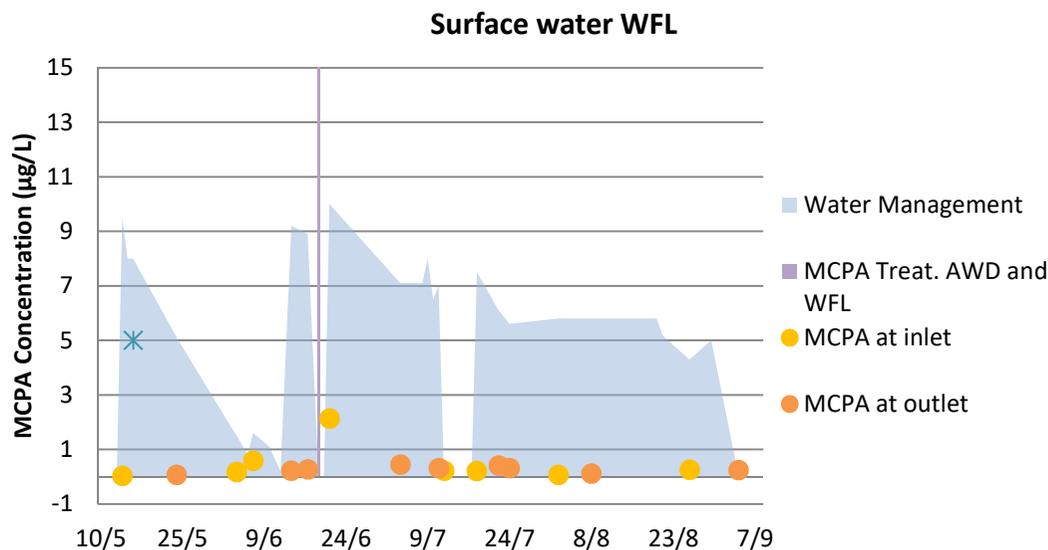
Surface water (MCPA and Clomazone)

- In all fields a concentration increase was observed after the specific herbicide treatment followed by a concentration decrease.

- Inflow contamination: negligible for Clomazone. More significant for MCPA (probably due to the wide use of the herbicide in rice areas upstream), but only in 2019: this may affect outflow concentrations.

- MCPA was slightly more mobile than Clomazone and this should lead to reaching the peak value sooner after treatment than for Clomazone.

- A factor to take into account is whether the treatment is applied on dry soil (DFL) or wet soil (AWD, WFL); this is because the active ingredient partitioning between soil and water and mass movement are influenced by the presence of water.

- Modelling (RICEWQ-VADOFT) is ongoing to test these hypotheses.

Surface water (MCPA and Clomazone)

Surface water WFL

(Clomazone Concentration (µg/L) vs date 10/5 – 7/9)

Legend:
- Water Management
- Clomazone Treat. AWD and WFL
- Clomazone at inlet
- Clomazone at outlet

Surface water WFL

(MCPA Concentration (µg/L) vs date 10/5 – 7/9)

