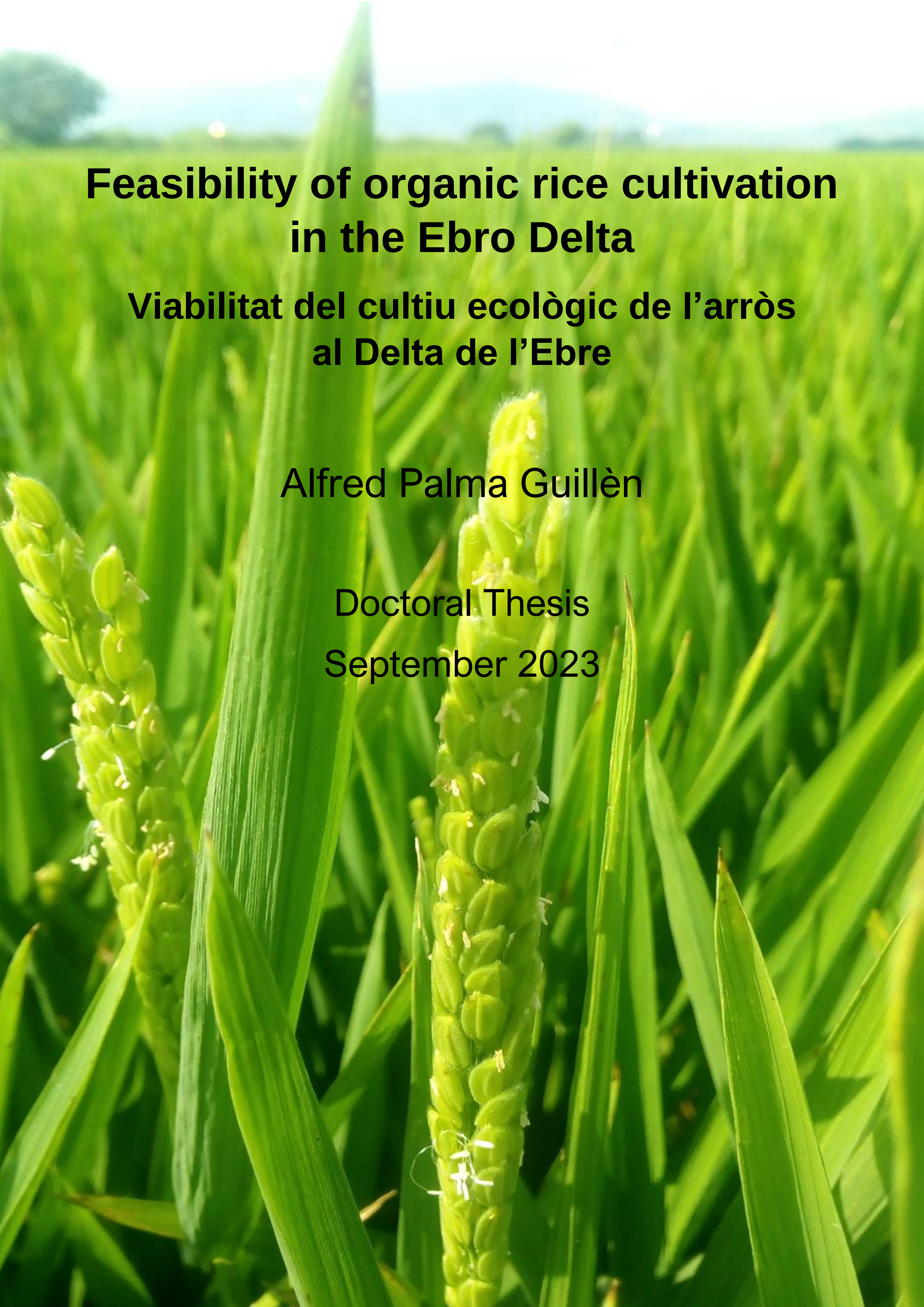
UNIVERSITAT DE BARCELONA

Feasibility of organic rice cultivation in the Ebro Delta

Alfred Palma Guillén



Feasibility of organic rice cultivation in the Ebro Delta

Viabilitat del cultiu ecològic de l'arròs al Delta de l'Ebre

Alfred Palma Guillèn

Doctoral Thesis

September 2023

Feasibility of organic rice cultivation in the Ebro Delta

Viabilitat del cultiu ecològic de l'arròs al Delta de l'Ebre

Thesis presented by Alfred Palma Guillén to obtain the Doctor degree from the Universitat de Barcelona. This thesis is framed within the PhD Program *Ecologia, Ciències Ambientals i Fisiologia Vegetal* corresponding to the period between 2019-2022 of the *Departament de Biologia Evolutiva, Ecologia i Ciències Ambientals*

This thesis has been conducted in the *Plant physiology section within the Evolutive Biology, Ecology and Environmental Sciences* Departament from the Biology Faculty (*Universitat de Barcelona*), under the supervision of Dr. Salvador Nogués Mestres and Dr. Xavier Serrat Gurrera

PhD student

Thesis supervisors

Alfred Palma Guillèn

Dr. Salvador Nogués Mestres

Dr. Xavier Serrat Gurrera

Barcelona, September 2023

“If you do the same over and over again

you cannot ever expect a different outcome”

Albert Einstein

AGRAÏMENTS (Acknowledgements in catalan)

Són 10 anys de la meva vida caminant pel territori del Delta de l'Ebre. Des del 2014, que vaig entrar a treballar al laboratori de l'IRTA fins al meu pas com Director E.O.R. per Agroserveis.cat, m'han permès créixer a tots els nivells professional i personalment, fent noves amistats i experiències que m'han inundat de ciència i naturalesa. En el transcurs de la Tesi, he conviscut amb la pandèmia de la Covid-19, el temporal Gloria i Filomena, la guerra d'Ucraïna, però finalment estic escrivint aquestes línies.

En primer lloc, vull agrair a la meva mare i al meu pare per tot el que m'han donat, pel recolzament emocional i perquè sempre han cregut i m'han ajudat amb tot el que he volgut fer en la vida. Molt especialment a les avies per tot el que m'han cuidat i tota la meva família pel seu suport moral.

En segon lloc, em sento profundament agraït del meu director de tesi, Salvador Nogués i el meu codirector, Xavier Serrat de la Universitat de Barcelona, per les immemorables hores que han dedicat en aquesta tesi i tota la paciència que han tingut per corregir versions i versions d'articles que no tenien el nivell suficient per enviar a les revistes. Els viatges a les ciutats de Bolonya i Milà que mai oblidaré, per tots els investigadors que vaig conèixer en el marc del projecte H2020 Neurice. També vull fer un reconeixement al catedràtic Miquel Salicrú per ajudar-me extraordinàriament amb el tractament estadístic de les dades amb la seva expertesa, professionalitat i paciència.

A l'empresa Agroserveis.cat SL, que ha sigut la meva casa, la meva família, i què durant 5 anys he compartit experiències i conegut a molta gent. Amb una especial atenció a qui ha sigut el meu mentor Àlex Navarro, que m'ha obert les portes del món professional de l'arròs i del Delta de l'Ebre. Gràcies a ell, he evolucionat professionalment i he acumulat un coneixement extens del cultiu de l'arròs, una visió global del sector arrosser i la indústria del seu voltant. Però sense deixar de banda els que han sigut companys i companyes durant aquests darrers anys: Xungo, Sisco, Joan Masià, Cristina, Dio, Joan Callizo, Guillem, Sergio, Àlex junior, Ferran, Karen... A Toni Bonafont, pujant des de Valencia per ajudar a l'execució del tractaments i seguiments dels assajos. A la meva amiga i companya de fatigues Ariadna Nadal, que m'ha ajudat en molt moments crítics. Moltes gràcies per tirar aquest projecte endavant.

Per altra banda, vull agrair a la Generalitat de Catalunya que a través de l'Agencia d'Ajuts Universitaris per la Recerca ha cofinançat aquest Doctorat Industrial. Encara me'n recordo quant vaig acabar el Batxillerat i sense fer la selectivitat vaig marxar a fer un cicle formatiu de grau superior a l'escola agrària d'Amposta per què tenia molt clar que jo no volia estudiar a la Universitat. Després d'una Enginyeria tècnica i un Màster oficial, he acabat fent el Doctorat. Les voltes que dona la vida, una cosa està molt clara, quant allò que fas t'apassiona els teus límits s'esvaeixen.

El Projecte Organic Delta Rice (ODR) ha suposat un gran repte personal a nivell acadèmic i professional. Sense el suport de tot el sector arrosser del Delta de l'Ebre, Arrossaires del Delta de l'Ebre, Nomen foods, Càmara

arrossera del Montsià, PRODELTA, Comunitat de regants, ADV Delta i I.R.T.A., aquest projecte no hagués agafat la magnitud i l’impacte mediàtic que ha tingut. Estic profundament agraït de l’acceptació que va tenir des de el primer dia de la presentació i del recolzament econòmic per millorar la competitivitat productiva del sector, aplicant recerca aplicada i que alhora m’ha servit per nodrir de dades, moltes dades, la meva tesi Doctoral.

Vull agrair especialment a Finca la Palma, al Marqués Carlos Alzola per haver posat a disposició la seva explotació per realitzar els experiments durant 4 anys. També agrair als treballadors de la finca: Lluís (regador) i Sisquet (maquinista) per haver cuidat els camps experimentals i avisar de quant sorgia algun imprevist. Aprofito per agrair a tots l’equip de birbadors: Ahlamdar, Reinaldo, Gerarad, Sergio, Juan, per aguantar tantes hores al sol fent aquesta feina dura i pesada.

Vull agrair a l’Estació experimental I.R.T.A., a Mar Català per oferir-se a col·laborar des del primer dia. Va oferir la sala de reunions per la primera presentació del Projecte ODR a l’Abril del 2019, i per haver-me donat suport moral i logístic en totes les coses que li he demanat. En segon lloc, al meu amic i investigador Néstor Pérez per tota l’ajuda, consells i suport endavant per tirar endavant. Sense deixar de banda tot l’equip de l’arròs, els quals han sigut companys i companyes meus durant els anys que vaig treballar a l’I.R.T.A.: Eva, Núria, Andrea, Oriol, Sisco, Pili. Ni tampoc l’equip de Protecció Vegetal Sostenible: Maria Teresa Martínez que va ser cap meva i em va ensenyar molta metodologia científica, em va transmetre il·lusió per treballar i em despertar la meva faceta d’investigador. A Jose Miguel perquè sempre tenia una somriure i als companys Rafel i Xemi.

Vull agrair a la cooperativa de llavors Copsemar i les empreses de productes fitosanitaris que han participat al projecte i les quals no puc anomenar per confidencialitat. Gràcies a elles, també s’ha pogut assajar diversos productes per producció ecològica d’arròs i han aportat el seu granet de sorra econòmic per cobrir les despeses dels 4 anys de recerca, en som més de 15 empreses diferents. A qui si puc nombrar és a Carlos Fornós (Xotis), de la empresa Ebrecultius, que ha col·laborat cedint la maquinaria per la sembra en sec, el conductímetre o qualsevol consulta relacionada en l’arròs.

Vull agrair al Departament d’Acció Climàtica, Alimentació i Agenda Rural pel seu suport. Per interessar-se pel projecte i per venir a conèixer al camp personalment: Jordí Giné, Gemma Galimany, Jesús Gomez, Neus Ferreté, Anna Goutan, Silvia Marco, Àlvaro, Xavi i David. També vull agrair a Gemma Murillo de l’oficina de dejeccions ramaderes de Lleida, per la cessió de l’aparell N-Tester per mesurar el nivell de clorofil·la de les fulles. A l’Escola agrària d’Amposta, per oferir-me a fer un curs d’arròs ecològic de docent a l’escola on em vaig formar.

Als meus amics i amigues que m’han donat suport incondicional: Deniz, Joan, Manel, Carlos, Mari, Rafa, Toni i Sarah.

Gràcies a tots i totes

ABSTRACT

In the Mediterranean basins, rice is mainly cultivated in wetland protracted areas such as deltas and marshlands, where it is the prevailing crop due to the high soil salinity. This salinity is continuously increasing for reasons such as the soil subsidence, the rising sea level, the reduction in yearly precipitations and the increase of temperatures, which are intensified due to the effects of climate change. Rice is one of the most salt sensitive crops (Horie et al. 2012; Munns and Tester 2008). Spain is the second European country in terms of rice production (30%) just after Italy (FAOSTAT 2023). Andalucia represents the main Spanish rice production área (38,997 ha, 336,154 t, 8,620 kg/ha), followed by Extremadura (19,038 ha, 155,559 t, 8,171 kg/ha), Catalonia (20,769 ha, 151,157 t, 7,278 kg/ha), Valencia (15,769 ha, 118,425 t, 7,510 kg/ha), Aragón (6,083 ha, 32,969 t, 5,420 kg/ha), Navarra (3,382 ha, 18,902 t, 5,589 kg/ha), Murcia (96 ha, not available) and Baleares (61 ha, 317 t, 5,200 kg/ha) (MAPA 2020). In Spain, the main yield-limiting factors in organic rice production is weed control (Delmotte et al. 2011a; Reddy et al. 2023), blast rice control (Agbowuro et al. 2020a; Hoosain et al. 2013) and organic fertilization (Maimunah et al. 2021).

Weed control is one of the major challenges for sustainable rice cultivation (Farooq et al. 2023; Liu et al. 2023; Rajkhowa et al. 2023). Weeds proliferate in cultivated paddy fields, this happens because they are created by converting drylands to artificially flooded wetlands, which therefore lack native flora adapted to flooding (Osuna et al., 2012). With *Echinochloa* spp*., Leptochloa* spp*., Oryza sativa* f. *spontanea* (red rice)*, Cyperus* spp*., Heteranthera* spp. and *Alisma plantago-aquatica* are the main weeds in Spanish paddy fields (Osuna et al. 2012). Culture rotations would help reducing weed problems in organic rice cultivation, although not successfully achieved in salinized paddy fields.

Rice blast disease (*Magnaporthe grisea* (Herbert) Barr, anamorph *Pyricularia grisea* Sacc., synonym *P. oryzae* Carava) represents one of the worst rice diseases (Ebbole 2007; Nalley et al. 2016; Sakulkoo et al. 2018; Tan et al. 2023b). Introducing management strategies using synthetic fungicides has proven to be ineffective under field conditions for long-term blast control (Deng and Naqvi 2019). Sulphur is a common and highly effective fungicide that has been in use in one form or another for a long time (Khandagave 2023). Silica is known as an essential element for rice plants and is effective in controlling rice blast (Nakashima et al. 2001).

Nitrogen is an important factor that affects soil ecology and limits the availability of nitrogenous organic matter in agroecological systems (Hu et al. 2023). Optimized N fertilizer management achieved delayed senescence, higher canopy photo assimilation, higher N fertilizer use efficiency, and less N loss (Ma et al. 2023).

The main objective of this Thesis is to study the feasibility of organic rice cultivation in the Ebro Delta. The specific objectives are to investigate which non-chemical strategies can be used to reduce the number of weeds in paddy fields (chapter I), to assess the effectiveness of Sulphur or Silicon-based fungicides in controlling blast disease in different rice cultivars in Ebro Delta conditions (chapter II), and to evaluate the efficiency of organic fertilizers for organic rice production systems (chapter III):

Chapter I, reports some of the non-chemical weed control methods which can reduce weed pressure to levels similar to chemical herbicide treatments. Simple dry seeding was the best treatment for dry seeding, while stale seed bed and best performing planting conditions was the underwater seeding. Our findings demonstrated that dry seeding favoured grasses weeds such as *E. crus-galli*, *E. oryzoides*, while discouraging sedges and aquatic weeds. On the On the contrary, in water-seeding treatments, sedges and aquatic weeds (*S. maritimus*, *C. difformis* and *H. reniformis*) are favoured and grasses are still a problem in the paddy fields. Chapter II reports the effect of non-chemical fungicide treatments on different rice cultivars. The most blast-sensitive cultivar is Bomba. Rice cultivars with low blast sensitivity does not require the application of fungicides as varietal tolerance is enough. On the On the contrary, Sulphur treatments are effective in medium blast sensitivity varieties such as Argila, Guara or J. Sendra. We conclude that Sulphur (Thiopron, 82.5 % a.i. L-1, SC, UPL Iberica) at a 7.5 l·ha-1 dose has potential to help organic farmers control rice blast. In Chapter III, the chemical fertilizer showed the best results on grain yield and tillering, followed by the organic fertilizer named OPF. An organic fertilizer (OPF) has been tested for organic rice cultivation resulting only in a 17% yield reduction in front of chemical fertilization. This fertilizer formulation is granulated and adapts to the farmers equipment.

In conclusion, in this thesis we have demonstrated, for the first time, the feasibility of organic rice cultivation and added knowledge to weed management, fungus diseases and organic fertilization. The outcome of these study is important since it will contribute efficiently to organic rice cultivation in Ebro Delta.

RESUM DE LA TESI

En l’àrea mediterrània, l’arròs és principalment cultivat en zones humides protegides com deltes i aiguamolls, on és el cultiu predominant degut a l’elevada salinitat del sòl. L‘arròs és un dels cultius més sensible a la salinitat (Horie et al. 2012; Munns and Tester 2008). La salinitat del sòl, continua augmentant per moltes raons; la subsidència de la plataforma deltaica, l’augment del nivell del mar, la reducció anual de les precipitacions i l’augment mitjà de les temperatures, que es veuen intensificats per l’efecte del canvi climàtic. Espanya és el segon país europeu pel que fa a la producció d’arròs (30%), només darrera d’Itàlia (FAOSTAT 2023). Andalusia representa la principal zona productora (38,997 ha, 336,154 t, 8,620 kg/ha), seguida d’Extremadura (19,038 ha, 155,559 t, 8,171 kg/ha), Catalunya (20,769 ha, 151,157 t, 7,278 kg/ha), València (15,769 ha, 118,425 t, 7,510 kg/ha), Aragó (6,083 ha, 32,969 t, 5,420 kg/ha), Navarra (3,382 ha, 18,902 t, 5,589 kg/ha), Múrcia (96 ha, no disponible) i Balears (61 ha, 317 t, 5,200 kg/ha) (MAPA 2020). Els principals problemes que limiten la producció orgànica d’arròs són les adventícies (Delmotte et al. 2011a; Reddy et al. 2023), les malalties fúngiques (Agbowuro et al. 2020a; Hoosain et al. 2013) i la fertilització orgànica (Maimunah et al. 2021).

Les adventícies és un dels majors reptes de la producció sostenible d’arròs (Farooq et al. 2023; Liu et al. 2023; Rajkhowa et al. 2023). Les adventícies proliferen als arrossars conreats perquè aquests es creen normalment convertint les terres seques, en aiguamolls inundats artificialment, i no tenen flora autòctona adaptada a les inundacions (Osuna et al., 2012). Les principals adventícies als arrossars espanyols són: *Echinochloa* spp*.,* *Leptochloa* spp*.,* *Oryza sativa* f. *spontanea* (red rice)*,* *Cyperus* spp*.,* *Heteranthera* spp. i *Alisma plantago-aquatica* (Osuna et al. 2012). Les rotacions de cultius ajudarien a reduir les adventícies al cultiu ecològic de l’arròs, tot i que no s’ha aconseguit una rotació de cultius exitosa als camps salinitzats.

La Piriculariosis (*Magnaporthe grisea* (Herbert) Barr, anamorph *Pyricularia grisea* Sacc., synonym *P. oryzae* Carava) representa la pitjor malaltia que afecta a l’arròs a nivell mundial (Ebbole 2007; Nalley et al. 2016; Sakulkoo et al. 2018; Tan et al. 2023b). A demés, la gestió amb fungicides químics ha demostrat ser una estratègia ineficaç pel control de la malaltia a llarg termini en condicions de camp (Deng and Naqvi 2019). El sofre és un fungicida comú i mostra eficàcia durant molt de temps (Khandagave 2023). El silici és conegut com un element essencial de les plantes d’arròs i alhora, és efectiu pel control de la malaltia de la piriculariosis (Nakashima et al. 2001).

El nitrogen és un factor important que afecta l’ecologia del sòl i limita la disponibilitat de matèria orgànica en els sistemes agroecològics (Hu et al. 2023). La gestió optimitzada dels fertilitzants nitrogenats retarda la senescència, millora l’assimilació i eficiència de l’ús del nitrogen, així com una menor pèrdua (Ma et al. 2023).

L’objectiu principal d’aquesta Tesi doctoral és estudiar la viabilitat de la producció ecològica d’arròs al Delta de l’Ebre. Els objectius específics de la Tesi son investigar quines estratègies no químiques redueixen el nombre d’adventícies als arrossars (capítol I), l’avaluació de l’eficàcia dels fungicides amb una base de sofre o silici pel control de la malaltia de la piriculariosis en diferents varietats d'arròs del Delta de l'Ebre (capítol II) i l'avaluació de l'eficiència de fertilitzants orgànics per sistemes de producció ecològica d'arròs (capítol III):

El capítol I informa dels mètodes no químics pel control d'adventícies que poden reduir el nombre de plantes a nivells similars als herbicides. La sembra en sec simple, va ser el millor tractament per la sembra en sec, mentre que la falsa sembra acompanyada del trasplant, va mostrar el millor rendiment de gra en condicions de sembra en aigua. La sembra en sec afavoreix les adventícies de la família gramineae: *E. crus-galli*, *E. oryzoides*, mentre reprimeix altres de les famílies cyperaceae i pontederiaceae. Oposadament, les condicions de la sembra en aigua afavoreixen les adventícies de les famílies cyperaceae i pontederiaceae (*S. maritimus*, *C. difformis* i *H. reniformis*), mentre que la família gramineae contínua sent un problema als arrossars. El capítol II informa de l'efecte dels fungicides no químics en diferents varietats d'arròs. La varietat de major sensibilitat a piriculariosis és el Bomba. Les varietats amb menor sensibilitat, no requereixen fungicides ja que la tolerància varietal és suficient. Per altra banda, els tractaments amb sofre són efectius en varietats de mitja sensibilitat com Argila, Guara o J. Sendra. Concloem que el sofre (Thiopron, 82.5 % a.i. L^{-1}, SC, UPL Iberica) aplicat a una dosi de 7.5 l·ha^{-1}, és una eina potencial per ajudar als agricultors de producció ecològica d'arròs. El capítol III informa que el fertilitzant químic ha mostrat els millors resultats en producció i número de fillols, seguit del fertilitzant orgànic OPF. El fertilitzant orgànic OPF ha sigut l'únic a mostrar una reducció de producció del 17% en comparació amb el químic. La formulació en pellet del fertilitzant OPF, s'adapta als equips actuals d'aplicació dels arrossers.

