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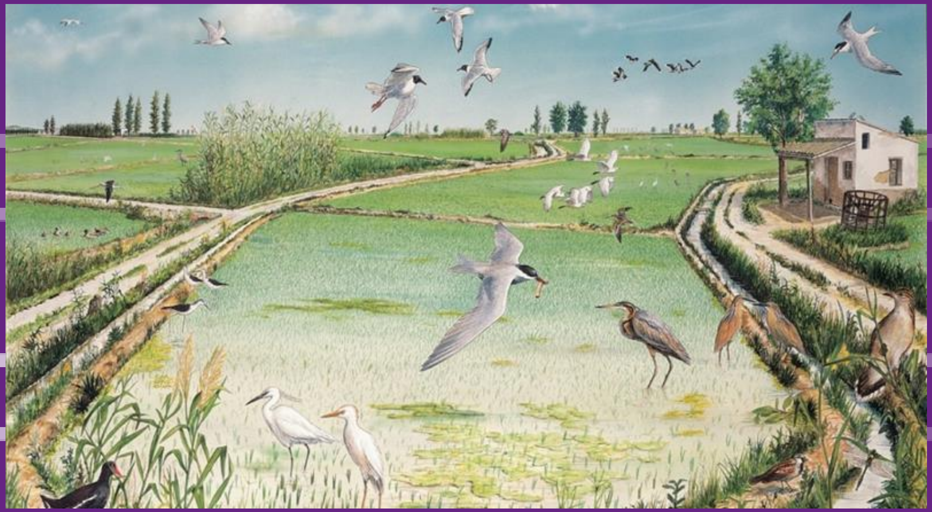
Towards climate resilient rice farming as a nature-based solution



Dr. Carles Ibáñez, Climate Resilience Centre, Eurecat - Technology Centre of Catalonia

"innovant amb les empreses"

The 4 pillars of CR-NBS rice production

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1. BIOECONOMY: organic/regenerative farming, towards zero pollution. Possibility to combine with aquaculture. Socioeconomic added value.

2. BIODIVERSITY: wildlife-friendly rice farming, compatible with rice production. Pest control by natural predators.

3. ECOSYSTEM SERVICES: the rice field as a green filter to improve water quality. Recreation and tourism, environmental education.

4. CLIMATE RESILIENCE: mitigation by reducing methane emissions and adaptation by reducing water use and increasing sediment inputs.

Towards climate resilient rice production

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- Rice fields occupy about **9% of the world's cropland** and their soils play an important role in the carbon cycle.
- Present rice cropping systems show a **low resilience against climate impacts** such as drought and at the same time contribute to global warming due to significant greenhouse gas emissions, since they **contribute to circa 10% of the global CH_4 emissions**.
- The high productivity of rice and the **flooding conditions of the crop promote carbon storage in the soil, but they can also produce greenhouse gas emissions**, such as carbon dioxide, methane, and nitrous oxide.
- The **introduction of more sustainable practices** is of paramount importance to make the crop more climate-resilient and contribute to climate mitigation. Practices such as the **alternate wetting and drying can achieve significant water savings and reduce up to 90% the methane emissions during the growing season**.
- However, **in temperate rice fields it has been shown that most of the methane emissions may occur in the post-harvest period**, and in this case the management of water and straw is very important to reduce the global warming potential of the crop.
- At the same time, the change of farming practices can be the base to **develop carbon farming and agri-environmental schemes** to economically support rice farmers to carry out the transition towards a climate-resilient rice production.

Methane has accounted for roughly 30 per cent of global warming since pre-industrial times and is proliferating faster than at any other time since record keeping began in the 1980s

The Global Methane Pledge announced today at COP26 in Glasgow, UK, commits signatories to reducing their overall emissions by 30 per cent by 2030, compared with 2020 levels.