Legend:
- Water Management
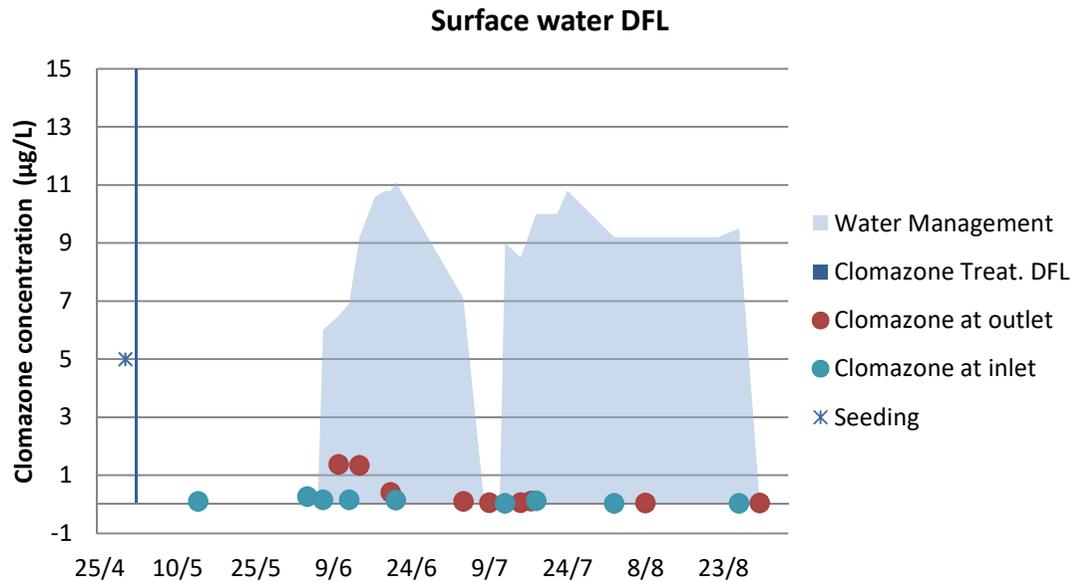- MCPA Treat. AWD and WFL
- MCPA at inlet
- MCPA at outlet

2019 WFL (similar behaviour in 2020) Clomazone: Concentration peak (1.8 ug/l) observed after treatment (vertical line). Negligible inflow concentrations.

2019 WFL MCPA: Concentration increase observed after treatment (vertical line). High inflow concentration peak (2.13 ug/l) may affect outflow.

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Surface water (MCPA and Clomazone)

Surface water DFL

Clomazone concentration (µg/L)

Legend:
- Water Management
- Clomazone Treat. DFL
- Clomazone at outlet
- Clomazone at inlet
- ✳ Seeding

Surface water DFL

MCPA Concentration (µg/L)

Legend:
- Water Management
- MCPA Treat. DFL
- MCPA at outlet
- MCPA at inlet
- ✳ Seeding