Es conclou que s'ha demostrat per primera vegada la viabilitat de la producció ecològica d'arròs i s'afegeix coneixement del maneig de les adventícies, les malalties fúngiques i la fertilització orgànica. Els resultats son rellevants per que contribueixen a la sostenibilitat del Delta de l'Ebre.

TABLE OF CONTENTS

List of abbreviations

ACCASA	Acetyl coenzyme A
AEI	Spanish Ministry of Science and Innovation State Research
AGAUR	*Agencia d'Ajuts Universitaris per la Recerca*
ALS	Acetolactate synthase
Atm	Atmosphere
a.i.	Active ingredient
AXI	Drop size classification of nozzles
BBCH	Phenological states scale
CAP	Common Agricultural Policy of the European Union
CCPAE	Council Catalan Production Agriculture Organic
CEC	Caption exchange capacity
COPSEMAR	*Cooperativa de Productores de Semilla de Arroz*
COVID-19	Covid-19 coronavirus disease 2019
CYPDI	*Cyperus difformis* (L.)
DAS	Days after seeding
DBS	Days before seeding
DOP	*Denominació d'origen protegida "Arròs del Delta de l'Ebre"*
DP	Dustable powder formulation
DSC	Dry seed control
DSH	Dry seed with herbicide
DSI	Dry seed with supplemental irrigation
EC	Emulsifiable concentarte
ECHCRU	*Echinochloa crus-galli* (L) Beauv
ECHORY	*Echinochloa oryzoides* (Ard.) Fritsch
EU	European Union
FAO	Food and Agriculture Organisation of the United Nations
FAOSTAT	Statistics Division of FAO, the Food and Agriculture Organisation of the United Nations
FiBL	Forschungsinstitut für biologischen Landbau – Research Institute of Organic Agriculture, Switzerland
FSP	False seeding and planting

FSW	False seeding and seeding
G	Gram
GLM	Generalized linear models
GMOs	Genetically modified organisms
GPS	Global Position System
H	Hour
Ha	Hectare
HETRE	*Heteranthera reniformis* (Ruiz & Pavon)
i.e	Id est
IFOAM	Organics International: Formerly International Federation of Organic Agriculture Movements
IMPRORICE	Improvement rice varieties in front of Climate Change Project
Kg	Kilo gram
Km	kilometre
m	Metre
m^2	Square metre
m^3	Cubic metre
Mha	Million hectares
Mm	Millimetre
N	Nitrogen
Nº	Number
NFU	Nitrate fertilization units
$(NH_4)_2SO_4$	Ammonium nitrate
NO_3	Nitrite nitrate
OD	Oil dispersion formulation
ODR	Organic Delta Rice Project
OF	Over flooding technique
OM	Organic mature
OPF	Organic pellet fertilizer
P	Phosphorus
PAS	*Producció Agrària Sostenible* (Sustainable Agricultural Production)
PGPM	Plant Growth Promotion Mechanism

SAFA	Sustainability of assessment of food and agriculture systems
SC	Suspension concentrate formulation
SDS	Simple dry seed
SCPMA	*Scirpus maritimus* (L.)
V.EXP 1	Experimental cultivar rice
WG	Water dispersible granulates formulation
WP	Wettable granulates formulation
WSC	Water seed control
WSH	Water seeding and herbicide

List of figures

List of tables

GENERAL INTRODUCTION

GENERAL INTRODUCTION

1 Rice crop

Rice is one of the most important cereals and food staple for more than half of the world. Climate change and diminishing resources are the major challenges in the sustainable rice production (Farooq et al. 2023). Rice belongs to the monophyletic group of Phanerogams or Spermatophytes, Angiosperm subtype, Monocotyledon class, *Poaceae* (*Gramineae)* family and *Oryza* genus (Degiovanni Beltramo et al. 2010; Kellogg 2009; Strasburger et al. 2004). Although having a wide genetic diversity with more than 20 species, only two of those are cultivated: *Oryza sativa* L. and *Oryza glaberrima* Steud. (Ito and Lacerda 2019; Londo et al. 2006).

Several studies suggest that rice domestication begun 9.000 years ago from wild ancestor *O. rufipogon*, under both natural and human selective pressure initially in tropical and subtropical areas of Asia (Londo et al. 2006; Wei and Huang 2019; Yang et al. 2012). *O. sativa* species was originated in South-East Asia but cultivated in all continents except Antarctica. On the contrary, *O. glaberrima* is native to West Africa and grown solely in Niger river delta (Roma-Burgos et al. 2021; Samyor et al. 2017).

O. sativa has two main subspecies, Indica and Japonica. Generally, Indica varieties have long grains with low stickiness, However, high tillering capacity, tall stature, weak stems, droopy leaves, slow germination, blast-sensitiveness, have long and dense glume pubescence and long awn in some varieties (Chauhan et al. 2017; Degiovanni Beltramo et al. 2010; Wei and Huang 2019), being cultivated in tropical and equatorial latitudes (Agrama et al. 2010). On the contrary, Japonica varieties have shorter grains and preferentially grown and consumed in temperate regions such as Europe, Japan, Korea, northern China, California and Australia (Hori et al. 2017; Hu et al. 2014). Traditional Japonica varieties are characterized by stronger cold tolerance, shorter plant height, shaper leaf shape, light leaf colour, stronger lodging resistance and poor shattering. They are highly responsive to nutrient inputs and are limited to temperate zones.

1.1 Rice morphology and crop traits

The vegetative organs of the rice plant consist of roots, culms, and leaves. The floral or reproductive organs are arranged in panicles. It has round, hollow, jointed culms, rather flat, sessile leaf blades, a terminal panicle and is adapted to an aquatic habitat. It is a pluriannual grass, although cultivated as an annual grass. In Europe it can only be grown once a year in the spring-summer season. The plant height of the Mediterranean cultivated varieties can range from 50 to 150 centimetres (Degiovanni Beltramo et al. 2010; Pérez Lotz 2016). It is a very demanding crop in both temperature and water, tolerating the water saturation of soil. In flooding rice crops, the land may remain submerged for as long as 5 months at a time with water depth from 0.5 to 4.0 meters (Chauhan et al. 2017). The temperature must be high and constant, being sensitive to abrupt temperature oscillations. It can be grown on loamy sands to heavy clay loams or clays and in acid to basic soils. These different crop conditions have varying plant nutrition problems, weed species and pest problems, thus demanding different rice crop management strategies (Chauhan et al. 2017).

When the stem grows, it divides into internodal sections bounded by nodes. Depending on the genotype, soil, climate conditions and crop management, the tillering is variable. The reproduction of rice is anemophilous and mostly autogamous, by self-fertilization, gives a rise to the rice grain, formed by the fruit in caryopsis and covered by the integuments of ear (Chang and Bardenas 1965; Osca Lluch and Gómez De Barreda Ferraz 2016; Pérez Lotz 2016). The development of the fertilized egg and endosperm becomes visible a few days after the fertilization. Grain development is a continuous process, although agronomic terms such as the milky stage, soft dough stage, hard dough stage and fully ripe stage are often used to describe the different maturation stages. In the Mediterranean region, the rice cycle usually lasts between 125 and 150 days depending on the cultivated variety and climatic conditions of the campaign (Pérez Lotz 2016). The BBCH scale is generally used to define their phenological stages. These divide the crop cycle into 10 main stages and 100 phenological stages (BBCH 00 – BBCH 99) (Lancashire et al. 1991).

Figure 1: Rice phenological states BBCH. Since BBCH 09 – BBCH 80

1.2 Rice production and consumption worldwide

Rice is a major cereal crop and one of the most widely grown crops in the world, being the main food staple for over 3000 million people, almost half of the world's population (Ito and Lacerda 2019; Pérez Lotz 2016). It is estimated that each year 408,661 million metric tons of rice is consumed worldwide, supplying 20% of the world's total caloric intake (Figure 2) (Londo et al. 2006). Asia is the main continent in terms of rice consumption and production (McLean et al., 2013).

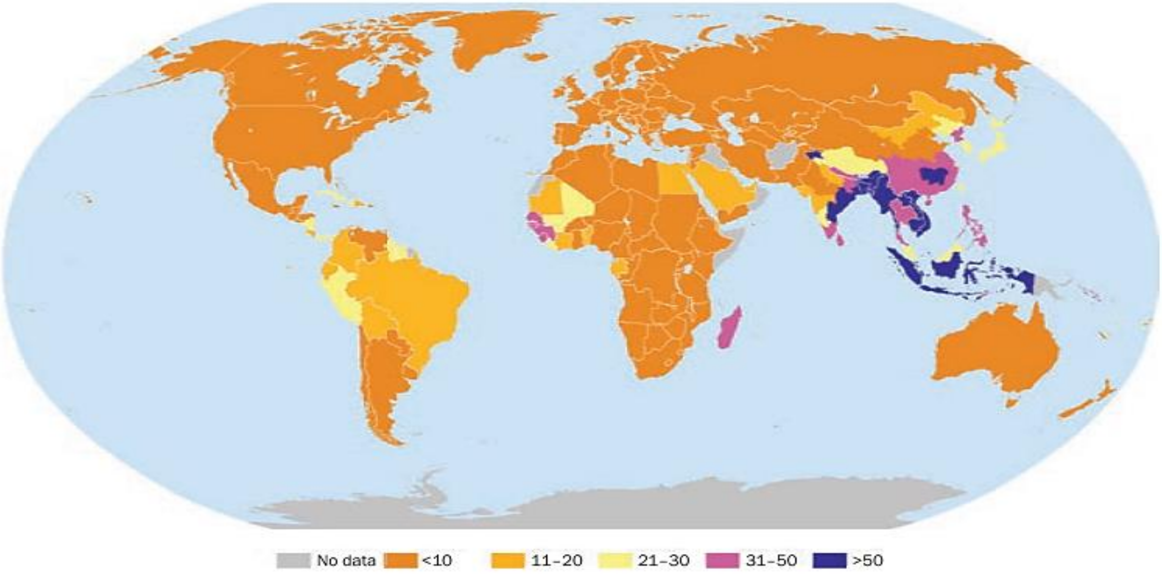


Figure 2: Percentage of calories supplied by rice in the diet. Retrieved from (Maclean et al. 2013).

In the regions of South Asia and Southeast Asia, Indica varieties are mainly cultivated due to the abundance of submerged regions. In contrast, Japonica varieties are grown in areas with less water, like northern latitudes of East Asia, elevations in South Asia and upland areas in Southeast Asia (Wei & Huang, 2019). In 2021, approximately 787 million tons of paddy rice were produced worldwide (FAOSTAT 2023), with the top seven producers placed in Asia and accumulating 80% of the production (Figure 3).

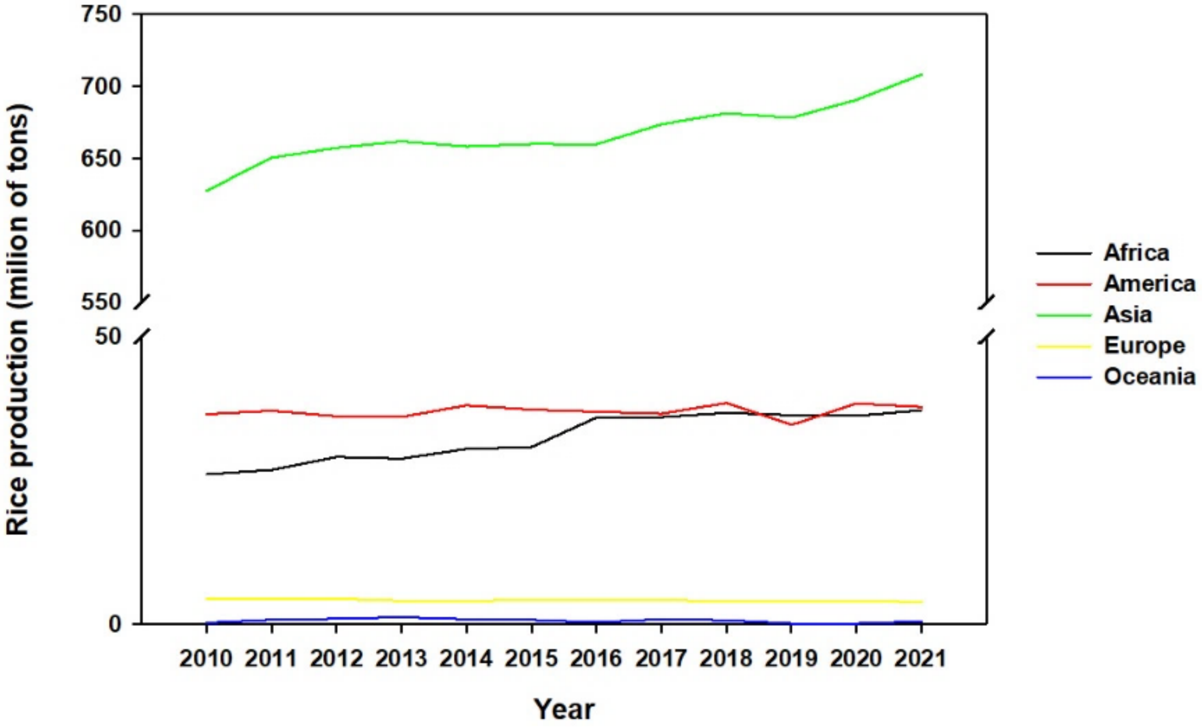


Figure 3: Rice production (paddy) worldwide in 2010-2021. Data retrieved from FAOSTAT database online.

China and India are the main rice producing countries worldwide. Although India possesses more hectares of paddy fields than China, China is the main producer due to its higher yields (Figure 4). This is because China has almost all fields irrigated in opposition to India, whose irrigation only gets to half of the paddy fields (McLean et al., 2013).

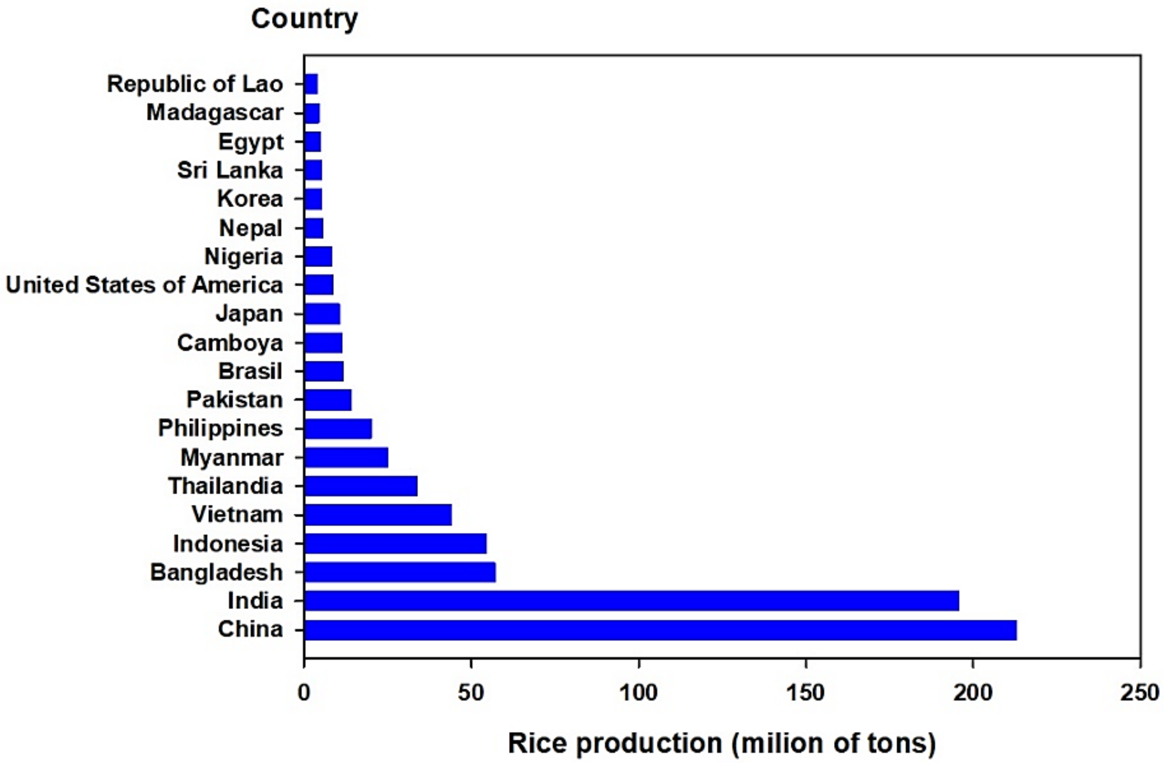


Figure 4: Top 20 paddy rice-producing countries in 2021. Spain would be placed at the 44th position with 0.62 million tons produced in 2021. Data retrieved from FAOSTAT database online.

Although rice yields are still growing, the growth rate has slowed down significantly in recent years. At global level, the rice sharing represents about 20% total cereal production (Chauhan et al. 2017; Pandey et al. 2010). According to the Food and Agriculture Organization (FAOSTAT), rice-harvested area in the year 2021 was about 165 million hectares (M ha) with a production of 787 million tons of paddy rice approximately (FAOSTAT 2023), and it is expected not to change much by the year 2023. About 89.98% of this rice production is from Asia. Around 80% of worldwide area under rice is gathered in eight Asian countries: China, India, Indonesia, Bangladesh, the Philippines, Vietnam, Thailand and Myanmar (Fig. 3); they hold 46.6% of the world's population approximately (Chauhan et al. 2017) (FAOSTAT 2023).

Since the time of its initial domestication, Asian cultivated rice has been moved around the world with migrating human populations. Thus, rice cultivation is nowadays cultivated on all continents except for Antarctica (Londo et al. 2006) .It is widely distributed from tropical to temperate zones and grows in various conditions of water availability (Figure 5) (Yang et al. 2012).

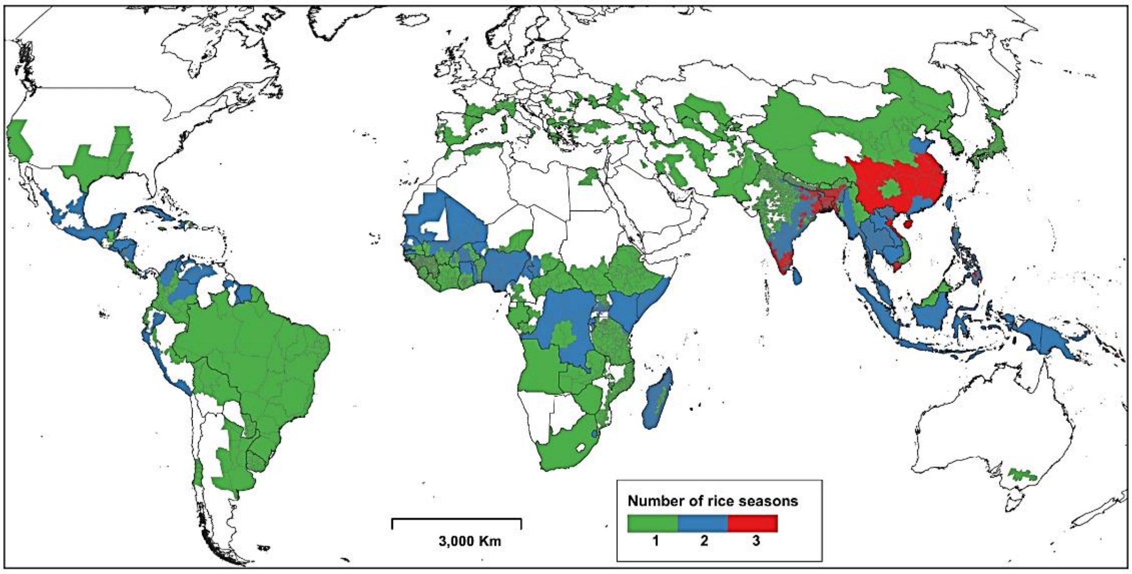


Figure 5: Rice Atlas, a spatial data base of global rice calendars and production (Laborte et al. 2017)

Irrigated lands cover about half of the world's rice lands and produce about 75% of the world's rice. The largest rice importing regions are Middle East and sub-Saharan and Western Africa (Chauhan et al. 2017).