Reducing the GWP and water use of the rice crop

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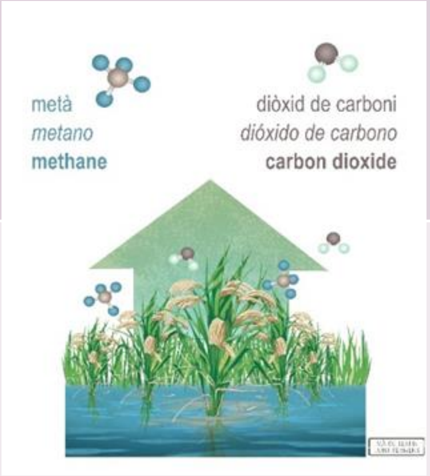
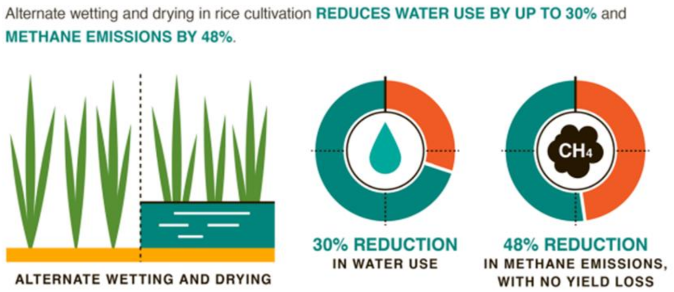
Impact of/on CC		Measure	Strategy	
Water scarcity Sea level rise Increase of salinity	Water and salinity stress	Adaptation	• Reduce water consumption • Salinity tolerant cultivars	
GHG (CH_4) emissions from rice		Mitigation	Shorter flooding periods	• Alternate wetting and drying (AWD) • Midseason drainage period
			Straw management/ winter flooding	• Incorporation vs non-tillage • flooding vs non-flooded winter season





Results from experimental research in the Ebro Delta

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PLOS | ONE

RESEARCH ARTICLE

Neglecting the fallow season can significantly underestimate annual methane emissions in Mediterranean rice fields

Maite Martínez-Eixarch[1]*, Carles Alcaraz[1], Marc Viñas[2], Joan Noguerol[2], Xavier Aranda[3], Francesc Xavier Prenafeta-Boldú[3], Jesús Antonio Saldaña-De la Vega[1], Maria del Mar Català[4], Carles Ibáñez[1]

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Plant Soil
https://doi.org/10.1007/s11104-020-04809-5

REGULAR ARTICLE

The main drivers of methane emissions differ in the growing and flooded fallow seasons in Mediterranean rice fields

Maite Martínez-Eixarch · Carles Alcaraz · Marc Viñas · Joan Noguerol · Xavier Aranda · Frances-Xavier Prenafeta-Boldú · Mar Català-Forner · M. Siobhan Fennessy · Carles Ibáñez

Received: 2 July 2020 / Accepted: 14 December 2020

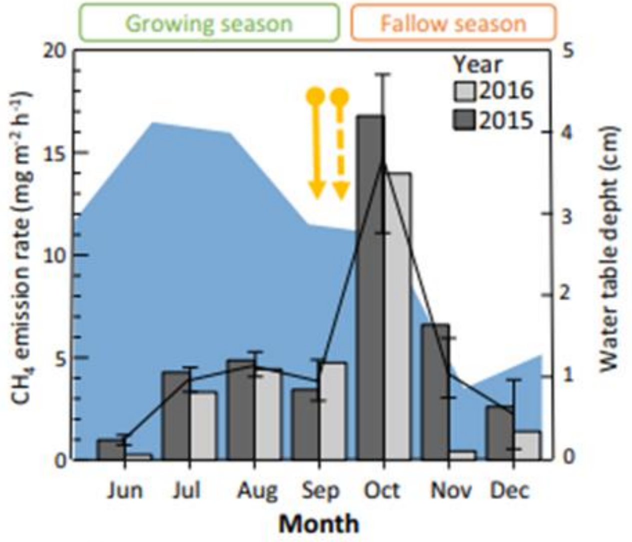

Fig. 3 Mean monthly CH_4 emissions rates in rice fields in Ebre Delta over the growing (June to September) and flooded fallow (October to December) seasons in years 2015 and 2016. Columns indicate monthly mean emissions within each year and line represent the two-year monthly emission rates. Blue shaded area represents water level (monthly means across rice fields and years). Solid arrow represent harvest (September) and dashed arrow straw incorporation (in early October). Fields are sown from late April to early May (not represented in the Figure)

Main conclusions: two thirds of the CH_4 is emitted in the fallow season. Edaphic factors exert more influence during the growing season whereas agronomic factors have a higher impact in the fallow.