2019 DFL Clomazone: Concentration peak (1.4 ug/l) observed after treatment (vertical line). Negligible inflow concentrations.
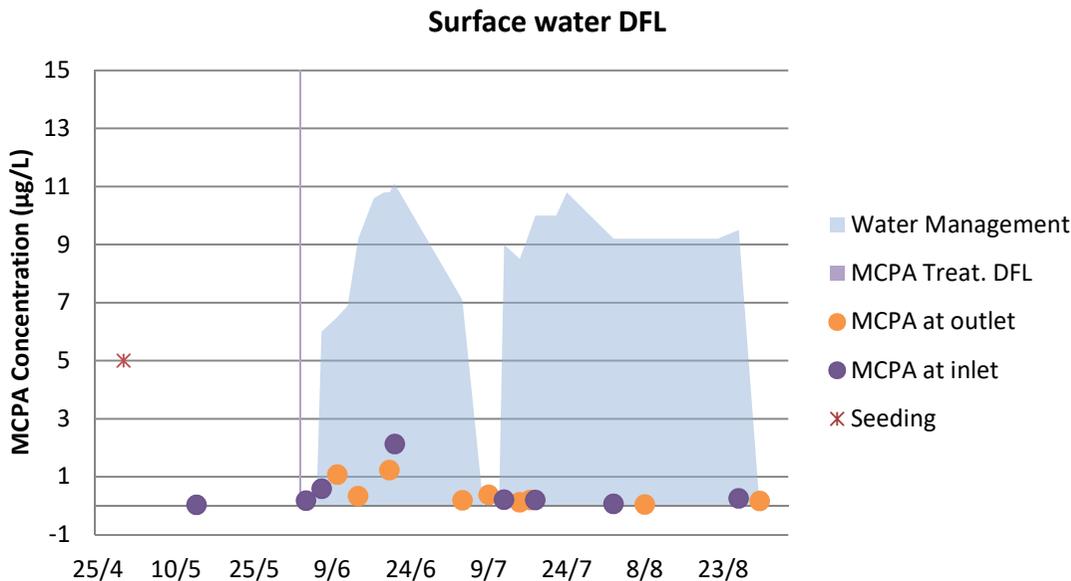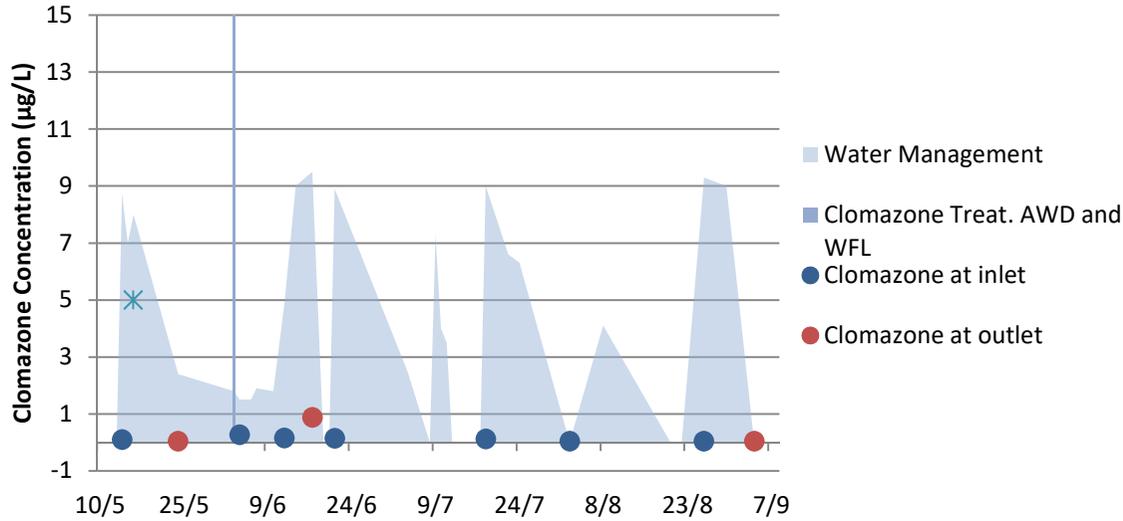
2019 DFL MCPA: Concentration peaks (1.02 and 1.23 ug/l) observed after treatment (vertical line). A.i. moved by water flow. High inflow concentration peak may affect outflow.

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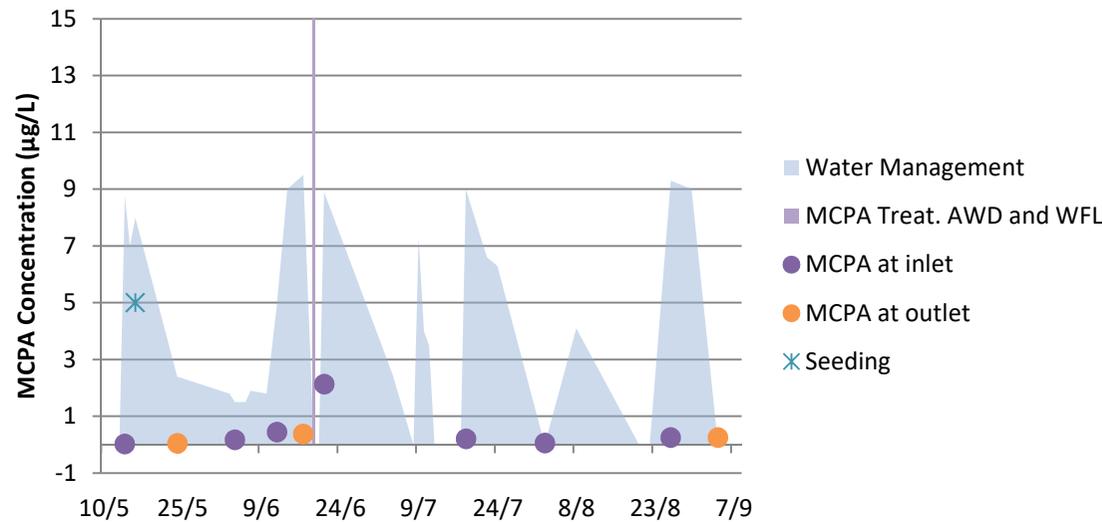# Surface water (MCPA and Clomazone)

Surface water AWD

2019 AWD (similar behaviour in 2020) Clomazone: Concentration peak (0.87 ug/l) observed after treatment (dashed vertical line). Negligible inflow concentrations.