1.3 Rice in the Mediterranean basin

Rice is cultivated in the European Union mainly on submerged land in the coastal plains, rivers basins and deltas. All paddy fields in Europe are irrigated. The climate ranges from tropical to sub-tropical (Kraehmer et al. 2017) and the total rice crop area is about 400,000 km^2, mostly located in the southern-Europe Mediterranean basins. Per capita rice consumption in Europe ranges 4.6 to 5 kg·year^{-1} (OECD et al. 2022). Long grain is the most consumed rice in northern countries, while short to medium grain rice is mainly consumed in the southern Mediterranean countries. Short to medium rice is cultivated on two-thirds of European acreage, while long grain rice on one-third (Garris et al. 2005; Kraehmer et al. 2017).

The rice production and consumption in Europe discrete when compared to the Asian production. Despite of that, rice in Europe holds an important sociocultural meaning since it is one of the basic foods of the Mediterranean diet. Some regions have developed famous rice dishes, like *risotto* in Italy or *paella* in Spain. Rice in Europe also has a ecological importance, due to the great biodiversity that lives and benefits from the paddy fields. The average crop yields range between 2.75 and 7.29 t·ha^{-1}, according to the water availability and environmental conditions of the campaign (Table 1) (FAOSTAT 2016).

Table 1: Rice production (paddy), area harvested and yield in 2021 in Europe. Data retrieved from FAOSTAT database online.

Country	Production (tn)	Area harvested (ha)	Yield (hg/ha)
Italy	1.459	227.040	6.428
Spain	617	84.680	7.288
Greece	242	34.890	6.926
Portugal	176	29.360	5.991
France	62	12.290	5.072
Bulgaria	58	12.050	4.823
Ukraine	49	10.100	4.899
Romania	15	5.440	2.754

Italy and Spain are the two leading rice-producing countries in Europe with more than 75% of acreage (Kraehmer et al. 2017). Italy is the largest rice production country in Europe (227,000 hectares of cultivation area and 1.46 million tons of total grain production in 2021). Followed by Spain that has about 84,680 hectares of rice crop and produces about 617,000 tons of paddy rice (FAOSTAT 2023) (Table 1, Figure 6).

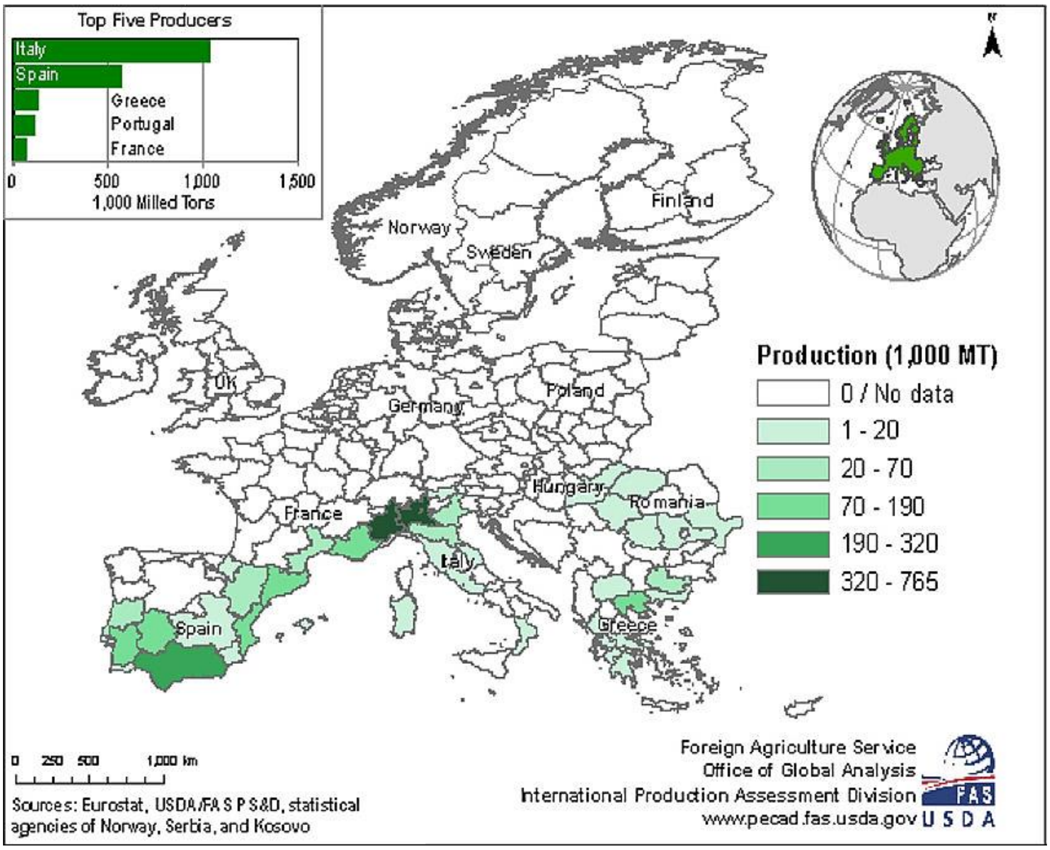


Figure 6: Harvested rice production 2001-2010 average in Europe (Masseroni et al. 2018).

Rice production in Spain is very restricted due to saline zones with important environmental restrictions, such as deltas or marshlands. The main producing areas are Andalusia, Extremadura, Catalonia, Valencia, and Aragón

(MAPAMA 2018; Morillo 2023; Rodrigo and Ribeiro 2023). In 2021, the rice crop has been at its lowest in 18 years (61,909 ha), as a consequence of the pressing drought suffered in the campaign (MAPA 2021b).

In Italy, fields are placed in the Po valley, in the regions of Piedmont, Venetia, Lombardy and Romagna (Gharsallah et al. 2023). Other regions that contribute in lesser quantity to the production are Tuscany, Latium or Sardinia. Greece production is focused in Thessaloniki (Ntantos and Karpouzos 2010). Portugal production comes from three regions, Coimbra, the Tagus plain, and the Sado and Guadiana valleys (Fraga et al. 2019). France obtains rice from the Rhône delta, placed in the Camargue region (Mouret et al. 2004). Bulgaria produces rice in the Plovdiv and the Pazardzhik regions, while Romania cultures rice in the counties of Ialomiţa, Brăila, Olt and Dolj. In Hungary, paddy fields are placed in the Great Hungarian Plain (Kraehmer et al., 2017; McLean et al., 2013).

All the cultivated rice varieties fall into the Japonica subspecies and long-grained varieties show a certain degree of Indica introgressions but being more predominate the Japonica varieties by about 70-80% (short to intermediate) (Ferrero 2005; Franquet Bernis and Borràs Pàmies 2004)**.** Spain has a relative higher production of Indica rice in comparison to the European average. The average yield of Japonica varieties ranges between 7.57 t/ha, meanwhile is 7.86 t/ha for Indica varieties (MAPA 2021a; MAPAMA 2017). This fact could explain why Spain holds the highest yield of all the European producing countries (Kraehmer et al. 2017). The European Union legislation (CEE Regulation No. 1785/2003) considers four types of grains: long A, long B, medium and round (Table 2).

Table 2: Rice commercial criteria produced in Europe Union.

Kind of grain	**Round**	**Medium**	**Long (A)**	**Long (B)**
Lenght (cm)	≤ 5.2	5.2 < L ≤ 6.0	> 6.0	> 6.0
Lenght / wide (cm)	< 2.0	< 3.0	2.0 < L/w ≤ 3.0	≥ 3.0

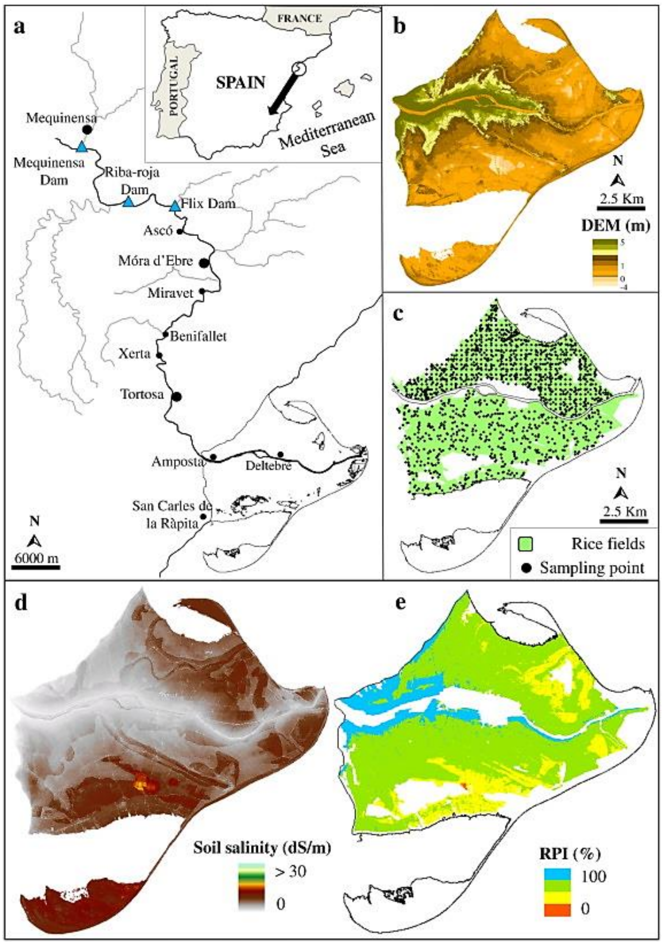
The most popular rice varieties cultivated in Spain are Puntal, Bomba, Balilla x Sollana, Montsianell, Gleva, Guadiamar, J. Sendra, Argila, and Sirio (Sales et al. 2023). Long-grain varieties (*Oryza sativa* var. *Indica*) are mainly cultivated in rice areas located in southern Spain (Extremadura and Marismas del Guadalquivir), while in the other four areas located in northeastern Spain, short–medium-grain (*Oryza sativa* var. *Japonica*) rice are cultivated (Gómez de Barreda et al. 2021). In Italy, the main cultured varieties are Arborio, Carnaroli, Roma, Baldo, Thaibonnet, Loto, Augusto, Sant' Andrea, Luna, Balilla, Centauro, Vialone nano, Padano, Lido, Crono, Sole and Selenio (Volpe et al. 2023).

1.4 Rice production in Ebro delta

Ebro Delta is in the north-east coast of Spain, facing the Mediterranean Sea, between 40º38’ and 40º48’ N parallels and 4º16’ and 4º34’ E meridians. Rice crop began to expand in 19th century mainly thanks to the construction of the two Ebro River canals. The total surface of Ebro Delta is 32,059 ha approximately. The rice crop area corresponds to 20.400 ha, which represents 83% of the total cultivated land. Rice cultivation contributes to the conservation of the environment, since it maintains an extensive layer of water for many months that serves as a habitat for birds, aquatic plants and invertebrates (Egea-Fernández and Egea-Sánchez 2006; Primack et al. 2001). In 1998, a promotion of agricultural production methods compatible with environmental protection in wetlands included the Ebro Delta in the list of the Ramsar Convention (Bartual Figueras and Pareja Eastaway 2015).

The yield is around 7 $t\cdot ha^{-1}$ in average, depending on the cultivated variety and the campaign. Rice production in the Ebro Delta corresponds to 98% of the total Catalan production (140 million $kg\cdot year^{-1}$), although less than 100 ha are devoted to organic rice cultivation. About 70% of the paddy fields are subjected to *Denominació d'Origen Protegida (DOP) ‘’Arròs del Delta de l’Ebre’’* (Franquet Bernis and Borràs Pàmies 2004; Navarro 2007).

The Ebro Delta has been developed in the last 5,000-7,000 years and has been originated as a consequence of the sedimentary progradation that took place from the last stabilization of the sea level (Casals et al. 2013). The development of rice cultivation in the Ebro Delta is related to the special characteristics of the area where the maximum altitude is 4 m above sea level. Its soil salinity and the height of the water level, do not allow any other type of crop exploitation further than rice (Eixarch 2010). The geological and hydrological dynamics of the delta is controlled by the flow and the channelling of the river. In the absence of natural floodings, irrigation is the only alternative where sediment can be transported and deposited on the surface, to offset the effects of subsidence and marine intrusion (Ibáñez et al. 1999; Torres Herrero 2021). The future projections regarding soil salinity are not favourable to rice production in this region. The models predicts a rise of 1 – 8 ds/m mean soil salinity, depending on distance from ricer and delta sea shores, clay presence and surface elevation (Figure 7 and 8) (Ramos de Fuentes 2018).



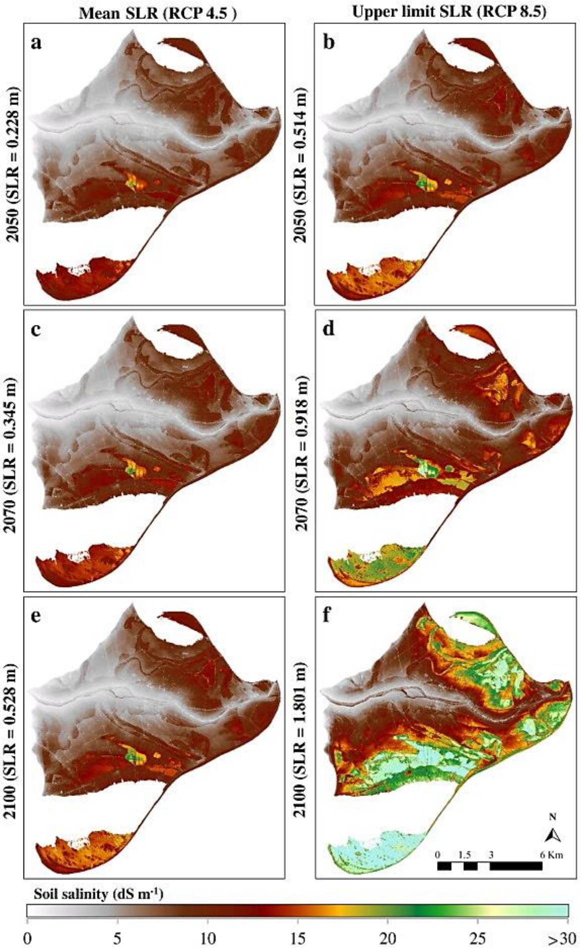


Figure 7 (Left): Location of the Ebro Delta (a); Ebro Delta Digital Elevation Model (DEM) map (b); distribution of paddy fields along with soil salinity sampling points (c); soil salinity (d); and rice production index maps (e) in the reference state (2010) (Genua-Olmedo et al. 2016). **Figure 8:** Distribution of estimated soil salinity in the Ebro Delta under different SLR scenarios (SLR). Modeled scenarios shown in the figure are the mean RCP 4.5 (AR5 IPCC) and the upper RCP 8.5 (Genua-Olmedo et al. 2016).

The orographic situation of the Ebro Delta involves a series of environmental characteristics of humidity that are especially favourable for fungal diseases in rice cultivation (Blast rice, Brown spot rice, Rice spikelet rot disease). The dominance winds in the summer season come from the sea towards the land and bring more humidity to the environment, on the other hand, in the rice cultivation phase, the presence of dry winds are anecdotal and helps to lower the percentage of humidity (Cierzo or Tramontana). All this makes this rice area a hot spot for common pathologies for crops.

2. Organic food in the world and Europe

The absence of pesticides and the decrease in heavy metals may be the main reasons for the possible health effects of organic food (Vigar et al. 2019). According to the latest FiBL-IFOAM survey on the certification of organic agriculture worldwide, there are 72.3 million hectares (Mha) of organic agricultural land, including areas in conversion (Willer et al. 2021). The regions with the largest areas of organic agricultural land are Oceania, Europe, Latin America, Asia, and Africa (Figure 9). The countries with the largest agricultural area are Argentina, Australia, and the USA (FiBL-IFOAM 2022).

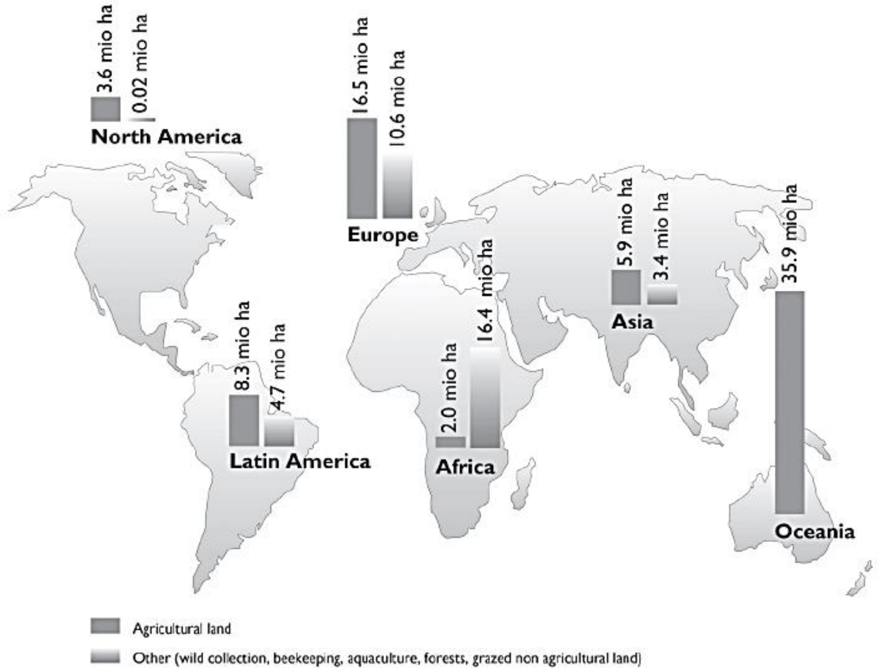


Figure 9: Organic agriculture land and non-agricultural areas in 2019. Source: FiBL-IFOAM

Currently, 1.5% of agriculture worldwide is organic and an increase in organic agricultural area have been taken place in Asia, Europe, North America, and Oceania. The region with the highest percentages are found in Oceania (9.6%) and Europe (3.3%) (Table 3) (FiBL-IFOAM 2022).

Table 3: World: Organic Agriculture land (including in conversion areas) and organic share of total agriculture land by region 2019.

Region	Organic agri. Land (ha)	Share of total agri. land
Africa	2,030,830	0.2 %
Asia	5,911,622	0,40%
Europe	16,528,677	3.3 %
Latin America	8,292,139	1.2 %
North America	3,647,623	0.8 %
Oceania	35,881,053	9.6 %
World	**72,285,656**	**1.5 %**

The organic agriculture production land of the total agricultural area and the number of organic farms continues to grow and are represented in Figure 10. Spain is the third country in the world in terms of certified organic agricultural area 2,354,916 ha. The growth of the organic sectors are also due to various political support measures such as funding in rural development programs, legal protection and action plans, research support and advisory services (FiBL-IFOAM 2022).

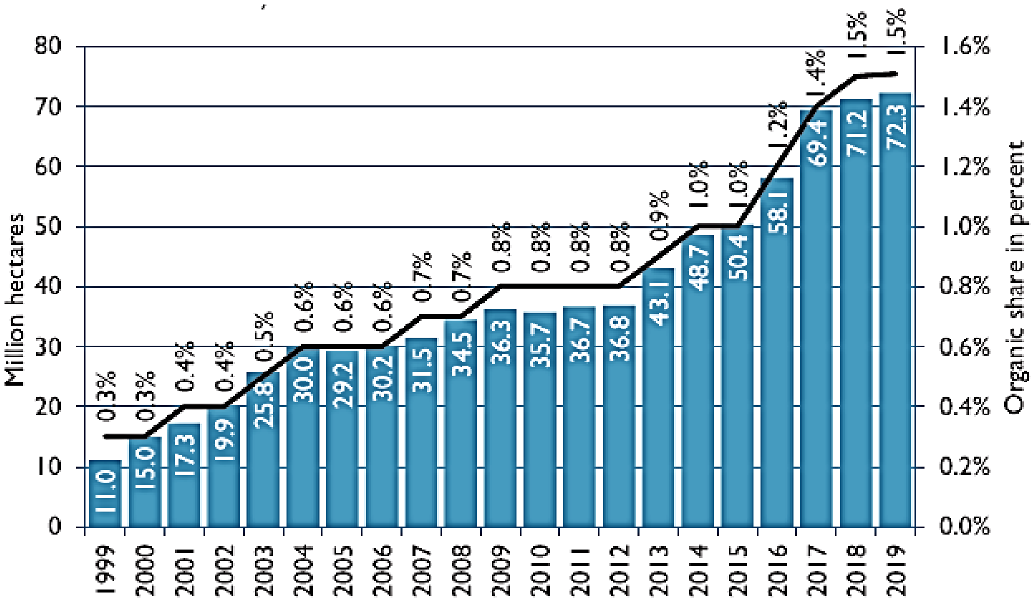


Figure 10: Growth of the organic agricultural land and organic share 1999-2019. Source: FiBL-IFOAM-SOEL-Surveys 2001-2021

The European Union (EU) is the second-biggest organic agri-food products market. In 2019, the EU imported a total of 3.2 million tonnes of organic agri-food products. Imports of tropical fruit (fresh os dried), nuts and spices represented the single biggest category, totalling 885,930 tonnes or 27.3 percent of total imports, followed by oilcakes, cereals other than wheat, as well as rice and wheat. The People’s Republic of China is the biggest supplier of organic agri-food products to the EU, with 433,705 tonnes; 13.4 percent of the total organic import volume. Ukraine, the Dominican Republic, and Eucador represent the 10 percent of the total organic import volume (Willer et al. 2021). In the European Union, 5.4% of farmland is organic. Although, some countries reach higher percentages, for example, Falkland Islands (35.9%), Liechtenstein (27.3%) and Austria (19.7%) (Figure 11) (FiBL-IFOAM 2022).