Results from experimental research in the Ebro Delta

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ELSEVIER

Multiple environmental benefits of alternate wetting and drying irrigation system with limited yield impact on European rice cultivation: The Ebre Delta case

Maite Martínez-Eixarch[a,*], Carles Alcaraz[a], Mercè Guàrdia[a], Mar Català-Forner[b], Andrea Bertomeu[b], Stefano Monaco[c,1], Nicole Cochrane[d], Viktoria Oliver[d,e], Yit Arn Teh[d,e], Brigitte Courtois[f], Adam H. Price[d]

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[c] CREA - Council for Agricultural Research and Economics, Research Centre for Cereal and Industrial Crops, SS 11 km 2,500, 13100 Vercelli, Italy
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[f] CIRAD - Centre de coopération internationale en recherche agronomique pour le développement, UMR AGAP, Avenue Agropolis, TA A-108/03, 34398 Montpellier, France

Main conclusions: AWD significantly reduced CH4 emissions and the GWP by 90% being such a large mitigation capacity explained by the negligible N2O emissions found in both water treatments.

Table 5
Marginal means (± standard error) of the seasonal CH_4, N_2O, CO_2 and GWP in both water treatments, AWD and PFL, in Gleva cultivar in the two years of the study (2016 – 2017) and ANOVA of the effect of water management (WM), year (Y) and their interaction (WM x Y). The asterisks indicate significance of the factor at 0.05 (*), 0.01(**) and 0.001 (***) levels.

Year	WM	CH_4(g m^{-2})	N_2O(g m^{-2})	CO_2(g m^{-2})	GWP(g CO2eq m^{-2})
2016	PFL	1.85 ± 0.66	0.007 ± 0.006	101.70 ± 12.90	53.66 ± 16.86
	AWD	0.17 ± 0.01	0.003 ± 0.003	42.91 ± 12.90	5.50 ± 0.56
2017	PFL	6.98 ± 1.05	-0.001 ± 0.000	161.08 ± 26.76	195.11 ± 29.53
	AWD	0.32 ± 0.16	-0.003 ± 0.003	90.73 ± 28.75	8.02 ± 4.94
ANOVA					
Factor		$F_{1,8}$	$F_{1,8}$	$F_{1,8}$	$F_{1,8}$
Year		17.68 * *	3.40	6.13*	17.55 * *
WM		44.34 * **	0.73	8.89*	46.86 * **
Y x WM		15.76 * *	0.030	0.07	16.35 * *

Plant Soil
https://doi.org/10.1007/s11104-021-05234-y

REGULAR ARTICLE

Effect of post-harvest practices on greenhouse gas emissions in rice paddies: flooding regime and straw management

María Belenguer-Manzanedo · Carles Alcaraz · Antonio Camacho · Carles Ibáñez · Mar Català-Forner · Maite Martínez-Eixarch

Received: 25 May 2021 / Accepted: 15 November 2021

Main conclusions: avoiding winter flooding greatly reduced CH4 emissions in the post-harvest and next growing seasons, while delaying straw incorporation prevented CH4 and CO2 emissions during post-harvest. None of the treatments increased N2O emissions.

Table 5 Annual characteristics of rice yield, GHG emissions, net GWP and GHG intensity (GHGI) under different post-harvest managements

Treatments	Grain yield (kg grain ha^{-1})	Annual Fluxes (kg ha^{-1})			GWPs (kg CO_2eq ha^{-1} yr^{-1})			Net GWP (kg CO_2eq ha^{-1} yr^{-1})	GHGI (kg CO_2 eq $yield^{-1}$)
		CH_4	N_2O	NECB	CH_4	N_2O	NECB		
WFL-ESI	5158.2 a	258.9 ab	-1.02 a	1095.4 a	7249.4 ab	-270.9 a	4016.5 a	2961.2 b	0.57 b
WFL-LSI	5571.3 a	294.3 b	-0.53 a	1424.2 a	8239.4 b	-140.5 a	5221.9 a	2876.9 b	0.52 b
NWF-ESI	5370.1 a	153.2 a	0.48 a	1377.0 a	4290.8 a	127.8 a	5048.9 a	-630.4 ab	-0.12 ab
NWF-LSI	4894.2 a	155.8 a	-1.25 a	1973.4 a	4361.1 a	-330.4 a	7235.7 a	-3204.4 a	-0.65 a
Flooding (F)	ns	*	ns	ns	*	ns	ns	*	*
Incorporation (I)	ns	ns	ns	ns	ns	ns	ns	ns	ns
F x I	ns	ns	ns	ns	ns	ns	ns	ns	ns