2019 AWD MCPA: Concentration increase already before treatment. High inflow concentration peak may affect outflow.
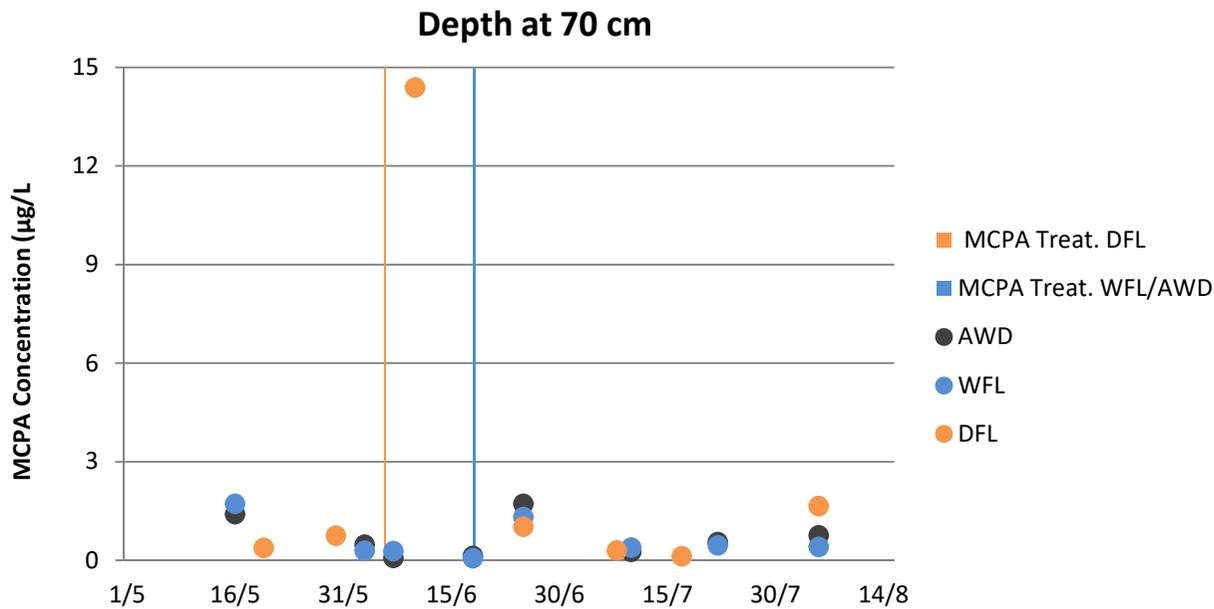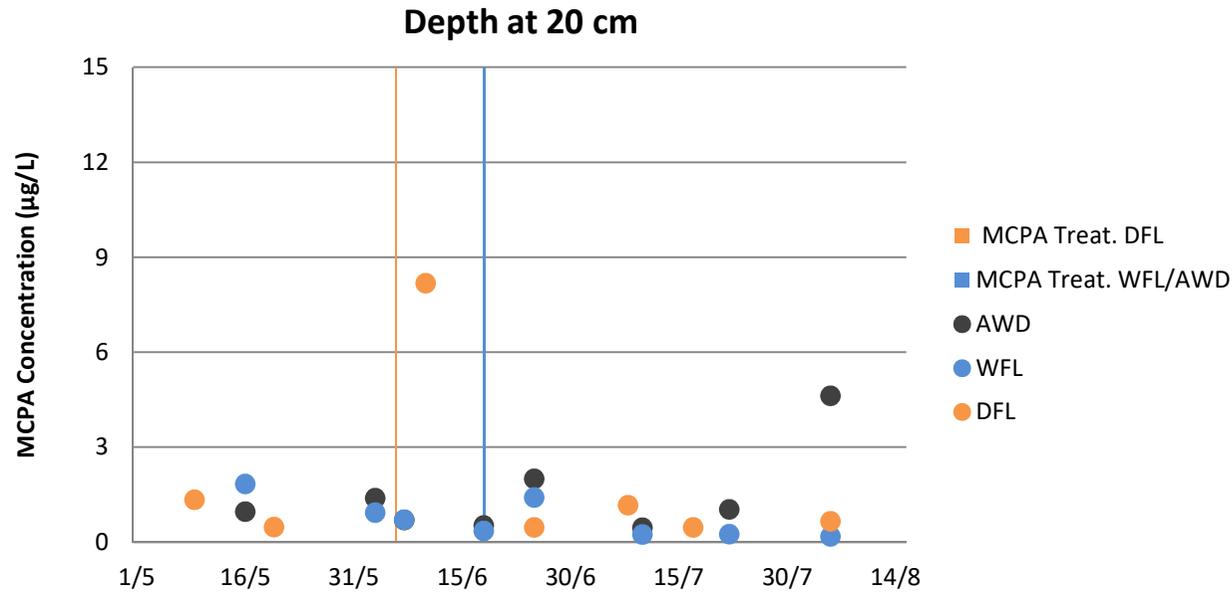
Soil solution (MCPA and Clomazone)