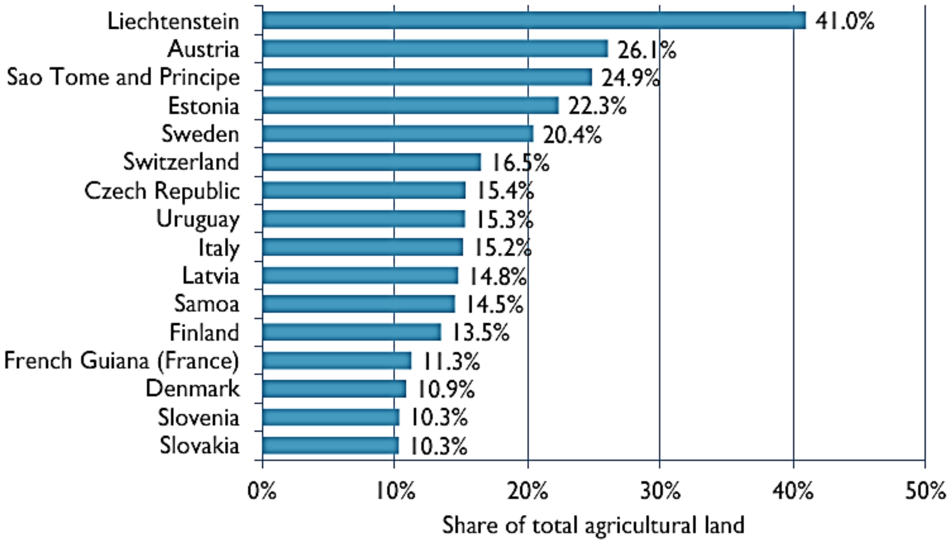
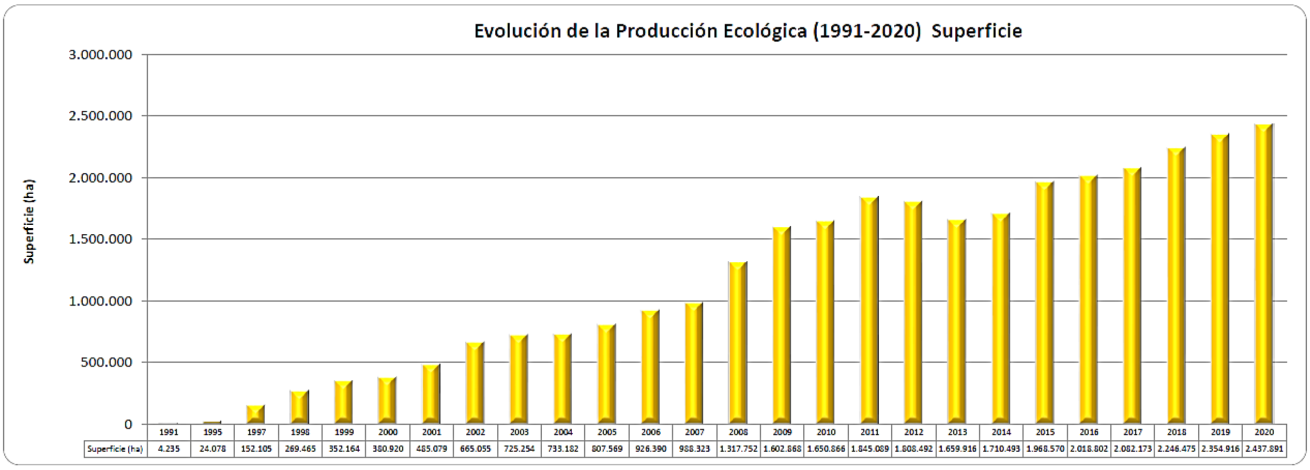


Figure 11: World: Countries with an organic share of the total agriculture land of at least 10 percent 2019. Source: FiBL survey 2021

In Spain, since 1997 the agrarian surface holding organic certification reached a positive increase, and from 2008 it is exceeded for the first time one million of hectares (Figure 12), and in 2020 it exceeded more than 2 million hectares (FiBL-IFOAM 2022; MAPA 2021a).

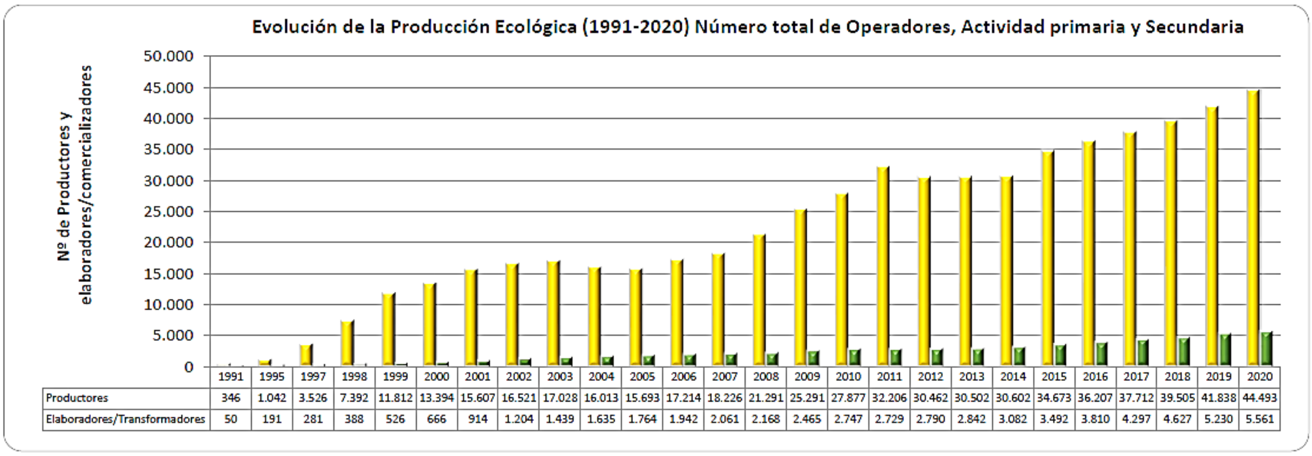


	1991	1995	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Superficie (ha)	4.235	24.078	152.105	269.465	352.164	380.920	485.079	665.055	725.254	733.182	807.569	926.390	988.323

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Superficie (ha)	1.317.752	1.602.868	1.650.866	1.845.089	1.808.492	1.659.916	1.710.493	1.968.570	2.018.802	2.082.173	2.246.475	2.354.916	2.437.891

Figure 12: Changes in the certified agricultural area in Spain (1991-2020). Source: MAPA

The evolution of operators in primary and secondary activities (farmers, industrialists, and marketers) has been growing in the last decade. The number of registered organic operators exceeds 44,000, with nearly 42,000 agricultural producers and more than 5,500 processors/processors, employing around 85,000 workers, with a high participation of the female sector (Figure 13) (MAPA 2021a).



	1991	1995	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Productores	346	1.042	3.526	7.392	11.812	13.394	15.607	16.521	17.028	16.013	15.693	17.214	18.226	21.291	25.291	27.877	32.206	30.462	30.502	30.602	34.673	36.207	37.712	39.505	41.838	44.493
Elaboradores/Transformadores	50	191	281	388	526	666	914	1.204	1.439	1.635	1.764	1.942	2.061	2.168	2.465	2.747	2.729	2.790	2.842	3.082	3.492	3.810	4.297	4.627	5.230	5.561

Figure 13: Changes in the operators in primary and secondary activities (farmers, industrialists, and marketers) in Spain (1991-2020). Source: MAPA.

The organic rice surface production in Spain (1,476 ha) under organic certification, it represents less 2 % of total rice surface (84,680 ha) in 2021 (MAPA 2021a). On average, each Spanish individual consumed an average amount of 3.83 kilograms of rice during the year 2022. The average price of rice increases with respect to the year 2021, in a very notable way, 13.4% and stands at 1.99 €/kg (MAPA 2022).

2.1 Organic rice in the Ebro Delta

Ebro delta has a low Organic production at 0.6% of the certified area according to CCPAE (CCPAE 2020a). The main factors that limits the growth and expansion are: (i) the lack of knowledge, (ii) the lack of practical experience, (iii) the lack of mechanized weeding options and (iv) a general belief among the rice sector that "nothing can be done". On the contrary, the main factor boosting the organic production is the price perceived by farmers, which is 250% compared to the conventional rice.

Extracting a viable and sustained organic yield is challenging. The main limitations for organic rice production at the agronomic level are the competition caused by weeds in rice cultivation, which in the worst cases can reduce organic rice production by up to 100%. At the same time, the rice industry is not able to cover the growing demand of the market where the sensitivity of consumers towards products from organic farming is increasing. This scenario forces the industry to import organic rice from other rice-growing areas, paradoxically increasing the impact of greenhouse gas emissions and the carbon footprint that exacerbate the effects of climate change.

2.2 Regulations of Organic rice in Ebro Delta

The European Commission has approved a series of specific regulations for organic farming (UE Regulation 2018/848). The general requirements of the legislation are as follows:

- Genetically modified organisms (GMOs) cannot be used.

- Renewable resources, such as waste and by-products of plant origin, must be recycled, thus contributing to soil nutrition.
- All stages during the production chain must guarantee ecological integrity.
- Nitrogenous mineral fertilizers cannot be used.
- All production techniques must prevent or minimize any damage to the environment.
- Authorized phytosanitary products will only be used in the event of an emergency.

The regulations at the Ministry level can be found in the General Registry of Ecological Operators, which is governed by *Real Decreto* 833/2014. In Catalonia, the control system for organic agricultural production is delegated to the Catalan Council for Organic Agricultural Production (CCPAE in catalan), Low 2/2014, CCAA CAT. For the organic production, transformation and distribution, Law 14/2003 of June 13 on agri-food quality applies. At regional level, the Ebro Delta is considered one of the most sensitive wetlands in Europe:

- Delta del Ebro Natural Park (Law 357/1983 of the Catalan Government and Law 332/1986 of the Spanish government).
- Special Protection Area for birds (1987) according to the European Bird Conservation Directive (79/408/EEC).
- The area is also included in the Ramsar list of wetlands of international importance Natural Area Interest (PEIN) 1992.
- Biosphere Reserve by UNESCO (2013).

The Catalan government is already implementing a quality certification called *Producció Agrària Sostenible* (PAS, Sustainable Agricultural Production). The objective of this certification is to visualize, assess and quantify the sustainability of organic farms, being focused on these three arguments: environmental, economic, and social sustainability. One of the main objectives of the PAS is the self-improvement of the farms. The PAS is a semaphoric picture of environmental sustainability: sources, soil, water, air, biodiversity, materials, fertilization, renewable energies. This PAS certifies will be free and able to everyone improving their sustainability. PAS is ongoing a process that will guarantee quality for Catalonia, Spain and Europe. This certification is based on the farmer production process and not on the final product. However, organic and integrated certifications are not obliged to be used.

The PAS certification is in line with the green deal (Fetting 2020), “from farm to fork” (Schebesta et al. 2020) and biodiversity (Hermoso et al. 2022) strategies. PAS is an inspiration for the European commission to help to compose new laws, which in turn is inspired by FAO’s SAFA (SAFA 2023). The strong point of the PAS is that they group three aspects: environmental, economic, and social and that plays on their favour. The PAS certificate will be compatible with Catalan Council for Organic Agricultural Production.

In this sense, this doctoral thesis contributes, for the first time, to generate the necessary knowledge on organic techniques and products in order to accelerate the agro-organic transition of the Ebro Delta rice sector for the year 2030.

3. Integrated pest management in paddy fields

3.1 Weeds in paddy fields

Weed control is one of the major challenges for sustainable rice cultivation (Farooq et al. 2023; Liu et al. 2023; Rajkhowa et al. 2023). Weed competition was the main factor affecting yield for both conventional and organic systems (Delmotte et al. 2011b; Reddy et al. 2023). Weeds proliferate in cultivated paddy fields because rice paddies are usually created by converting drylands to artificially flooded wetlands, which therefore lack native flora adapted to flooding (Osuna et al., 2012). With *Echinochloa* spp*., Leptochloa* spp*., Oryza sativa* f. *spontanea* (red rice)*, Cyperus* spp*., Heteranthera* spp*.* and *Alisma plantago-aquatica* are the main weeds in Spanish paddy fields (Osuna et al. 2012) Figure 14.

The main problem in the management of the paddy rice in conventional production in Ebro Delta is the weed control. There is a wide diversity of weed species and ecotypes, and the abusive use of pesticides have resulted in herbicide weed-resistant problems. The main families of weeds that are present in the fields are grasses, aquatic weeds, and sedge weeds. The biology of each family condition the methods and strategies to be used for their control. The conventional rice production system has problems controlling weeds with the aid of herbicides, the control in organic rice production is even harder.

Figure 14: Main weeds in Spanish paddy fields: a) Barnyard grass (*Echinochloa crus-galli*), b) Early barnyard grass (*Echinochloa oryzoides*), c) Salt meadowgrass (*Leptochloa fascicularis*) d) Red rice (*Oryza sativa* f. *spontanea*), e) Flatsedge (*Cyperus difformis*), f) Mud-plantin (*Heteranthera reniformis*), g) Water-plantin (*Alisma plantago-aquatica*)

3.2 Fungal diseases

Rice ecosystems are currently facing numerous threads, which often result in yield reductions (Kraehmer et al. 2017). Rice Blast is the major threat for rice crop production worldwide due to its wide distribution and yield reduction under favourable conditions. (Laha et al. 2017; Ou 1985; Pérez Lotz 2016; Rossman et al. 1990). It is the major threat to rice as it reduces the rice yield by 30% globally (Fahad et al. 2019) and it can cause up to 80% yield losses in some varieties in endemic regions (Ou 1985).

Rice blast is a fungal disease caused by the filamentous ascomycetous fungus *Pyricularia grisea* (Cooke) Sacc. on the anamorph form which can be found in the field, or *Magnaporthe oryzae* (Hebert) Barr. on the teleomorph form (which can be obtained in laboratory (Laha et al. 2017; Rossman et al. 1990). Pyricularosis fungal disease, is the major European rice disease causing significant yield losses in some rice-growing regions such as Ebro Delta (Catalá Forner et al. 2003; Kraehmer et al. 2017; Laha et al. 2017).

In winter, the rice blast survives as conidiophores and mycelium on the plant residues after the harvest or in the ground. In spring, the temperature and relative humidity increase displays the mycelium sporulation producing conidiophores which are the primary source of infection. However, *P. oryzae* can also be disseminated by infecting seeds or can hibernate in winter cereals or other plants like *Cynodon dactilon*, *Phragmites communis*, *Sorghum halepense* or *Arundo donax*. The rest of the cycle is usually found on the leaf, but it is similar in other tissues (Figure 15) (Talbot 2003; Wilson and Talbot 2009).

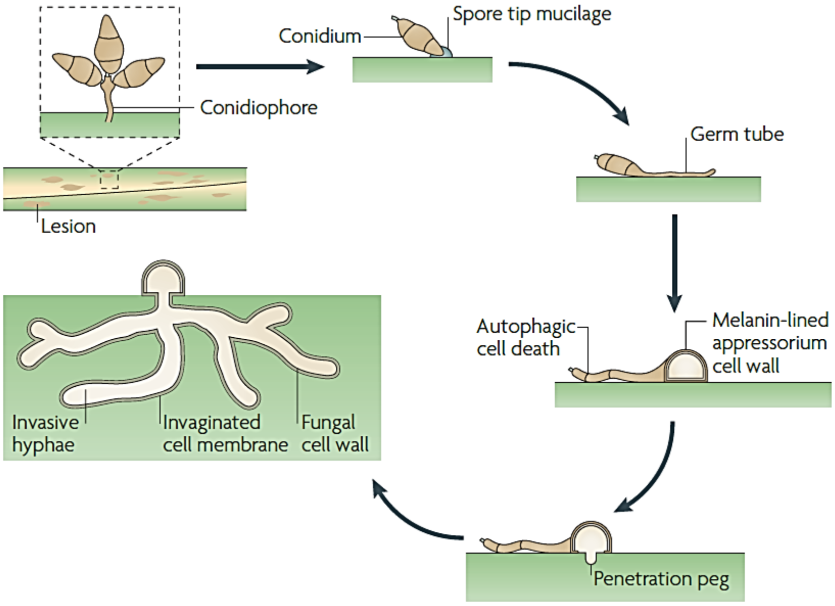


Figure 15: Life cycle of the rice blast fungus *Magnaporthe oryzae*. The rice blast fungus starts its infection cycle when a three-celled conidium lands on the rice leaf surface. The spore attaches to the hydrophobic cuticle and germinates, producing a narrow germ tube, which subsequently flattens and hooks at its before differentiating into an appressorium. The single-celled appressorium matures and the three-celled conidium collapses and dies in a programmed process

> that requires autophagy. The appressorium becomes melanized and develops substantial turgor. This translates into physical force and a narrow penetration peg forms at the base, puncturing the cuticle and allowing entry to intro the rice epidermis. Plant tissue invasion by means of epidermal cells. Cell-to-cell movement can initially occur by plasmodesmata. Disease lesions occur between 72 and 96 hours after infection and sporulation occurs under humid conditions; aerial conidiophores with sympodially arrayed spores are carried to new host plants by dewdrop splash (Wilson and Talbot 2009).

The first symptoms are visible in the host plant four or five days after the conidia germination P. oryzae sporulation can reach about 20,000 conidia per day, initiating a new infection cycle. However, the dissemination area is small, and the spores are usually between 1 – 5 m from the source. The optimum conditions for the germination of conidia and most of the cycle are between 24-28 ºC of temperature and 90 – 100 % of relative humidity but can be triggered at 20 ºC (Castejón-Muñoz 2008; Talbot 2003; Wilson and Talbot 2009). The symptoms of infection are the appearance of 0.3 to 1.5 cm diameter spots or lesions on leaves. The leaf spots are typically elliptical with more or less pointed ends. The centre of the spots are usually grey and the margins are usually brown or reddish-brown (Figure 16a) (Ou 1985). The pathogen also causes brown lesions on panicle. In severe infections, seedlings and plants may be completely killed (Figure 16 c) (Laha et al. 2017; Talbot 1995). Sulphur is a common and highly effective fungicide that has been in use in one form or another for a long time (Jang et al. 2015; Khandagave 2023).

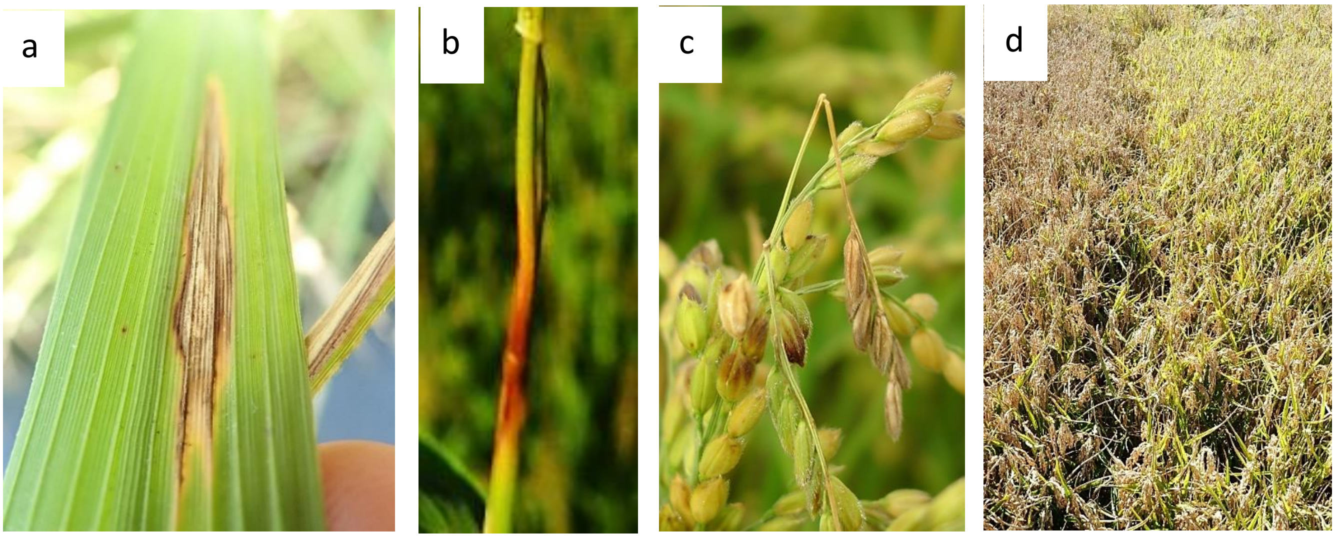


Figure 16: Rice blast symptoms. a) Leaf infection, b) collar infection, c) panicle infection, d) on the left side, blast attack

3.3 Organic fertilization

Nitrogen is an important factor that affects soil ecology and limits the availability of nitrogenous organic matter in agroecological systems (Hu et al. 2023). Soils are very important in agriculture. Agriculture that promotes a healthy and quality soil (regenerative, sustainable, ecological). The soil is the basis of sustainability, the higher content in organic matter gives a greater capacity to retain moisture, lower risk of erosion. We allow greater infiltration of water and therefore capture a greater amount of water that will then be available to the plants and that in periods of drought or irregular rainfall, it is very important to have a greater availability of water in the soil. Also increasing soil microbial biodiversity is very important to have quality soils. There are many agricultural practices that, if well focused, allow these characteristics to be increased or enhanced: minimal tillage, providing livestock droppings to provide more organic matter or enhancing the incorporation of waste in the sun that also increases the content of organic matter.