"*" Represents significant difference at $P < 0.05$. "ns" represents no significant. Different letters mean significative differences ($P < 0.05$) between treatments. WFL-ESI, winter flooding and early straw incorporation; WFL-LSI, winter flooding and late straw incorporation; NWF-ESI, non-winter flooding and early straw incorporation; NWF-LSI, non-winter flooding and late straw incorporation

Developing a carbon farming scheme for Spanish rice fields and beyond

- The project BIORESILMED aims to start the first carbon farming scheme in Spanish (and European) rice fields.
- The first phase will be implemented in the Ebro Delta (21.125 ha, 19% of rice production in Spain).
- Total emissions in the Ebro Delta rice fields: 262.6 Kg CH_4/ha·yr (7.35 Mt eCO_2/ha = 155,269 Mt eCO2/yr).
- The scheme aims to reduce CH4 emissions both in the growing (AWD) and post-harvest season (straw and water management).
- The scheme has the potential to reduce the GHG emissions by half (at least).
- The main barriers for their success can be the price of the carbon credit from the voluntary market. If too low the farmers will not have an incentive to change the management of the rice field.
- There are also some technical/agronomic barriers such as the potential yield decline when AWD is applied to rice fields with saline soils.
- This type of scheme is potentially replicable to all European rice fields.
- These carbon farming schemes are starting to be implemented in Asia and United States too.
- The application of these schemes have other benefits, such as water saving and the reduction of Arsenic content in the rice grain, for instance. The potential impacts of changing the flooding regime on biodiversity must be investigated.

Enhancing rice field ecosystem services

Rice fields can deliver many ecosystem services to humans:

- Climate regulation: towards a negative global warming potential.
- **Water quality: towards net zero pollution, the rice fields as green filters.**
- Recreation: rice fields as semi-natural landscapes for leisure, ecotourism and education.
- Food provisioning: rice and other food items (fish, crayfish, etc.).
- Fiber: crop residues as materials for many uses.
- Coastal protection: sediment deposition to offset sea-level rise.

Rice fields as green filters

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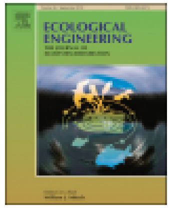

The role of rice fields and constructed wetlands as a source and a sink of pesticides and contaminants of emerging concern: Full-scale evaluation

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A R T I C L E I N F O

Keywords:
Rice field
Constructed wetland
Pesticides
Emerging contaminants
Risk assessment

A B S T R A C T

Urban, industrial, and agricultural development in river basins has resulted in the pollution of estuarine and coastal ecosystems with a great amount of organic microcontaminants (OMCs) such as pesticides and contaminants of emerging concern (CECs). This study takes the Ebro Delta as a case study to assess the increase or reduction of 25 OMCs in rice fields and one 86 ha constructed wetland (CW). Bentazone and MCPA were the most abundant pesticides in the rice-field drainage water, with a peak concentration of 21,318 and 938 ng/L respectively, whereas the greatest CEC concentrations were found for caffeine, benzotriazoles, and bisphenol A (20–71 ng/L, on average) in the rice irrigation water. Pesticide concentration increased after the irrigation water passed through the rice fields (from 102 to 1973 ng/L, on average), but CECs present in the irrigation water decreased by 37% (from 14 to 10 ng/L, on average). A mass balance study showed that the CW was capable of reducing OMCs by 67%. Risk assessment analysis showed that the cumulative hazard quotient for *Daphnia magna*, green algae, and fish was greater than 1 during several sampling campaigns for the rice-field drainage water, but the CW was capable of reducing it by 60–63%, resulting in values below 1, which indicates that the risk was not significant. The results thus indicate that rice fields reduce CECs, but increase pesticides, whereas the use of CWs seems to be a feasible nature-based solution to reduce the discharge of OMCs into estuarine and coastal areas.