- Concentrations at 70 cm for Clomazone tended to be higher than at 20 cm. For both herbicides, an increase of concentration was observed after treatment, followed by a decrease over time. Taking into account that the water table was shallow during the irrigated season, lateral flux from adjacent fields can contribute.

- In 2019, concentrations peak soon (few days) after the treatment and despite a low percolation. This behaviour is hard to explain.

- Further efforts and investigations are put in place to better understand pesticide behaviour in the soil.
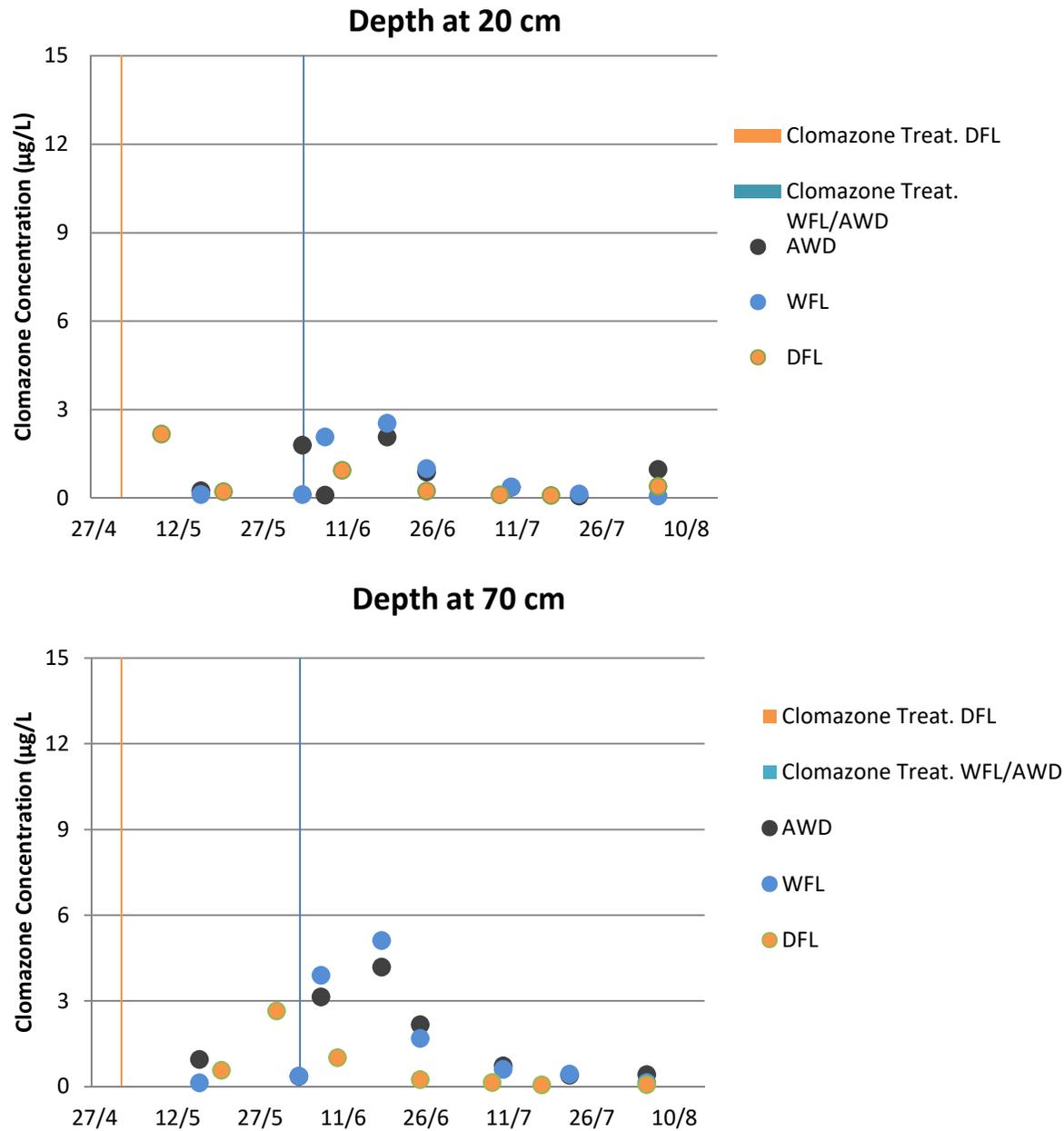
Soil solution (MCPA)