Organic manure and compost have been available to paddy fields fertilization (Saha et al. 2007), but also vermicompost (Sarkar et al. 2023). Other organic matter amendments such as the rice straw (Tang et al. 2019), rice husk (Peyghambarzadeh et al. 2023) give result in a good carbon source but poor nitrogen source. Finally, cover crops protect the sun and which we then incorporate superficially in the soil with roller crimper. If we produce more biomass in general, we end up having more organic matter in the sun because the effect of plant roots enhances the quality of the soil and ultimately does not reduce the content of organic matter and the characteristics of a quality soil (Weinert et al. 2023).

The technique of green manure, which consists of the winter cultivation of mixtures of leguminous seeds, grasses and plant species that are subsequently agitated with a mechanical tool called a roller crimper developed for the ecological production of horticulture as a viable alternative in the correct preparation of the fields for planting, while favouring the development of rice cultivation to the detriment of that of weeds and improving the fertility of the soil while fertilizing it ecologically while reducing fertilization costs. Legumes help increase the sustainability of agri-food systems. Through the insertion of legumes through different diversification strategies, among them rotations, the association of crops (inter cropping) or even relief cultivation. The development of these practices in our systems, and the limitations they currently have. The importance of valuing legumes and evaluating the advantages of their introduction in sustainable cropping systems must be highlighted.

4. The Organic Delta Rice Project (ODR)

The Organic Delta Rice Project raised in front of the necessity to cover the organic rice demand by the rice industry. Nowadays, the organic rice market demand is not covered, being necessary the creation of an R+D Project in organic rice production. The objectives of the project were (1) to Identify which non-chemical weeding strategies can be effective, (2) to assess the effectiveness of Sulphur or Silicon-based fungicides in controlling blast disease in different rice cultivars, and (3) to evaluate the organic fertilizers efficiency for organic rice production systems.

The most relevant innovations will be develop in a “good practices” guide for the organic rice farmers. The agronomic limitations of the organic production made necessary the collaboration of the rice industry, research centres and public administrations to successfully reach the objectives (Figure 17).

Figure 17: Stakeholders and structure of the Organic Delta Rice Project.

The ODR Project grouped all the stakeholders of rice sector in Ebro Delta for the same reason (organic rice production). This relevant fact it is very important because helps reinforce links between them and enhances the competitiveness. In the other hand, ODR was a pioneer project that impulse other projects that give continuity like Grup Operatiu ECO-de or Vegetal ground cover for margins and drains for organic paddy fields in Ebro Delta. The Organic Delta Rice Project began in 2019 and last for 3 years. The trial strategy is a huge challenge due to (i) the big complexity of objectives and (ii) reduced timeline. The Project was divided into independent work package to come together at the end with an integrate organic rice production techniques (Figure 18).

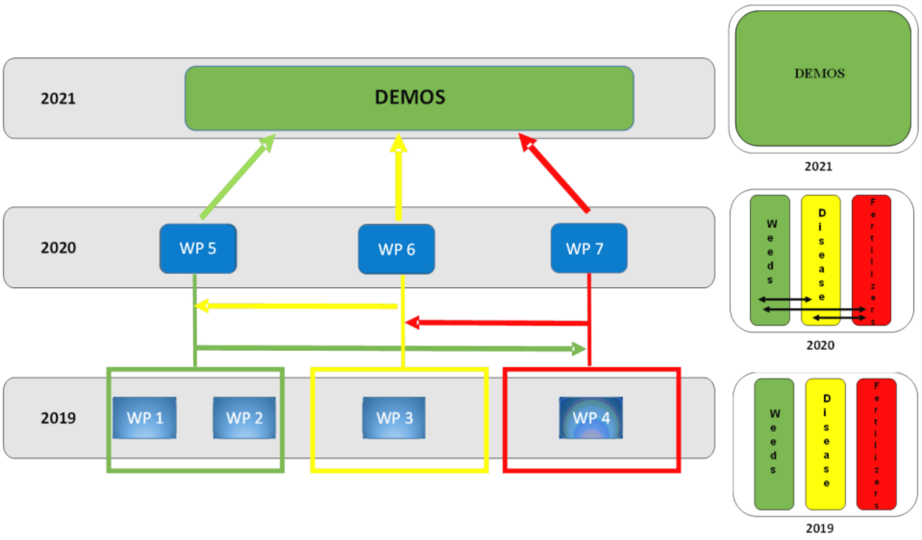


Figure 18: Work breakdown structure of Organic Delta Rice Project

The dissemination of Organic Delta Project included journal publications, oral communications and posters in congresses, open field days, technical trainings in Ebro Delta and Valencia, tv news, newspapers, and open field days and technical seminars to show the most relevant results (View ANNEXES III).

OBJECTIVES

OBJECTIVES

The main objective of this Thesis is to study the feasibility of organic rice cultivation in the Ebro Delta.

The specific objectives on this Thesis are:

- To investigate which non-chemical weeding strategies are effective under dry-seeding and water-seeding conditions (chapter I).
- To assess the effectiveness of Sulphur or Silicon-based fungicides in controlling blast disease in different rice cultivars in Ebro Delta conditions (chapter II).
- To evaluate the efficiency of organic fertilizers for organic rice production systems (chapter III).

CHAPTER I: Non-chemical weed management for sustainable rice production in the Ebro Delta

Alfred Palma-Guillén, Miquel Salicrú, Ariadna Nadal, Xavier Serrat, Salvador Nogués

Submitted to:
Weed Research

Non-chemical weed management for sustainable rice production in the Ebro Delta

Alfred Palma-Guillén[1,2], Miquel Salicrú[3], Ariadna Nadal[1], Xavier Serrat[2*], Salvador Nogués[2]

[1] AGROSERVEIS.CAT SL, Deltebre, Catalonia, Spain;

[2] Departament de Biologia Evolutiva, Ecologia i Ciències ambientals, Secció de Fisiologia Vegetal, Universitat de Barcelona, 08028 Barcelona, Catalonia, Spain;

[3] Departament de Genètica, Microbiologia i Estadística, Secció d'Estadística, Universitat de Barcelona, 08028 Barcelona, Catalonia, Spain;

ABSTRACT

Weed control is one of the major challenges in rice cultivation, and the use of agrochemicals in this crop is severely restricted under the new European agricultural policy. Therefore, new effective non-chemical weed control agents are the key to sustain European rice production. We investigated four non-chemical weed management strategies in the Ebro Delta in north-eastern Spain, two in dry-seeded paddy fields and two in water-seeded paddy fields. In addition, two controls per sowing conditions were included: a positive control consisting in chemical herbicides treatment and a negative control consisting in no weeding and no seeding. In all tests but negative controls, the rice variety Argila was employed. "Simple dry seeding" was the best treatment for dry seeding, while "false seeding" (stale seed bed) and planting was the best performing under water seeding conditions. Both mentioned treatments were as effective as chemical control in reducing the density of weeds and the weeding time for those species more abundant in Ebro Delta paddy fields (*i.e. Echinochloa oryzoides*, *Echinochloa crus-galli*, *Scirpus maritimus* and *Heteranthera reniformis*). Our results Indicated that some of the non-chemical weed control methods can reduce weed pressure to levels similar to standard chemical herbicide treatments under certain seeding conditions.

Key words: Rice farming, weeds, integrated management, barnyard grass, herbicides.

1 INTRODUCTION

Rice is the most important staple food for more than half of the world's population, providing up to 20% of total caloric intake. It is the most important staple food for more than half of the world's population, providing up to 20% of total caloric intake (Das 2017; Dass et al. 2017). In Europe, it is an important crop with a cultivated area of 637,872 ha and an average annual production of over 4 million tonnes of paddy rice (FAOSTAT 2022). Spain is the second largest European rice producer next to Italy. In 2021, Spain produced 617,180 tonnes of paddy rice on more than 84,680 ha, representing about 20% of European production (FAOSTAT 2022).

Agrochemical inputs are used in conventional agricultural production systems to achieve high yields. Unfortunately, this practise leads to an increase in production costs, dependence on non-renewable resources, biodiversity loss, water pollution, chemically contaminated food, soil degradation, and risks to farmers' health (De Wit and Verhoog 2007; Reganold and Wachter 2016; Suwanmaneepong et al. 2020; Willer et al. 2018; Willer et al. 2019).

Spain is the leading European country in terms of cultivated area for organic food production (2,246,475 ha) (FIBL, 2020). However, only 1,300 ha of organic rice are grown in Spain (less than 1.3% of the rice area), and only 0.8% of Spanish rice is marketed under organic certification. Thus, the current demand for organic rice in Spain (and all of Europe) is driven by Italy. Spanish farmers generally avoid organic rice production because of difficulty in managing weeds (Mañosa et al. 2001). In fact, weed control is one of the major challenges in organic rice production (Hoosain et al. 2013).

Manual weeding in direct-seeded paddy fields is not economically viable, and qualified weeding personnel are scarce because the work is physically demanding. Water control is an important land management tool to reduce the diversity and density of weed species that affect rice crop yields (Zhang et al. 2021). Farmers usually apply direct water-seeding technique shortly after performing the stale seed bed technique. This involves flooding the rice field to induce the first generation of weeds to emerge, which are then eliminated by mechanical puddling with a rotovator or herbicide treatment before rice sowing (Català 1995). This technique implies a delay in rice sowing, which jeopardises the production of long-cycle varieties due to low temperatures during rice maturation. In addition, the stale seedbed technique increases the risk of rice seed loss due to chironomids.

Weed competition was the main factor affecting yield for both conventional and organic systems (Delmotte et al. 2011b; Reddy et al. 2023). Weed proliferation during rice cultivation is determined by climatic and edaphic conditions, as well as the quality of the irrigation water (Ampong-Nyarko and De Datta 1991; Crafts and Robbins 1963; Kendig et al. 2003; Labrada et al. 1996; Scott et al. 2013; Smith 1977). Weeds proliferate in cultivated paddy fields because rice paddies are usually created by converting drylands to artificially flooded wetlands, which therefore lack native flora adapted to flooding (Osuna et al., 2012). With *Echinochloa* spp*., Leptochloa* spp*., Oryza sativa* f. *spontanea* (red rice)*, Cyperus* spp*., Heteranthera* spp. and *Alisma plantago-aquatica* are the main weeds in Spanish paddy fields (Osuna et al. 2012). In addition, *E. crus-galli* and *E. oryzoides* are the most problematic weeds in the Ebro Delta, (Lillebø et al. 2003) as spontaneous herbicide-resistant populations have emerged due to repeated applications of herbicides with the same modes of action (Barreda 2021). In fact, misuse of herbicide treatments and a reduction in the chemical modes of action targeted by commercially available herbicides have led to increased diversification of herbicide-resistant weeds (Osuna et al. 2012) and overpopulations of apple snails (Martínez-Eixarch et al. 2017; Zhiyu et al. 2011).

Maintaining weed density at a level low enough to avoid the threshold for herbicide treatment is difficult even in conventional rice production (Barreda 2021). Therefore, new weed control methods need to be developed, not only for conventional rice production, and especially for organic rice production, where the use of synthetic herbicides is explicitly prohibited. Innovations in seeding and mechanical weed control or planting represent opportunities for both organic and conventional rice production. In addition, organic agrochemical products and organic farming technologies are more sustainable, even though they require greater inputs, knowledge, and skills (Hoosain et al. 2013).

It is worth noting that rice is the most salt-sensitive cereal crop (Negrão et al. 2011) and its cultivation is particularly vulnerable to salt stress. In the Ebro Delta, some farmers have experimented with dry seeding and cultivated heavily salinized fields. Farmers were forced to use dry seeding to prevent infestation by apple snails, which invaded the Ebro Delta in 2009 (Català et al. 2010; Lopez et al. 2010; Pérez Pons 2012). The apple snail remains underground during the winter until the fields are flooded in the spring, at which time it becomes active and can completely scavenge a field seeded with water. In contrast, with dry seeding, the snails become active once the rice seedlings have grown to the point where they are less palatable than the germinating weeds (Franquet Bernis 2018). The same positive effect of dry seeding has been observed on chironomids (aquatic diptera larvae), which are considered key pests in rice cultivation and attack plant roots during the rice plantlet establishment phase. Early flooding combined with late seeding when soil and water temperatures are already warm also favours heavy chironomid infestations. The traditional puddling during the stale seed bed flooding destroys the first generation of weeds and interrupts up the chironomid life cycle, delaying the undesirable effects of chironomids (Català 2011; Franquet Bernis 2018). However, stale seed bed flooding and puddling does not prevent apple snail activity and does not control chironomids to the same extent as dry seeding. Nowadays, dry seeding is applied to about 10% of the paddy fields in the Ebro Delta (about 2,000 ha) specially in less-saline paddy fields, using the same technique used for other cereals, since rice seed can germinate without flooding, simply using the moisture present in the soil. In addition, dry seeding allows seedlings to be sown in rows, which is not possible with water-seeding rice (Franquet Bernis 2018).

Seedlings growing in rows create corridors where the first generation of weeds (mainly grassy weeds) can be easily weeded manually or mechanically (Ma Xu 2011). For mechanical weeding, a harrow can be used, although a rotovator or even a roller are alternative tools for weeding between rows. Harrows can be easily adapted to dry seeding in rows while the rotovator commonly used in the stale seed bed would be more difficult to work with among rice seedlings already growing in rows. Roller weeders or power weeders are useful weeding tools in planted (non-seeded) or in row-seeded crops. A grass harrow (with flexible tines) could be useful after dry seeding, although these are useless when fields are flooded.

In this work, we analyse the dynamics of weed species in different plots subjected to different treatments for weed control in rice cropping systems in the Ebro Delta. The objective of this work is to investigate which non-chemical strategies can be used to reduce the number of weeds in paddy fields, using both dry-seeding and water-seeding, since the conditions for grass emergence are very different.

2 MATERIALS AND METHODS

2.1 Experiment design

This study was conducted in a farmer’s field in the Ebro Delta (Tarragona, Spain) with an average annual temperature of 18º C and an annual precipitation of 500 mm. The experimental field (40º 42' 40''N 0º 37' 41''E) was a loamy-textured rice field with pH 7.9, CEC 1.13 dS·m^{-1}, 2.39% OM, 14.1 N-NO$_3$ mg·kg^{-1} and 23 mg P·kg^{-1}. Seeds of the temperate Japonica rice (*Oryza sativa*) variety *Argila* were provided by COPSEMAR (Valencia, Spain). Six different dry-seeding and water-seeding weed control treatments were applied for two consecutive years (Table 1) from May to October. The area of each of the plot was 8 x 30 m with independent water inlets and outlets and a 1.5 m wide land embankment surrounding each plot.

The experimental fields had not been treated with herbicides in the previous two years, and there was no cross-contamination from other adjacent fields. In addition, the weeds from the seed bank were qualitatively and quantitatively representative of the rice species present in the Ebro delta.

2.2 Experimental procedures

In our study, a total of eight weed control treatments tested during two consecutive years (Table SM1). Four non-chemical weed control treatments were tested. In addition, control treatments were also evaluated, two of which were managed as if they were dry-seeded and water-seeded plots, respectively, but without seeding rice (i.e., DSC dry-seeding control and WSC water-seeding control, respectively). These treatments were included to attain the maximum weed incidence and to determine the seed bank in each plot. The two remaining control treatments consisted of standard dry seeding and water seeding using herbicides commonly used by farmers in conventional rice production in Spain (i.e., DSH and WSH, respectively). In dry seeding, the seeding rate was 205

$kg{\cdot}ha^{-1}$ and 25 cm row spacing, while in water-seeding it was 274 $kg{\cdot}ha^{-1}$ to achieve optimal plant density. The weed control methods were named as follows: (1) dry seed control (DSC), (2) simple dry seed (SDS), (3) dry seed with supplemental irrigation (DSI), (4) dry seed with herbicide (DSH), (5) water seed control (WSC), (6) false seeding (stale seedbed) and water seeding (FSW), (7) false seeding (stale seedbed) and planting (FSP), (8) water seeding and herbicide (WSH) (Table SM1 in supplementary material).

All plots in the experimental plots were fertilised with 800 $kg{\cdot}ha^{-1}$ POLYSOL (2-6-10) as a basal dressing application. Dry-seeding plots (Table SM1) were fertilised with 400 $kg{\cdot}ha^{-1}$ $(NH_4)_2SO_4$ 45 days after seeding (DAS), 400 $kg{\cdot}ha^{-1}$ $(NH_4)_2SO_4$ at 60 DAS, and 200 $kg{\cdot}ha^{-1}$ $(NH_4)_2SO_4$ at 75 DAS, for a combined total of 236 $kg{\cdot}ha^{-1}$ total N. In the case of the water-seeded rice (Table 1), the basal fertilisation was supplemented with 400 $kg{\cdot}ha^{-1}$ $(NH_4)_2SO_4$ at 25 DAS (before flooding) and 250 $kg{\cdot}ha^{-1}$ $(NH_4)_2SO_4$ at 50 DAS, for a combined total of 250 $kg{\cdot}ha^{-1}$ total N.

2.3 Data collection

Weeds were identified per species and the plant densities were scored by using a 0.418 m^2 quadrat at different stages of weed growth. A final total weed scoring was performed by a human worker that exhaustively scored the number of plants per plot and species during a complete manual weeding in late July. In addition, the time required for manual weeding per surface was scored for each treatment.

Weed control efficacy was quantified by the percent of weeds that did not emerge per treatment compared to the unseeded control plot $R = ((C-E)/C) \times 100$, where R is the percent of weed reduction, C is the number of emerged weeds in the control plot, and E is the number that emerged in the treatment plot (Abbott 1925). When evaluating the occurrence of the aquatic weed *Heteranthera reniformis*, it was necessary to calculate the weed volume in litres per square metre ($l{\cdot}m^{-2}$) rather than the number of seedlings per area because of its biology.

For 2019, grain yield was estimated as follow: rice was manually mowed from placing randomly a circular surface of 0.418 m^2 and the results obtained were proportionally estimated to a plot size equivalent to 1 Ha based on the potential yield of the paddy fields. The grains and straw were threshed using a Kubota SRM27 harvester (Osaka, Japan), and the weight was recorded using a scale.

2.4 Statistical analysis

A three-factor design with double interactions was used to contrast the effects of treatment, species and year on the number of weeds per m^2 observed in the field. The Fisher-Snedecor (F) statistic was used for multiple comparisons of the levels of each factor. When significant differences were found for a factor, pairwise comparisons were made using Tukey's test and overlapping confidence intervals. The robustness of the statistics used was ensured by checking the validity conditions of the model or by checking the unimodality of the residuals. In addition, the Durbin-Watson statistic was used to check the independence of the sample values. The study with this design was conducted for dry and water water-seeding. The software used was Statgraphics Centurion XVIII software (Statistical Graphics Corp., Rockville, MD, USA).

3 RESULTS

3.1 Weed occurrence in dry-seeding

In dry seeding, statistical analysis of the results allowed the detection of significant differences between treatments ($p<0.0001$), between weed species ($p<0.0001$), in treatment-species interaction ($p=0.0001$) and in treatment-year interaction ($p=0.0440$). On the other hand, no significant differences were observed between years ($p=0.7033$) and no significant differences were observed in the species-year interaction (in the complete design, $p=0.9949$). This high p-value justifies that the species-year interaction was removed from the model. The comparison between treatment pairs showed that the average number of weeds per m^2 (plants/m^2), was significantly higher in the control treatment than in the other treatments (Figure 19a):

$$\overline{N}_{DSC}(9.54) > \overline{N}_{SDS}(1.73) \approx \overline{N}_{DSI}(1.54) \approx \overline{N}_{DSH}(0.49) \quad (1)$$

On the other hand, the number of observed plants of the grassy weed species *Echinochloa oryzoides* (Ard.) Fritsch (ECHORY) is significantly higher than that of the species *Echinochloa crus-galli* (L) Beauv. (ECHCRU) and the number of plants observed of the species *Oryza sativa.* spp*. spontanea* (L.) (red rice) (ORYSA), *Cyperus difformis* (L.) (CYPDI), *Scirpus maritimus* (L.) (SCPMA) and *Heteranthera reniformis* (Ruiz & Pavon) (HETRE) is almost residual (Figure 19b):

$$\overline{N}_{ECHORY}(11.71) > \overline{N}_{ECHCRU}(6.68) > \overline{N}_{SCPMA}(1.02) \approx \overline{N}_{ORYSA}(0.52) \approx \overline{N}_{HETRE}(0.02) \approx \overline{N}_{CYPDI}(0.00) \quad (2)$$

The interaction between treatments and species showed that the treatments SDS, DSI and DSH were effective in reducing the number of plants of the species with the highest abundance in the field (i.e. *E. crus-galli* and *E. oryzoides*), while they had an almost irrelevant effect when the species were present in residual form (i.e. *O. sativa* spp. *spontanea*, *C. difformis*, *S. maritimus* and *H. reniformis*). For the most abundant species in the field, the efficacy of the treatment relative to the control (i.e., percentage reduction of weeds) was evaluated as follows: 85.02% for *E. crus-galli* and SDS; 94.34% for *E. crus-galli* and DSI; 99.65% for *E. crus-galli* and DSH; 77.48% for *E. oryzoides* and SDS; 65.39% for *E. oryzoides* and DSI; and 98.62% for *E. oryzoides* and DSH (Table 5). On the other hand, the interaction between treatment and year showed the different effect of climatic conditions on the efficiency attributable to the treatments (Figures 19c and 19d).