Rice fields as green filters (chemicals)

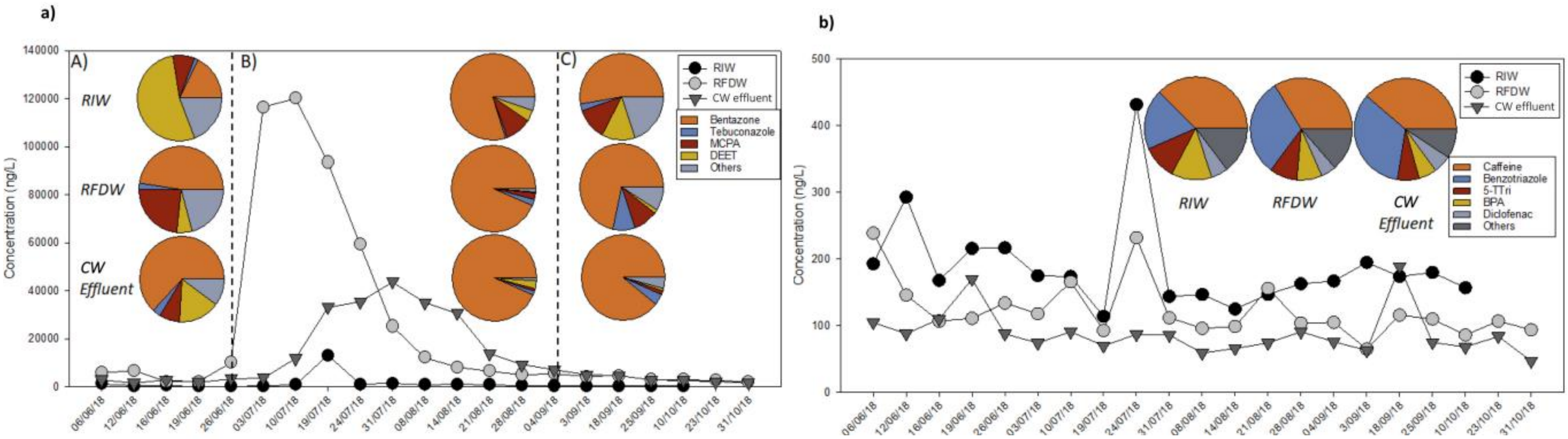

Fig. 2. Temporal trend of the concentration of pesticides (a) and CECs (b) in the RIW, RFDW and CW effluent. The pie chart shows the average abundance of pesticides (a) and CECs in each of the three sections. Pesticide chart shows 3 concentration periods, whereas concentration of pesticides in periods A and C was low, it increased in period B, following the pesticide treatments.

Rice fields as green filters (nutrients)

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Illa de Riu green filter

	% Efficiency NO_3	% Efficiency NO_2	% Efficiency NH_4	% Efficiency PO_4	% Efficiency SiO_2
2015					
C1	81.25±3.5	86.71±1.3	80.08±2.7	12.45±14.6	26.99±2.6
C2	57.55±10.5	41.05±6.9	36.12±20.7	56.25±6.46	39.91±5.3
C3	55.17±10.7	63.66±6.3	55.80±13.2	74.21±3.8	72.30±8.5
Total	96.59±0.8	97.25±0.6	96.16±1.3	90.95±1.8	88.03±3.6
2016					
C1	77.86±9.5	88.38±3.2	65.62±10.4		16.20±20.7
C2	28.89±33.7	12.22±20.1	-36.72±17.6	22.23±19.7	25.35±11.9
C3	9.66±25.2	25.09±16.0	-58.28±27.2	48.87±33.5	36.15±25.3
Total	93.89±1.6	92.76±3.1	25.52±22.6	49.38±17.9	67.27±12.7
2017					
C1	87.96±4.7	95.27±9.1	85.15±9.2	55.19±7.8	14.18±9.9
C2	24.40±17.3	-4.50±32.1	-56.03±32.1	-50.39±61.0	23.03±8.7
C3	13.85±13.1	23.57±20.0	10.82±20.0	19.77±17.7	-4.33±26.5
Total	82.29±9.4	95.82±5.2	89.35±5.2	63.72±11.3	38.78±10.8
TOTAL	**90.92±3.9**	**95.28±1.9**	**70.34±9.7**	**68.02±10.4**	**64.69±8.9**