Depth at 20 cm

Concentrations at 70 cm tended to be higher than at 20 cm.

Soil solution (Clomazone)

Depth at 20 cm

Legend:
- Clomazone Treat. DFL
- Clomazone Treat. WFL/AWD
- AWD
- WFL
- DFL

Depth at 70 cm

Legend:
- Clomazone Treat. DFL
- Clomazone Treat. WFL/AWD
- AWD
- WFL
- DFL

Concentrations at 70 cm tended to be higher than at 20 cm. Concentration increase or peak after treatment. At 70 cm concentration decrease over time was more apparent.

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Groundwater (MCPA and Clomazone)

- In all irrigated fields, a lagged concentration increase was observed after the specific herbicide treatment followed by a concentration decrease. The time lag was due to the time needed for the herbicide to move along the soil profile and reach the groundwater table at the depth at which groundwater was sampled.

- Concentrations were found to be generally very low, with the exception of one single date for MCPA (2019). Further analyses are being conducted to investigate this anomalous value and results will therefore be shown in the near future.

CONCLUSIVE REMARKS

- Compared to WFL, a reduction of about 10% and 20% in net irrigation (Q_{inflow}-$Q_{outflow}$) was observed for the 2019 agricultural season when adopting DFL and AWD-safe, respectively. Results were obtained by combining field measurements and a Darcy-type hydrological model. AWD-safe showed the lowest RWS and the highest WP. Results for the 2020 agricultural season are under elaboration.

- Rice grain yield in AWD-safe was comparable to the other water management strategies.

- Although values collected were not high, sterility caused by a higher incidence of panicle blast was greater in the AWD-safe treatment rice.

- Cadmium level was statistically higher in the AWD-safe treatment.

- As to herbicides, the overall trend (i.e. a concentration increase immediately after the specific herbicide treatment followed by a concentration decrease) was the same for the 3 treatments, in suface water, soil solution and groundwater. Data for 2020 are under elaboration.

- Concentrations in soil solution samples tended to be lower in the WFL strategy, while in surface water samples they tended to be lower in the AWD (2019 data).

- The implementation of RICEWQ-VADOFT models will support the interpretation of the observed values.

Thanks for your attention!

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