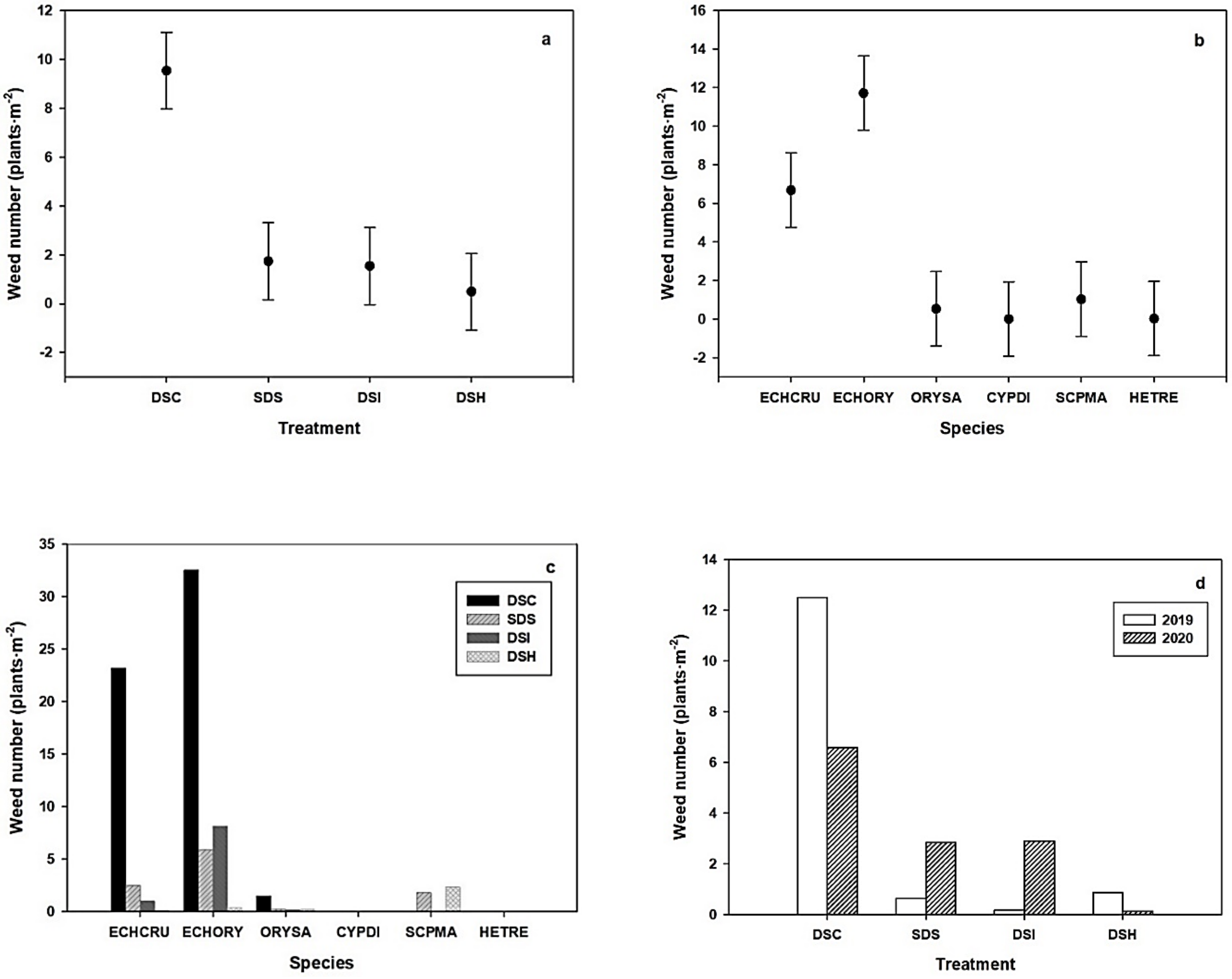


Figure 19: Results for the dry-seeding treatments a) weed density of all species average of both years: Dry seeding control (DSC), simple dry seeding (SDS), dry seeding with supplemental irrigation (DSI) and dry seeding with herbicide (DSH). b) weed density of all treatments average of both years: *Echinochloa crus-galli* (ECHCRU), *Echinochloa oryzoides* (ECHORY), *Oryza sativa*. spp. *spontanea* (ORYSA), *Cyperus difformis* (CYPDI), *Scirpus maritimus* (SCPMA) and *Heteranthera reniformis* (HETRE). c) weed density per treatment and specie average of both years: WSC (black), FSW (incrementing line), FSP (grey cross line) and WSH (decreasing line) d) weed density in each treatment per year: 2019 (white) and 2020 (increasing line).

3.2 Weeding time in dry-seeding

The statistical analysis of the experimental results for weeding time (hours/Ha) has highlighted the significance of the treatment ($p<0.0001$), weed species ($p<0.0001$) and the treatment-species interaction ($p=0.0001$). On the other hand, no significant differences were observed between years ($p=0.4663$) nor in the treatment-year interactions ($p=0.1441$) and species-year interactions ($p=0.2333$). The contrast between pairs in weeding time has provided similar results to those obtained in the number of weeds. In treatments (Figure 21a),

$$\bar{T}_{DSC}(93.45) > \bar{T}_{SDS}(17.88) \approx \bar{T}_{DSI}(15.28) \approx \bar{T}_{DSH}(9.92) \quad (3)$$

and in species (Figure 21b),

$$\bar{T}_{ECHORY}(120.64) > \bar{T}_{ECHCRU}(60.41) > \bar{T}_{ORYSA}(14.38) \approx \bar{T}_{SCPMA}(7.32) \approx \bar{T}_{HETRE}(2.06) \approx \bar{T}_{CYPDI}(0.00) \quad (4)$$

The treatment-species interaction has also shown that the SDS, DSI and DSH treatments are effective in reducing weeding time for species with more presence in the field (*i.e. E. crus-galli* and *E. oryzoides*), but treatments have almost an irrelevant effect when the species are present in residual form (*i.e. S. maritimus*, *O. sativa* spp. *spontanea*, *H. reniformis* and *C. difformis*) (Figures 21c).

3.3 Weed occurrence in water-seeding

For water seeding, significant differences have been found between treatments ($p<0.0001$), between weed species ($p<0.0001$), between years ($p=0.0214$) and in the treatment-species interaction ($p=0.0001$) and the species-years interaction ($p=0.0363$). On the other hand, no differences were observed in the treatment-year interaction ($p=0.4389$). The contrast between pairs of treatments has shown that the average of weeds observed per m^2 in the control treatment is significantly higher than the average observed in the other treatments (Figure 20a):

$$\bar{N}_{WSC}(23.67) > \bar{N}_{FSW}(5.00) \approx \bar{N}_{FSP}(4.19) \approx \bar{N}_{WSH}(0.48) \quad (5)$$

The number of plants observed per m^2 of *S. maritimus* and *H. reniformis* species is significantly higher than that of the other species. For water-seeding, the differences between *S. maritimus* and *H. reniformis* species are statistically significant and the number of plants observed of the *E. crus-galli*, *E. oryzoides*, *O. sativa.* spp. *spontanea* and *C. difformis* species is almost residual (Figure 20b):

$$\bar{N}_{SCPMA}(30.18) > \bar{N}_{HETRE}(14.23) > \bar{N}_{ECHCRU}(2.37) \approx \bar{N}_{ECHORY}(1.41) \approx \bar{N}_{CYPDI}(1.38) \approx \bar{N}_{ORYSA}(0.46) \quad (6)$$

Further, the number of plants observed in 2020 is significantly higher than that observed in 2019 ($\bar{N}_{2020}(11.41) > \bar{N}_{2019}(5.26)$) and this effect occurs in all the treatments studied (Figure 20d).

The treatment-species interaction has shown that the treatments FSW, FSP and WSH are effective in reducing the number of plants of the majority species (i.e. *S. maritimus*) and reduce or stabilize the number of the *H. reniformis* species. Regarding the most residual species (*i.e. E. crus-galli*, *E. oryzoides*, *O. sativa.* spp. *spontanea* and *C. difformis*), the effect is almost irrelevant (Figure 20c). For the species most abundant in the field, the efficiency per treatment in relation to the control has been evaluated as follows; 90.56% for *S. maritimus* and FSW; 85.61% for *S. maritimus* and FSP; 98.44% for *S. maritimus* and WSH; 19.31% for *H. reniformis* and FSW; 59.82% for *H. reniformis* and FSP; and 97.71% for *H. reniformis* and WSH. Similarly, the species-year interaction showed the differences observed between the majority species and the residual species (Table 6).

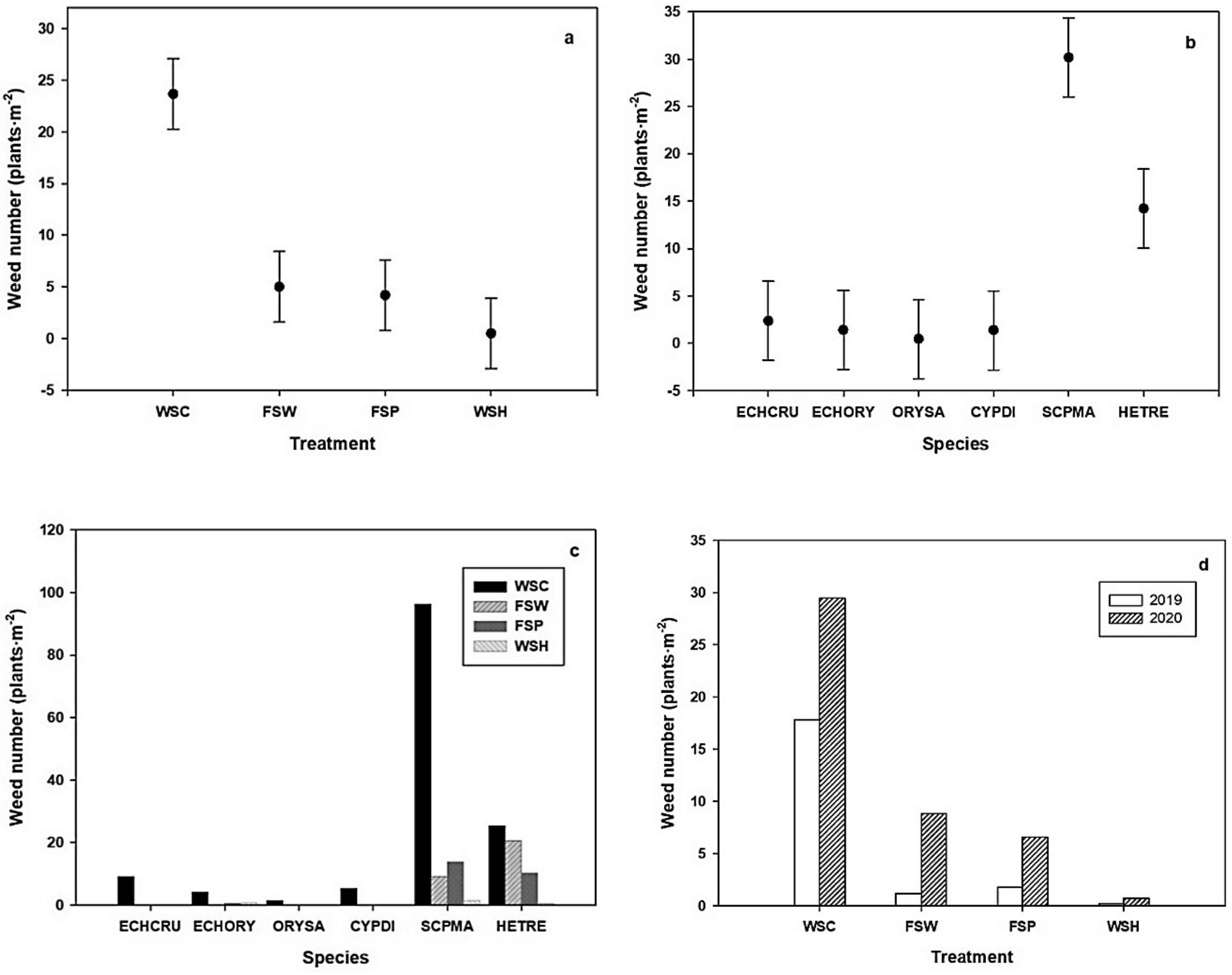


Figure 20: Results for the water-seeding treatments a) weed density of all species average of both years: Water seeding control (WSC), stale seedbed followed and water seeding (FSW), stale seedbed and planting (FSP) and water seeding with herbicide (WSH). b) weed density of all treatments average of both years: *Echinochloa crus-galli* (ECHCRU), *Echinochloa oryzoides* (ECHORY), *Oryza sativa*. spp. *spontanea* (ORYSA), *Cyperus difformis* (CYPDI), *Scirpus maritimus* (SCPMA) and *Heteranthera reniformis* (HETRE). c) weed density per treatment and specie average of both years: WSC (black), FSW (incrementing line), FSP (grey cross line) and WSH (decreasing line) d) weed density in each treatment per year: 2019 (white) and 2020 (dashed line).

3.4. Manual weeding costs in water-seeding

The statistical treatment of the experimental results during the weeding time has revealed the significance of the treatment ($p<0.0001$), the weed species ($p<0.0001$) and the treatment-species interaction ($p=0.0097$). On the On the contrary, no significant differences were observed between the years ($p=0.5263$). The interactions treatment-year ($p=0.8056$) and species-year ($p=0.9993$) have been removed from the statistic model. The contrast between pairs in weeding time has provided results compatible with those obtained in the number of weeds. In treatments (Figure 21d),

$$\bar{T}_{WSC}(170.26) > \bar{T}_{FSP}(47.75) \approx \bar{T}_{FSW}(36.92) \approx \bar{T}_{WSH}(16.29) \quad (7)$$

and in species (Figure 21e),

$$\bar{T}_{HETRE}(169.82) \approx \bar{T}_{SCPMA}(149.05) > \bar{T}_{ECHCRU}(29.43) \approx \bar{T}_{CYPDI}(25.49) \approx T_{ECHORY}(24.63) \approx \bar{T}_{ORYSA}(8.41) \quad (8)$$

The treatment-species interaction has also shown that the FSW, FSP and WSH treatments are effective in reducing the number of plants of the majority species (*S. maritimus*) and reduce or stabilize the number of plants of the *H. reniformis* species (Figure 21f).

3.5 Potential grain yield

For dry-seeding, the estimated (potential) yield in a commercial plot has been evaluated as follows ($\bar{X} \pm s$): 10586 ± 1741 Kg·Ha^{-1} for SDS; 7540 ± 537 Kg·Ha^{-1} for DSI; and 11899 ± 780 Kg·Ha^{-1} for DSH. For water-seeding, the estimated (potential) yield has been evaluated as follows: 11452 ± 750 Kg·Ha^{-1} for FSW; 11163 ± 234 Kg·Ha^{-1} for FSP; and 10801 ± 659 Kg·Ha^{-1} for WSH.

4 DISCUSSION

The non-chemical treatments are very efficient in reducing the number of weeds and the weeding time. In dry-seeding and water-seeding conditions no significant differences were observed between the chemical and non-chemical control treatments (Figures 19a, 20a, 21a and 22a). The negative controls gave not only an idea of the diversity and density of all weed species in the fields, but also gave a picture of the effects of the sowing strategy in the weed species proliferation. In detail, *E. crus-galli* and *E. oryzoides* were the most abundant weed species when dry-seeding (Figures 19b and 19c), while *S. maritimus* and *H. reniformis* were the most abundant weed species in the case of water-seeding (Figures 20b and 20c).

In dry-seeding, both (SDS and DSI) non-chemical weeding treatments were effective not only in reducing the weed densities, but also the weeding time for the most abundant weed species *E. crus-galli* and *E. oryzoides.* The species of this genus have high intra- and interspecific variability, with many ecotypes. Its competitiveness is also explained by the prolific generation of seeds and rapid vegetative growth (Masum et al. 2022). As expected, SDS and DSI treatments were less efficient for those residual weed species (*i.e. O. sativa* spp. *spontanea, C. difformis S. maritimus* and *H. reniformis*) (Figure 1c). Both treatments better controlled *E. crus-galli* than *E. oryzoides* and it would be good to even improve them to better control *E. oryzoides*.

Regarding the potential yield, there are significant differences between non-supplemental irrigation SDS (10,586 kg·ha^{-1}) and supplemental irrigation previous to dry seeding DSI (7,540 kg·ha^{-1}). Irrigating before dry seeding could be a good option when the soil is too dry, and we aim display weeds emergence to later kill them chemically or mechanically (Català, 1995). In our case, the sudden solubilization of crystalized salt patches strongly affected the rice seedlings germination and establishment. Thus, DSI better controlled the weeds although the potential yield was clearly lower than in SDS, due to an excess of salinity. The economic thresholds defined in weed management models (Das et al. 2021) could explain similar potential yields between SDS (10,586 kg·ha^{-1}) and DSH (11,899 kg·ha^{-1}) treatments. The yield is not affected under a certain weed pressure threshold as stated by many authors (Munnoli et al. 2023). Indeed, SDS is the common practice in dry seeding in Ebro Delta (Franquet Bernis, 2018). In this current work, the rotatory harrow placed in front of the seeder tractor effectively reduced the first generation weed.

S. maritimus and *H. reniformis* were the most abundant weed species after water-seeding (Figure 2b and 2c). These species have been documented in paddy fields in Europe (Campagna et al. 2022; Carretero 2004; Gussev et al. 2020), Southeast Asia (Caton 2010; Pacanoski and Mehmeti 2023) and America (Kraehmer et al. 2016). The high abundance of *S. maritimus* in Ebro Delta flooded paddy fields can be explained by its fast sprouting from tubers and its high salt-tolerance, which both give an initial advantage in front of rice and other weed species (Lillebø et al. 2003), although its reproduction based in tubers reduces its spatial dispersion (Charpentier et al. 2000). On the contrary, *H. reniformis* competitivity can be explained by its propagation capacity based in high seed production with a stepwise germination specially adapted to aquatic environments (Csurhes and Zhou 2008; Ferrero 1996; Zaidan et al. 2021). For weed species that are more prevalent in the field, chemical and non-chemical treatments are successful in reducing weed densities; however, when the species are not abundant, the effects of treatments are less effective. For the most abundant weed species, the efficacy of the FSW and FSP treatments is almost the same (Figures 20a, 20b and 20c).

Chemical (WSH control) and non-chemical (FSW and FSP) weed control practices have negligible differences in water-seeded potential productions: 11452 kg·ha^{-1} (FSW), 11163 kg·ha^{-1} (FSP) and 10801 kg·ha^{-1} (WSH). Again, the weed density thresholds affecting the rice yield are high (Das et al., 2021) and can explain why there's no effects in production. In India, the yield reductions derived from weeds competence in fields managed following FSW is higher than in FSP (Kumar et al. 2023). Mechanical planting permits mechanised weeding between rows and eases manual weeding (Pipeng et al. 2021), thus reducing the need of herbicides (Liu et al. 2023). In contrast, small weeding rollers for small tractors have been widely used in Japan for years (Shibayama 1994, 2001). Indeed, FSW was an old-fashioned standard water-seeding technique now replaced by pre-emergence herbicide treatments (Carreres 2013).

Gloria Extratropical cyclone in 2020 increased substantially the precipitation (Amores et al. 2020) during the second year of the study, flooding the fields in February, March and firsts April, and delaying all the fields preparation tasks and sowing (Figure 22). The delayed sowing affected rice production and favoured migratory birds rice predation at the end of the season. This exceptional event could partly explain the differences that have been observed between the years 2019 and 2020. Without significant differences in the average of the treatments (chemical and non-chemical), the number of weeds observed in crops with no chemical treatment was lower than or equal to that observed in crops with chemical treatment in 2019. In 2020, the result has been reversed (Figure 19d and 20d).

5 CONCLUSIONS

All of the non-chemical treatments were quite effective at reducing the number of weeds and the amount of time spent weeding. In the Ebro Delta, simple dry seeding (SDS) was the best dry-seeding treatment and could compete with herbicide-based common weeding method (DSH). False seeding and water seeding (FSW) and false seeding and planting (FSP) approaches can compete with the herbicide-based chemical method (WSH) in water-seeding. Our findings demonstrated that dry seeding favoured grassland weeds such as *E. crus-galli*, *E. oryzoides*, while discouraging sedges and aquatic weeds. On the contrary, in water-seeding treatments, cyperaceae and aquatic plants (*S. maritimus*, *C. difformis* and *H. reniformis*) are favoured and grasses are still a problem in the paddy fields. There are some encouraging outcomes, including the fact that non-chemical weed treatments increase control and produce results comparable to chemical treatments.

We are reporting on various non-chemical weeding techniques that can effectively control weeds at close levels of herbicide treatments. The proposed non-chemical weeding options represent better improvement over the chemical ones in the case of water-seeding than in the case of dry seeding. For weeding rice crops, new precision instruments are being developed. For sowing in rows and weeding between rows, all of them will require GPS-guided tractors. Smart farming for organic rice production is still being researched, and it will assist rice farmers in properly weeding their fields. These technological advancements will be critical in increasing organic rice output since they will assist both mechanized and human weeding and can be employed in either water or dry sowing. We improved non-chemical weed control through innovative seeding techniques and diversified cropping practises to contribute to the best integrated weed management.

The outcomes of this study will benefit both conventional and organic farming methods. As a result, we believe that these new and innovative strategies will help to efficiently reduce weed populations in sustainable rice cultivation.

ACKNOWLEDGEMENTS

This work was funded by the Spanish Ministry of Science and Innovation-State Research Agency (AEI) through the IMPRORICE Project, *Ministerio de Ciencia, Innovación y Universidades* (RTI2018-094487-B-I00), by the Catalan government (AGAUR) through the Alfred Palma-Guillén Industrial PhD program and by the Ebro Delta rice sector through the “Organic Delta Rice” Project. The authors wish to thank COPSEMAR (Valencia, Spain) for providing the rice seeds.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

A.P. and X.S. conceived the project and designed the experiments. A.P. and A.N. managed the field trial work, data collection and sample processing. M.S. and A.P analysed the results. A.P., M.S., X.S. and S.N. have interpreted the results A.P., X.S and M.S. have written the manuscript. All authors reviewed the submitted manuscript.