L'Embut green filter

	% Efficiency NO_3	% Efficiency NO_2	% Efficiency NH_4	% Efficiency PO_4	% Efficiency SiO_2
2015					
C1	71.21±6.8	72.69±10.0	84.10±4.9	50.84±5.9	15.11±1.9
C2	59.39±13.8	55.93±6.1	-43.10±71.2	27.30±11.0	57.15±12.0
C3	-48.08±42.6	-4.85±±31.0	-71.08±49.9	48.05±10.6	10.70±15.8
Total	85.79±7.1	89.844.4	63.34±	78.36±8.0	69.40±9.8
2016					
C1	74.00±9.3	80.79±5.5	74.33±10.7	50.44±11.8	-8.67±16.1
C2	31.19±16.8	46.82±13.3	23.81±20.5	20.28±12.6	41.70±10.8
C3	-8.70±22.5	-56.70±63.6	-7.06±19.	9.37±21.4	36.96±9.0
Total	75.6315.8	79.66±9.6	84.27±5.3	76.04±5.9	61.27±7.9
2017					
C1	69.96±23.3	87.93±3.0	33.47±13.8	65.08±9.8	-8.23±14.8
C2	47.55±16.7	33.51±19.1	68.26±8.5	25.40±14.1	28.33±6.3
C3	19.46±18.3	28.89±8.4	28.82±9.5	17.30±2.9	31.38±7.3
Total	92.18±5.7	95.79±1.3	87.61±2.9	81.56±3.7	47.36±8.3
TOTAL	**84.53±4.8**	**88.43±4.7**	**78.41±7.6**	**78.65±1.6**	**59.34±6.4**

Rice fields as biodiversity hotspots

Influence on Birds of Rice Field Management Practices during the Growing Season: A Review and an Experiment

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Abstract.—Most literature on birds and rice (*Oryza sativa*) focuses on the non-growing period and little is known about the influence of management practices during cultivation. A review found that the main factors affecting species composition and abundance in rice fields during the growing season were water level, flooding period, rice plant structure and size, and pesticide use. Highest bird density and diversity occurred at intermediate water levels (10-20 cm). Early flooding and late drying favored waterbird density and diversity, and the stopover of migrating species. Taller plants, at higher densities, reduced prey availability to most waterbirds but favored smaller species. Pesticides and herbicides have been shown to be toxic to birds and reduce food resources. A case study is presented for the Ebro delta, Spain. Three management schemes were compared: organic, agri-environmental and conventional. Bird density, biomass and diversity throughout the growing and non-growing seasons were determined in three consecutive years. Bird biomass, density and diversity averaged higher in the organic rice fields, but only biomass was significantly different. The higher biomass reflects the presence of a higher biomass of prey items (fish, invertebrates and macrophytes) in the organic rice fields, likely due to the lack of pesticides. Further research should focus on a quantitative assessment of the effects of specific management practices. *Received 22 October 2007, accepted 15 June 2009.*

Key words.—agri-environmental scheme, biomass, density, diversity, growing season, management practices, organic farming, rice fields, waterbirds.