DATA AVAILABILITY STATEMENT

All data used for analyses are available from the corresponding author upon request.

SUPPORTING INFORMATION

Table 4: List summarizing different management treatments. DSC plots were managed in the same way as the following dry-seeded strategies, although this plot was neither seeded nor weeded. SDS plots were dry seeded while weeding with a rotary harrow placed in front of the seeder. DSI plots were watered twice before dry-seeding and weeding with a rotary harrow placed in front of the seeder. DSI was an additional weeding with a flexible tine harrow on plots. DSH plots were dry seeded with a rotary harrow placed in front of the seeder and an herbicide treatment was applied before flooding. WSC plots were managed in the same way as the following water-seeded strategies, although the parcel was neither weeded nor seeded. FSW plots were flooded and puddled using a metallic roller before water seeding. FSW plots were additionally weeded during the second year by using an experimental roller frame. FSP plots were flooded and puddled using a metallic cylinder before transplanting. WSH plots were weeded using herbicides before water-seeding. During the first year the FSP parcel was similarly flooded and puddled but transplanted. During the second year, the FSP parcel was additionally weeded twice by using a roller frame between rows.

	Code	Seeding management treatment	False seeding	Rice seeding	Weeding method
1	DSC	Dry seeding control	No	No seeding	None
2	SDS	Dry-seeding	No	Dry-seeding	Rotovator
3	DSI	Dry-seeding with supplemental irrigation	Yes	Dry-seeding	Rotovator + Flexible tin harrow
4	DSH	Dry-seeding with herbicide	No	Dry-seeding	Pendimenthalin (1.880 kg a.i.·ha-1) Penoxsulam (0.408 kg a.i.·ha-1)
5	WSC	Water-seeding control	No	No seeding	Puddling roller
6	FSW	Stale seed bed followed by water-seeding	Yes	Water-seeding	Roller weeder
7	FSP	Stale seed bed followed by water-seeding and planting	Yes	Water-seeding	Roller weeder
8	WSH	Water-seeding with herbicide	Yes	Water-seeding	Oxadiazon (0.325 kg a.i.·ha-1) Penoxsulam (0.410 kg a.i.·ha-1) Bentazona (1.150 kg a.i.·ha-1) MCPA (0.870 kg a.i.·ha-1)

(1) Dry-seeding control (DSC). The parcel was tilled and neither seeded nor weeded, so it was possible to use this parcel to score the maximum weed incidence per species under the dry-seeding method. (2) Simple dry seeding (SDS). Rice was dry-seeded in rows in a tilled plot using a MASCHIO

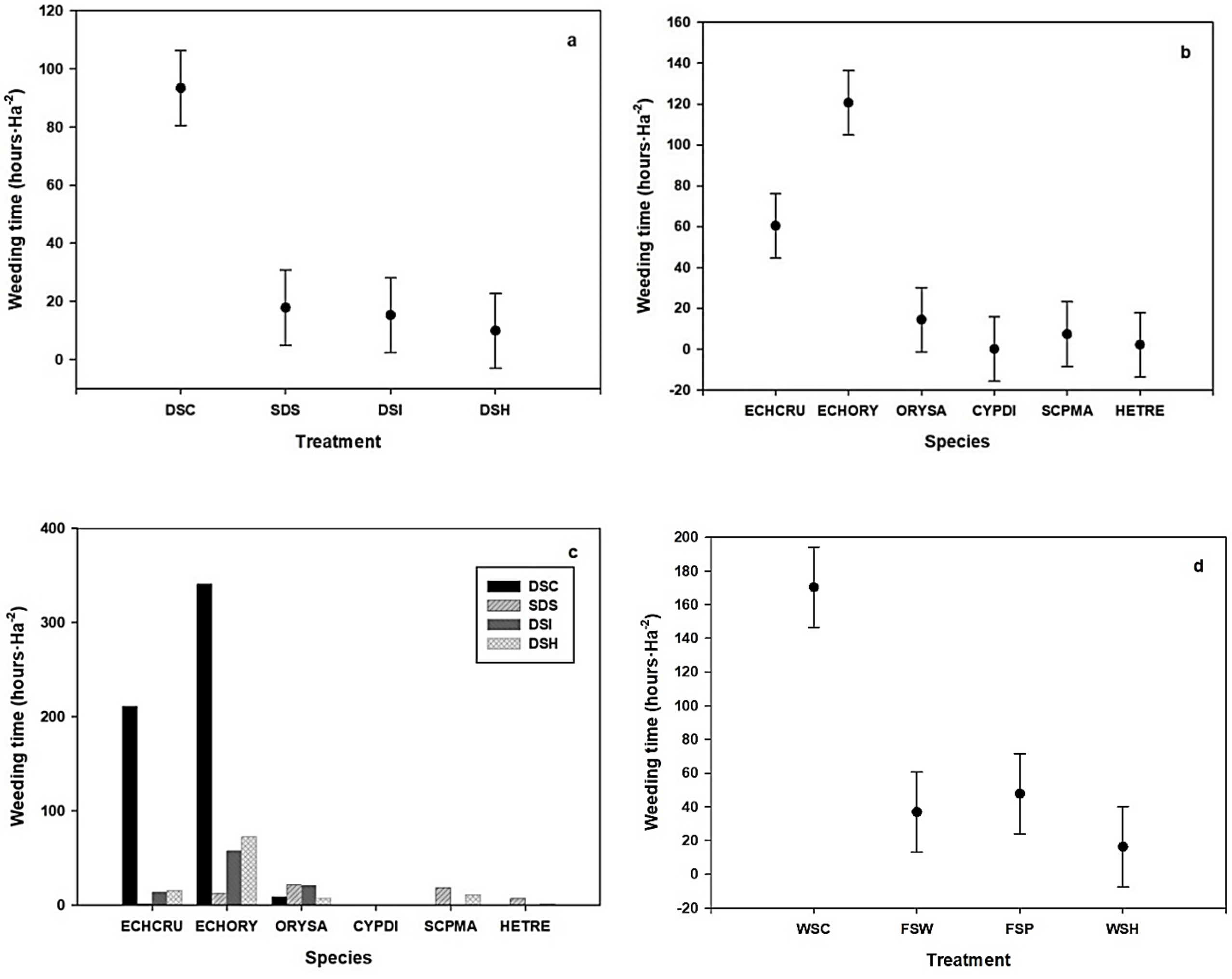
GASPARDO MTR-HD seeder at a 205 kg·ha^{-1} seeding dose and 25 cm row spacing. A rotary harrow placed in front of the seeder was used during seeding. (3) Dry seeding with supplemental irrigation (DSI). The tilled plot was watered twice to promote weed germination. Then, dry-seeding of the rice in rows using a MASCHIO GASPARDO MTR-HD seeder at a 205 kg·ha^{-1} seed rate, 25 cm row spacing, and a rotary harrow placed in front of the seeder. Dry seeding with flexible tine harrow weeding during the second year, the DSI treatment was similarly tilled and dry seeded in rows, but an extra weeding with a flexible tine harrow was performed at eight and 15 DAS to remove weeds while breaking down the crusted soil that resulted from strong precipitation after seeding. (4) Dry seeding with herbicide (DSH). A tilled parcel was dry seeded using a MASCHIO GASPARDO MTR-HD seeder at a 205 kg·ha^{-1} seed rate, 25 cm cm row spacing, and a rotary harrow placed in front of the seeder. Before flooding the field, 1.88 kg a.i.·ha^{-1} Pendimethalin (Pendinova 330 g a.i.·L^{-1}, LAINCO) + 40.8 g a.i.·ha^{-1} Penoxsulam (Viper 20.4 g a.i.·L^{-1}, CORTEVA AGRISCIENCE) were applied using a KUBOTA SPD8 tractor before flooding the field, 41 DAS using 8 m width bars and yellow ALBUZ AXI-0.15 spray nozzles, 1.4 atm., spray volume 200 l·ha^{-1}, and a 2.5 km·h^{-1} application speed. The field was flooded 4 days later (45 DAS) and the water depth was maintained at 10-15 cm. (5) Water-seeding control (WSC). The parcel was tilled, and the water was managed in the same way as the following water-seeded treatments, although the parcel was neither weeded nor seeded at all, so it was possible to use this parcel to score the maximum weed incidence per species under the water-seeding method. (6) False seeding (stale seed bed) followed by direct water-seeding (FSW). A tilled parcel was flooded to induce weed emergence and puddled using a metallic roller 30 days after flooding (DAF). After four days (34 DAF), the parcel was direct water-seeded using a KUBOTA SPD8 seeder at an increased 274 kg·ha^{-1} seed rate. During the second year, the parcel was mechanically weeded at 15 and 30 DAS by using an experimental 3m roller frame capable of weeding between rows. (7) False seeding (stale seed bed) and planting (FSP). A tilled parcel was flooded and puddled using a metallic cylinder 40 DAF. Then a YANMAR YR8D was used to transplant rice seedlings 42 DAF. During the second year, the parcel was weeded twice between rows by using a 3m roller frame at 15 and 30 DAS. (8) Water-seeding and herbicide (WSH). Ten days before seeding, 0.325 kg·ha^{-1} Oxadiazon (Ronstar 250 g a.i. L^{-1}, BAYER) was applied and the parcel was direct water-seeded using a KUBOTA SPD8 seeder at an increased 274 kg·ha^{-1} seed rate. Then, 40.8 g a.i.·ha^{-1} Penoxsulam was applied 30 DAS, both treatments using a KUBOTA SPD8 tractor having 8 m width bars and yellow ALBUZ AXI-0.15 spray nozzles, 1.4 atm., spray volume 200 l·ha^{-1}, and 2.5 km·h^{-1} application speed. During the second-year assay, a supplemental herbicidal treatment consisting of 1.15 kg a.i.·ha^{-1} of Bentazona (Basagran 870 g a.i.·kg^{-1}, BASF), 0.2 kg a.i.·ha^{-1} of MCPA (MCPA DMA SL, 500 g a.i. L^{-1}, NUFARM) and 34.8 g a.i.·ha^{-1} of methyl oleate and methyl palmitate mixture (DASH HC, 34.8 g a.i.·L^{-1}, BASF) was applied 50 DAS.

Table 5: Efficacies in reduction weed plants of dry-seeding treatments compared with dry seeded control during both years: Dry seeding (SDS), dry seeding with supplemental irrigation (DSI) and dry seeding with herbicide (DSH). The efficiency calculation does not apply (n.a.) when the number of weeds of the species in the control is 0.

DS treatments	SDS-19	SDS-20	DSI-19	DSI-20	DSH-19	DSH-20
ECHCRU	99.7	70.3	99.2	89.5	99.9	99.3
ECHORY	82.7	62.3	98.7	32.0	99.8	97.4
ORYSA	84.7	n.a.	88.9	n.a	87.4	n.a
CYPDI	n.a	n.a	n.a	n.a	n.a	n.a
SCPMA	n.a	n.a	n.a	n.a	n.a	n.a
HETRE	n.a	n.a	n.a	n.a	n.a	n.a

Table 6: Efficacies in reduction weed plants of water-seeding treatments compared with water seeded control during both years: Stale seed bed (false seeding) followed by water seeding (FSW), stale seed bed and planting (FSP) and water seeding with herbicide (WSH). The efficiency calculation does not apply (n.a.) when the number of weeds of the species in the control is 0.

WS treatments	FSW-19	FSW-20	FSP-19	FSP-20	WSH-19	WSH-20
ECHCRU	99.6	100	99.8	96.0	100	95.0
ECHORY	95.0	100	82.1	86.4	88.1	82.9
ORYSA	86.8	n.a	91.4	n.a	100	n.a
CYPDI	98.3	100	95.8	100	100	100
SCPMA	95.4	87.9	99.7	77.7	98.6	98.4
HETRE	79.0	-5.6	36.7	69.4	100	96.7



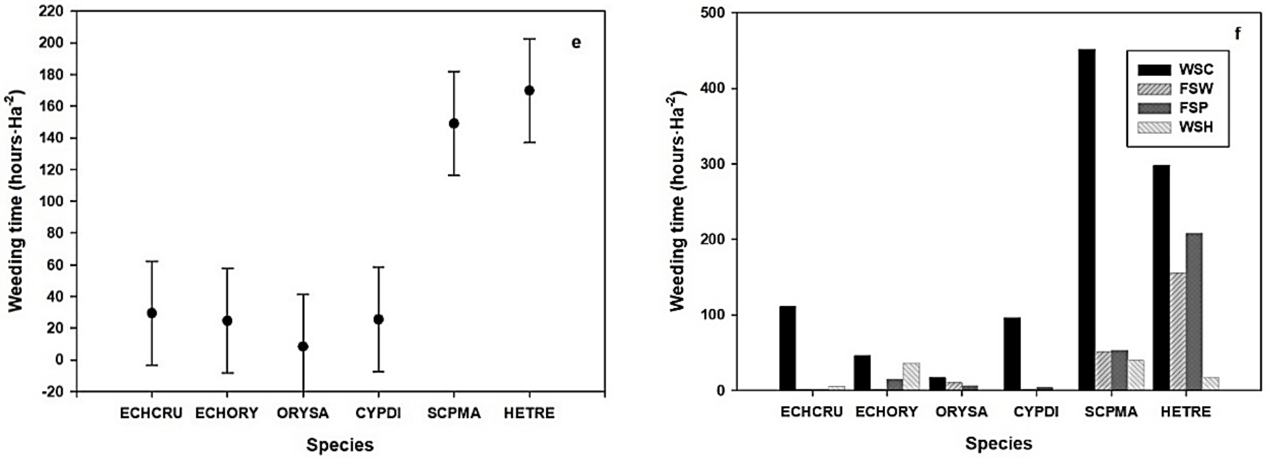


Figure 21: Results for the dry-seeding treatments a) weeding time of all species average of both years: Dry seeding control (DSC), simple dry seeding (SDS), dry seeding with supplemental irrigation (DSI) and dry seeding with herbicide (DSH). b) weed incidence of all treatments average of both years: *Echinochloa crus-galli* (ECHCRU), *Echinochloa oryzoides* (ECHORY), *Oryza sativa.* spp. *spontanea* (ORYSA), *Cyperus difformis* (CYPDI), *Scirpus maritimus* (SCPMA) and *Heteranthera reniformis* (HETRE). c) weed incidence per treatment and specie average of both years: WSC (black), FSW (incrementing line), FSP (grey cross line) and WSH (decreasing line). Results for the water-seeding treatments d) weeding time of all species average of both years: Water seeding control (WSC), stale seedbed followed and water seeding (FSW), stale seedbed and planting (FSP) and water seeding with herbicide (WSH). e) weed incidence of all treatments average of both years: f) weed incidence per treatment and specie average of both years: WSC (black), FSW (incrementing line), FSP (grey cross line) and WSH (decreasing line).

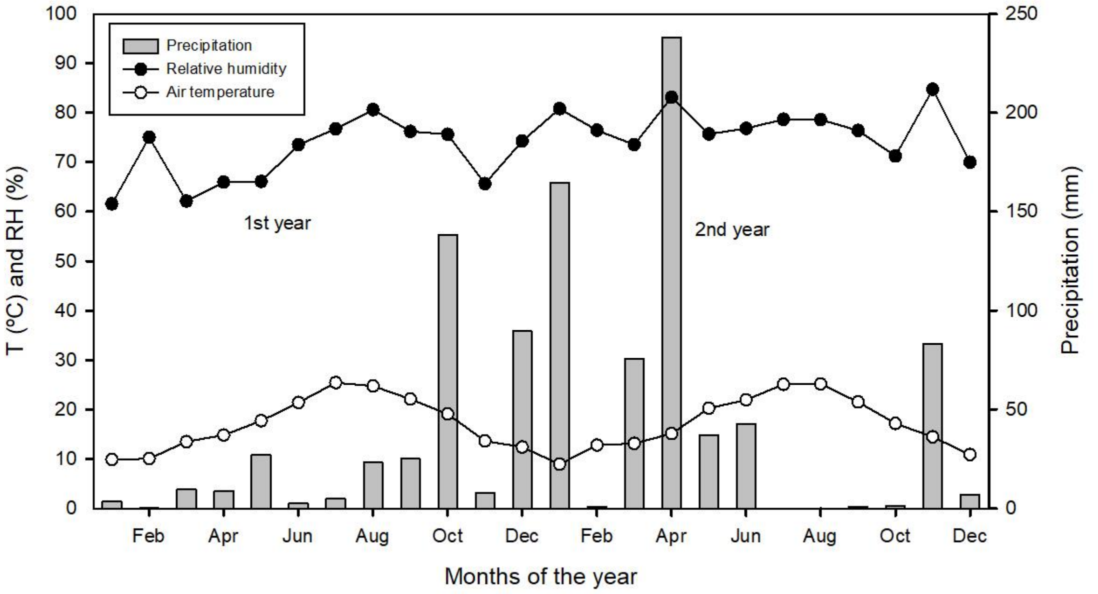


Figure 22: Data of climate conditions in Amposta station for years 2019 and 2020: (Left) temperature in ºC and relative humidity in percentage, (right) precipitation in mm.

CHAPTER II: Screening of rice cultivars and non-synthetic phytosanitaries to control blast disease in Ebro Delta paddies

Alfred Palma-Guillén, Ariadna Nadal, Néstor Pérez-Méndez, Maria del Mar Català-Forner, Salvador Nogués, and Xavier Serrat.

Submitted to:
Plant disease

Screening of rice cultivars and non-synthetic phytosanitaries to control blast in Ebro Delta paddies

Alfred Palma-Guillén1,2*, Ariadna Nadal1, Néstor Pérez-Méndez3, Maria del Mar Català-Forner3, Salvador Nogués2, and Xavier Serrat 2.

1 AGROSERVEIS.CAT SL, Polígon Industrial Les Molines, Parcel·la 2.1, 43580 Deltebre, Tarragona, Spain;

2 Departament de Biologia Evolutiva, Ecologia i Ciències ambientals, Secció de Fisiologia Vegetal, Universitat de Barcelona, 08028 Barcelona, Spain

3 IRTA-Amposta, Ctra. Balada Km1, 43870, Amposta, Tarragona, Spain

ABSTRACT

Rice blast (*Magnaporthe grisea* (Herbert) Barr, anamorph *Pyricularia grisea* Sacc., synonym *P. oryzae* Carava) represents one of the worst rice diseases (Ebbole 2007). The application of synthetic fungicides is the main method for blast control, yet not allowed for organic rice farming. As alternative, Sulphur and silica-based commercial fungicides might effectively control rice blast in organic farming without contributing to adverse effects on rice growth, yet evidence on their efficacy across a broad range of Japonica rice cultivars is still scarce. The objective of this work is to screen blast tolerance in six temperate Japonica rice cultivars while assessing the efficacy of Sulphur and silica-based non-synthetic fungicides for blast control. The experiment was performed during both two years (2019-2020), with a Completely Randomized Block Design (CRBD) arranged in a single factor with 4 replications. The most blast-sensitive cultivar was Bomba, followed by Argila, Guara, J. Sendra and Montanelli, while V.exp.1 was exceptionally blast tolerant. The only effective non-synthetic fungicide was Sulphur at high doses for cultivars with medium blast sensitivity. In contrast, none of the treatments resulted in blast-tolerance improvement in either the most blast-tolerant (V.Exp.1) or the most blast-sensitive (Bomba) cultivars. We conclude that Sulphur (Thiopron, 82.5 % a.i. L-1, SC, UPL Iberica) at a 7.5 l·ha-1 dose has potential to help organic farmers control rice blast. Thiopron fungicide yet being registered and commercialized in Spain for rice cultivation.

Keywords: Oryza sativa, organic production, fungicides, rice blast, Spain.

1 INTRODUCTION

Globally, there is increasing pressure for a transition towards organic farming systems, but it has been limited by certain factors. The control of blast rice is one of the majors constrains because affected directly to rice grain yields. Thus, it is necessary the assessment of the strategies available with an organic production that allows fungus disease control efficiency. This work analyses a wide class of the Japonica cultivars and non-synthetic products blast control in paddy fields.

The world's growing population is expected to exceed nine billion people by 2050, which poses a critical challenge to the conservation of global biodiversity while maintaining food security (Godfray et al. 2010). Rice is an important staple food consumed by more than half of the global population. It is cultivated in more than 100 countries, in which over 1 billion people depend on it for their livelihood, particularly in Asia. Based on the rice production quantity data (2020) estimated by the Food and Agriculture Organization of the United Nations (FAO), the world production of paddy rice in 2020 was about 758 million tons (Tan et al. 2023a). Rice is not just a grain; it is the lifeline and the second most important crop next to wheat at a global level (Tony Cisse 2005). Rice can be grown under varying climatic conditions but widely affected by many diseases caused by fungi, bacteria, viruses, and mycoplasmas that can results in significant yield losses (Ou 1985).