Waterbirds 33 (Special Publication 1): 167-180, 2010

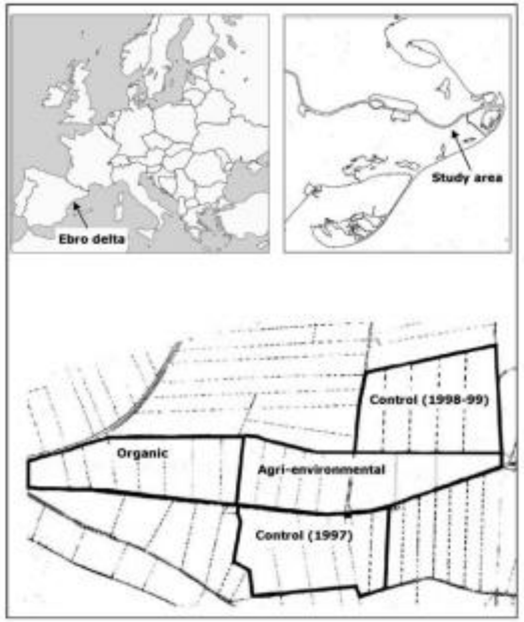
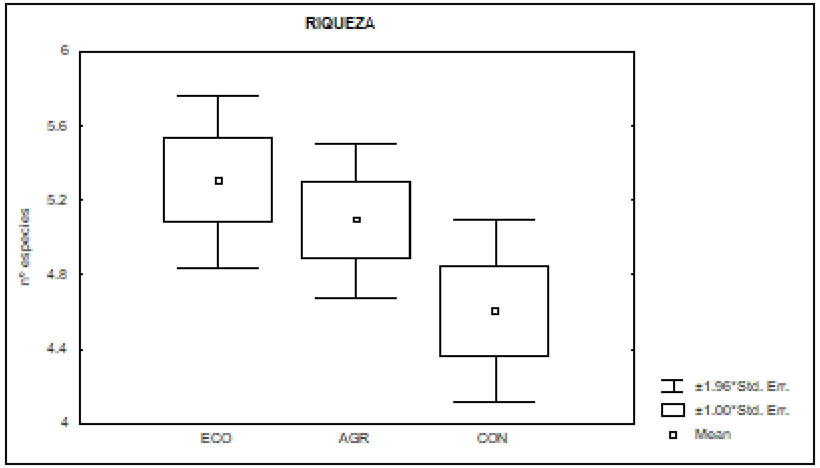
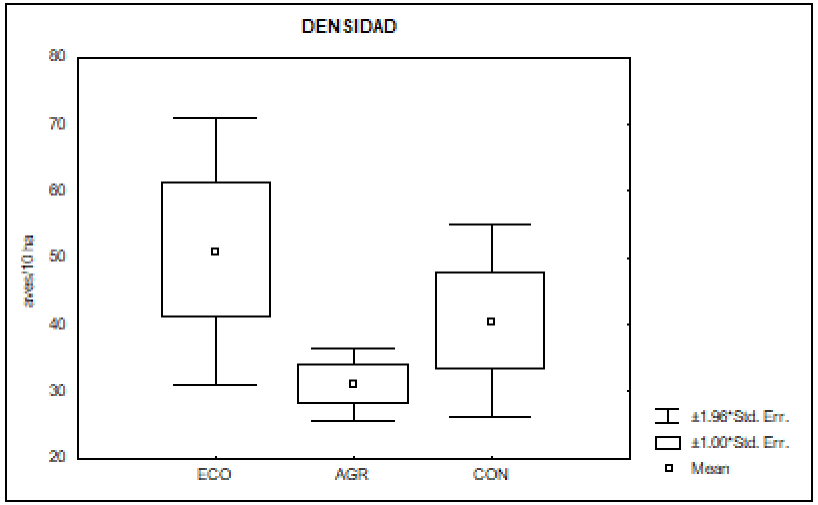


Figure 1. Study area location and detail of the experimental fields.





Rice fields as bioeconomy hotspots

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Conclusions: towards CR-NBS rice farming

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	PRESENT	FUTURE	MEANS
CLIMATE RESILIENCE	Rice significantly contributes to global warming and is vulnerable to climate change impacts (drought, etc.).	Rice significantly contributes to global cooling and is better adapted to climate change impacts.	Carbon farming schemes: Alternate wetting & drying, post-harvest management, sediment inputs, etc.
BIODIVERSITY	Intensification is leading to a decline in biodiversity.	Environmentally-friendly schemes help to recover biodiversity (birds, fish, etc.).	Wildlife-friendly rice farming, agri-environmental schemes. Consumer commitment.
ECOSYSTEM SERVICES	Intensification is leading to a decline in ecosystem services.	Environmentally-friendly schemes help to recover ecosystem services (water quality, food, fiber, etc.).	Research on the benefits of CR-NBS rice farming for humans. Payment for the provided services.
BIOECONOMY	Decreasing economic revenues for farmers.	Increasing revenues by diversification and higher added value of rice.	Organic farming, circular economy, ecotourism, etc. Public & private funding.

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