The Ebro delta, in northeast Spain is a 320 km^2 area with 199 km^2 of paddy fields in 2021, representing 62% of the Ebro Delta's surface area (Catalunya, Spain). Rice cultivation is the main economic activity in the delta (Genua-Olmedo et al. 2022). Organic food production has been steadily increasing in Catalunya over the past 10 years (CCPAE 2020b), although organic rice production has not been increasing at the same rate. Production of organic crops is characterised by irregular yield and substantial productivity gaps with respect to conventional systems (Delmotte et al. 2011a). Unfortunately, transitioning rice to organic production is risky for two main reasons: weeds and blast (Agbowuro et al. 2020b; Hoosain et al. 2013). In the Ebro Delta, rice blast represents one of the priorities for farmers due to annual yield losses, but especially the potential yield losses during the high blast-incidence years (Català et al. 2008; Galimany et al. 2006; Marín et al. 1992).

The application of synthetic fungicides is currently the main blast control method in use. Although they are effective, synthetic fungicides affects to human and environmental health, while driving fungal populations to gradually become resistant to the fungicides (Agbowuro et al. 2020b; Bartlett et al. 2002; Sella et al. 2021). Several molecules with diverse modes of action against rice blast have been developed and registered since the 1960s (Amoghavarsha et al. 2021). (Kongcharoen et al. 2020; Lobo 2008; Mohiddin et al. 2021; Pak et al. 2017). However, management strategies using synthetic fungicides has proven to be ineffective for long-term blast control under field conditions (Deng and Naqvi 2019).

Additional management strategies relying on more cultural inputs such as the use of blast-resistant cultivars or reductions in nitrogen fertilization and plant densities have previously been used. Non-synthetic synthetic fungicides such as Sulphur have been used for organic crop cultivation (Khandagave 2023; van Bruggen et al. 2016). Sulphur is a common and highly effective fungicide that has been in use in one form or another for a long time (Khandagave 2023) Silica is known as an essential element for rice plants and is effective in controlling rice blasts (Nakashima et al. 2001). Many researchers have demonstrated that applying Silicon to the soil causes greater Silicon concentrations in rice, and as a consequence, an increase in blast resistance (Ishiguro 2001). Adequate Silicon fertilization can increase rice yield and mitigates biotic and abiotic stress and improves grain quality by lowering the content of cadmium and inorganic arsenic. Silicon is incorporated into structural components of rice cell walls where it increases cell and tissue rigidity in the plant (Meharg and Meharg 2015).

The objective of this work is to assess the efficacy of Sulphur or Silicon-based fungicides in controlling rice blast in different rice cultivars in Ebro Delta conditions. The experimental design consisted in a Completely Randomized Block Design arranged in a single factor with 4 replications. The cultivar and treatments as fixed factors to assess the efficacy of treatments and both percentage of failed panicles and grain yield as variables of interest.

"The combination of Japonica rice cultivars with grain yield potential and non-synthetic phytosanitary will be integrated blast management in the organic paddy fields in Ebro Delta". (1) We expect found Japonica rice cultivars with potential grain yield in organic production system. (2) We expect found non-synthetic phytosanitaries to control blast failed panicles. (3) We expect found positive interactions between both factors Japonica rice cultivars and non-synthetic phytosanitaries.

2 MATERIAL AND METHODS

2.1 Fungicide applications

The first application was performed before the flag leaf sheath opening stage BBCH 32-45 (Lancashire et al. 1991), the second application was performed at the end of the panicle emergence stage (BBCH 49-59), and the last application was carried out at the early dough stage (BBCH 55-71). Thiopron was applied at two different doses: 7.5 litres $\cdot ha^{-1}$ (high dose) and 6 litres $\cdot ha^{-1}$ (low dose). In turn, diatomaceous earth was applied at a 20 $kg \cdot ha^{-1}$ dose. We used a combination of synthetic fungicides as the positive control, which represents the maximum potential control for rice blast. Specifically, this strategy included a first application of Amistar top (Azoxistrobin 20% a.i. $litre^{-1}$ + Difenoconazol 12.5% a.i. $litre^{-1}$, WP, Syngenta), a second application of Flint (Trifloxistrobin 50% a.i. $litre^{-1}$, WG, Bayer Crop Science) and a third application of Ortiva (Azoxistrobin 25% a.i. $litre^{-1}$, WP, Syngenta) at commercial doses. We additionally used a negative control treatment, resulting from the no application of fungicide products, which can be used to assess the susceptibility of the different cultivars to rice blast. The application of synthetic fungicide and both Sulphur doses was achieved using a Kubota SPD8 tractor having 4 m wide booms adapted to the plot and yellow Albuz AXI-0.15 spray nozzles, 2.2 atm., spray volume 300 litre·ha^{-1} and 2.5 km·h^{-1} application speed. The application of diatomaceous earth was achieved using Stihl SR-450 motorized backpack sprayer (Stihl, Inc., Virginia Beach, VA) on setting ensure complete leaf coverage, with a flow rate of 1.30 m^{3}·h and 2,5 km·h^{-1} application speed.

2.2 Experimental design

The research was performed in the Delta del Ebro (Tarragona, Spain), having an 18º C average yearly temperature and 500 mm precipitation. The experimental field was a rice paddy with silty clay loam texture, pH 7.9, CEC 1.13 dS·m^{-1}, 2.39% OM, 14.1 N-NO_3 mg·kg^{-1} and 23 mg P·kg^{-1}. The experiment was performed during two consecutive years (2019-2020), including six of the most widely used temperate Japonica rice cultivars in the Ebro Delta: Argila - Nº 10866 – Semillas certificadas Castells S.L. – Tarragona (Spain), Bomba – free license, Guara – free license, J.Sendra – Nº 12627 – Coop. Productores semillas de arroz SCL Copsemar – Valencia – (Spain), Montsianell – Nº 14420 – Coop. Productores semillas de arroz SCL Copsemar – Valencia – (Spain) and V.Exp 1 – Confidential (the latter deidentified for confidentiality). The non-synthetic fungicides were Thiopron, (Sulphur 82.5 % a.i. litre^{-1}, SC, UPL Iberica) and diatomaceous earth (15,5% Silicon, DP)

The experimental design consisted in a Completely Randomized Block Design arranged in a single factor with 4 replications. We overall established 120 experimental plots (6 x 5 m) with 4 replicates, resulting from the combination of 6 Japonica rice cultivars, 4 fungicide treatments and non-treated plot. Experimental plots were spaced by a 1 m buffer zone to avoid fungicide run-offs. We used a water seeding strategy by using a commercial seeder (Kubota SPD8). The sowing density was 205 kg·ha^{-1} for all cultivars except for Bomba 103 kg·ha^{-1}.

2.3 Other applications

All plots were fertilized using 800 kg·ha^{-1} Polysol (2-6-10) basic dressing supplemented with 400 kg·ha^{-1} $(NH_4)_2SO_4$ 25 days after sowing (before flooding) and 250 kg·ha^{-1} $(NH_4)_2SO_4$ 50 days after sowing, which represents 217 kg·ha^{-1} total nitrogen. A standard 1.3 litres·ha^{-1} pre-emergence herbicide treatment with oxadiazon (Ronstar 25 EC, 250 g a.i. litre^{-1}, EC, Bayer) was applied ten days before seeding and 2 l·ha^{-1} pre-emergence herbicide treatment with penoxsulam (Viper, 2.04 g a.i. litre^{-1}, OD, Dow Agroscience Iberica) was applied 20 days before seeding using a Kubota SPD8 tractor having 8 m wide booms adapted to the plot and yellow Albuz AXI-0.15 spray nozzles, 1.4 atm., spray volume 200 litre·ha^{-1} and 2.5 km·h^{-1} application speed. Manual weeding was also necessary 45-50 days after seeding using sickle to remove weed.

2.4 Data collection

The incidence was calculated by scoring the number of blast-affected panicles with blast disease symptoms (necrosis) in collar or/and neck. While the severity of the panicle blast attack was recorded based in four-category scale: 25, 50, 75 and 100% severity. All assessments were set up in the total area of each plot following visual estimation. The number of relative failed panicles was calculated by multiplying the incidence by the severity. The efficacy of fungicides was scored on the basis of the reduction in failed panicles between non-treated and treated plots.

The grain yield (kg·ha^{-1}) was estimated for each experimental plot by manually harvesting panicles from four 1 m^2 circles per plot. A Kubota RX 1050AD thresher was used to clean up the grain from the straw. Percentage grain moisture content was recorded for all the rice samples at harvest during October, with the use of John Deere MCXFA1873 grain moisture tester (Manufactured by AgraTronixTM Moisture Chek PlusTM, Deere and Company; Batch SW08122, U.S.A.). The rice yield at 14% moisture content was corrected in samples over 14% by subtracting 1.2% of the grain weight per 1% excess moisture above 14%. Rice impurities were also scored by running two 200 g replicates from each sample through a high-performance AEG grain sorting machine twice and weighing the discarded broken grains manually on a scale.

2.5 Statistical analysis

To assess the effect of each strategy on the percentage of panicle failure and rice yield across the different rice cultivars we applied a set of generalized linear models (GLM) for each of these response variables. Specifically, we applied a GLM for each rice cultivar that included the treatment strategy and the experimental year as interacting fixed factors to assess whether the efficiency of treatments was consistent between years. In general, we used a gaussian distribution of errors in all applied models except for the failed panicle models where the number of zeros was disproportionally high. In these models (Montsianell and V. Exp.1) we used a tweedy distribution with a *log* link function, which is intended to deal with data distribution with clustered zeros in response variables (Foster and Bravington 2013). Then we applied a poshoc Tukey test to evaluate statistical differences among levels of the treatment strategies and years. We used R software (v4.1.2) (R Core Team 2022) and the glmm TMB R package to perform all the GLMMs (Brooks et al. 2017). In addition, the DHARMa package was used to check for potential patterns in model residuals (Hartig 2020), emmeans for computing contrast between factor levels (Lenth et al. 2020), and tydiverse for both data management and visualization (Wickham et al. 2019).

3 RESULTS

3.1 Cultivar screening

Bomba showed the highest percentage of failed panicles 52% in 2019, and 74% in 2020. In contrast, V.Exp.1 was the most blast-resistant cultivar in terms of failed panicles, recording less than 1% panicle failure. Argila showed a lower percentage of panicle failed than Bomba and higher than V.Exp.1 in both years. Guara, J. Sendra and Montsianell showed a similar panicle failure in both years, although Guara tended to perform worse and Montsianell better. This group of three cultivars did not show statistically significant differences in failed panicles when compared to V.Exp.1 (Figure 23a and 23b).

3.2 Non-synthetic fungicide screening

Synthetic fungicide control was the only strategy resulting in a statistically significant reduction in the percentage of failed panicles during both years. Even though the high Sulphur treatment also showed a tendency for a reduction in the percentage of failed panicles in front of non-treated plot in all cultivars during both years (Figure 23c and 23d).

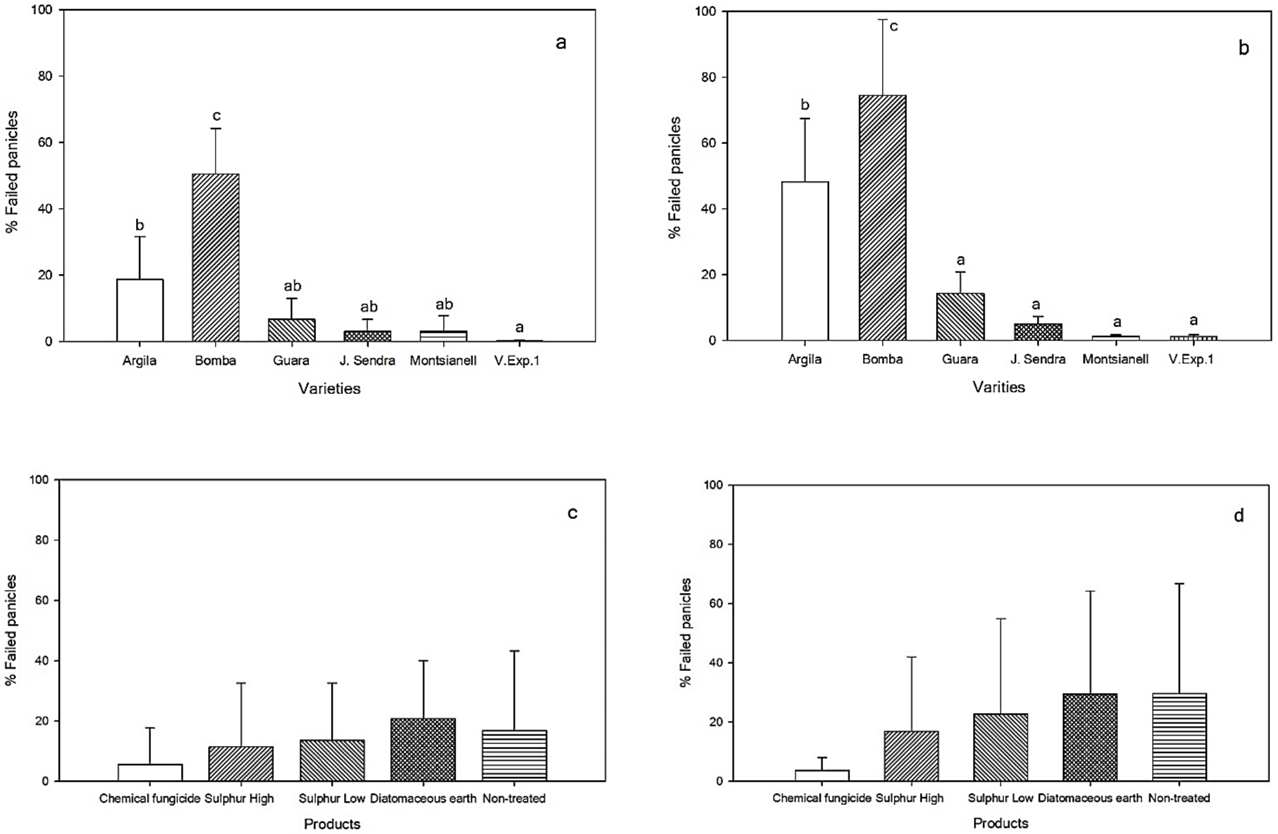


Figure 23: Blast failed panicles per cultivar in non-treated plot (Control): Argila (white); Bomba (lines increasing); Guara (lines decreasing); J. Sendra (cross hatch); Montsianell (horizontal lines) and V.Exp.1 (vertical lines) during the first (a) and second (b) years. Blast failed panicles per treatment in six Japonica rice cultivars during the first year (c) and second year (d): Chemical fungicide (white); high-dose Sulphur (lines increasing); low-dose Sulphur (lines decreasing); diatomaceous earth (mixed lines) and non-treated (horizontal lines). Different letters represent significant differences at the 95% confidence interval according to the Anova LSD test.

3.3 Interactions between non-synthetic fungicides and rice cultivars

The synthetic fungicide control treatment was the only one that reduced the incidence of blast-affected panicles in Bomba (Tables 7 and 8). The blast panicles affected of the non-treated plots were 68-95% for Bomba, 28-75% for Argila, 5-21% for Guara, 3-13% for J. Sendra, 3-5% for Montsianell and 1-4% for V.Exp.1 during 2019 and 2020, respectively (Figure 23a and 23b). High-dose Sulphur had the lowest blast incidence from 22 to 82% for the highly blast-sensitive cultivars, from 5% to 75% in the medium blast-sensitive ones and from 0.2 to 2% in the low blast-sensitive ones. Diatomaceous earth did not result in a clear reduction in blast incidence when compared to the non-treated plots (Tables 7 and 8).

Table 7: Panicle blast incidence per cultivar and treatment during the first year. Different letters represent significant differences at the 95% confidence interval according to the ANOVA LSD test.

S/No.	Treatments	Argila	Bomba	Guara	J. Sendra	Montsianell	V.Exp.1
1	Chemical Fungicide	4 ± 4 a	30 ± 17 a	2 ± 0.7 a	1 ± 0.5 a	0.4 ± 0.4 a	0.1 ± 0.2 a
2	High-dose Sulphur	11 ± 6.5 a	22 ± 81.5 ab	5 ± 3.1 ab	1.6 ± 0.3 a	0.8 ± 0.5 a	0.2 ± 0.3 a
3	Low-dose Sulphur	29 ± 47.1 a	32 ± 91 ab	10 ± 12.3 ab	2 ± 1.3 a	2 ± 1.3 a	0.3 ± 0.4 a
4	Diatomaceous earth	43 ± 44 a	52 ± 30.7 ab	24 ± 26.8 b	16 ± 24.5 a	14 ± 23 a	0.9 ± 0.3 b
5	Non-treated	28 ± 23.1 a	68 ± 30.2 b	5 ± 1.8 ab	3 ± 1.4 a	5 ± 4.2 a	1 ± 0.3 ab
	F	1.71	5.13	1.76	1.05	1.18	2.41
	CV (%)	120	34	138	234	236	74
	P-value	0.1974	0.0068	0.185	0.4468	0.3823	0.0861

Table 8: Panicle blast incidence per cultivar and treatment during the second year. Different letters represent significant differences at the 95% confidence interval according to the ANOVA LSD test.

S/No.	Treatments	Argila	Bomba	Guara	J.Sendra	Montsianell	V. Exp.1
1	Chemical Fungicide	25 ± 23.6 a	31 ± 11.1 a	9 ± 6.6 a	3 ± 1 a	1 ± 0.6 ab	1 ± 0.2 a
2	High-dose Sulphur	42 ± 25.7 ab	82 ± 14.8 b	14 ± 5.8 a	6 ± 1.8 b	1 ± 0.6 ab	2 ± 1.2 ab
3	Low-dose Sulphur	59 ± 32.9 bc	91 ± 6.8 b	19 ± 8.9 ab	5 ± 1.1 b	1 ± 0.9 ab	2 ± 1 bc
4	Diatomaceous earth	68 ± 36.8 c	95 ± 3.3 b	40 ± 34.3 b	12 ± 1.2 c	2 ± 0.7 bc	4 ± 1.6 cd
5	Non-treated	75 ± 39 c	95 ± 3.7 b	21 ± 3.8 ab	13 ± 1.8 c	3 ± 1.2 c	4 ± 2.5 d
	F	13.47	21.29	2.78	22.02	5.90	6.24
	CV (%)	26.96	11.40	69.56	18.88	34.38	46.09
	P-value	0.0001	<0.0001	0.0576	<0.0001	0.0038	0.003

Statically significant differences in blast severity were detected in Argila and Guara panicles between the synthetic fungicide and the Sulphur and diatomaceous earth treated and the non-treated plots. Bomba showed the highest blast severity, with 100% during the first year and 34-94% in the second year. Both the synthetic fungicide and the high-dose Sulphur resulted in the lowest severity in Montsianell during the first year but not in the second year. The high-dose Sulphur showed statistically significant reduced panicle severity in Argila and J. Sendra, while low-dose Sulphur showed statistically significant reduced panicle severity in Guara and J. Sendra (Tables 9 and 10).

Table 9: Panicle blast severity per cultivar and treatment during the first year. Different letters represent significant differences at the 95% confidence interval according to the ANOVA LSD test.

S/No.	Treatments	Argila	Bomba	Guara	J. Sendra	Montsianell	V.Exp.1
1	Chemical Fungicide	54 ± 10.7 a	100 ± 0	36 ± 7.4 a	48 ± 16.3 a	44 ± 31.5 a	25 ± 28.9 ab
2	High-dose Sulphur	86 ± 9.9 b	100 ± 0	78 ± 8.5 bc	63 ± 12.3 ab	44 ± 20.3 a	1 ± 1 a
3	Low-dose Sulphur	84 ± 8.2 b	100 ± 0	70 ± 13.9 b	63 ± 24.1 ab	59 ± 13.4 ab	16 ± 18.9 a
4	Diatomaceous earth	81 ± 13.2 b	100 ± 0	70 ± 9.7 b	60 ± 15.9 ab	77 ± 26.3 b	63 ± 39 b
5	Non-treated	81 ± 7.8 b	100 ± 0	86 ± 7.1 c	77 ± 12.9 b	62 ± 13.7 ab	20 ± 23.2 a
	F	4.10	sd	9.98	1.42	2.88	1.65
	CV (%)	13.28	0.00	13.94	26.43	31.67	112.55
	P-value	0.0159	sd	0.0004	0.2813	0.0518	0.2137

Table 10: Panicle blast severity per cultivar and treatment during the second year. Different letters represent significant differences at the 95% confidence interval according to the ANOVA LSD test.

S/No.	Treatments	Argila	Bomba	Guara	J. Sendra	Montsianell	V. Exp.1
1	Chemical Fungicide	37 ± 28.5 a	34 ± 13.8 a	36 ± 4 a	35 ± 5 a	58 ± 29 a	27 ± 4.2 a
2	High-dose Sulphur	68 ± 21.8 b	76 ± 24.4 b	61 ± 21.3 bc	42 ± 11.7 ab	75 ± 20.4 a	41 ± 17.2 ab
3	Low-dose Sulphur	77 ± 15.8 bc	88 ± 10.4 b	59 ± 16.8 b	44 ± 7 b	53 ± 17.8 a	44 ± 3.3 b
4	Diatomaceous earth	80 ± 14.1 bc	94 ± 3.4 b	72 ± 11.5 c	60 ± 13.6 c	57 ± 22.6 a	42 ± 5.7 ab
5	Non-treated	88 ± 10.7 c	93 ± 3.9 b	70 ± 20.9 bc	57 ± 12 c	60 ± 18.9 a	47 ± 15.8 b
	F	16.45	8.88	15.26	17.38	1.39	2.16
	CV (%)	13.73	17.16	13.00	10.41	32.57	25.29
	P-value	<0.0001	0.0006	<0.0001	<0.0001	0.2947	0.1152

Bomba showed the highest percentage of failed panicles at 30-68% in 2019 and 12-96% in 2020, showing statistically significant differences when compared to the non-treated and synthetic fungicide treated plots. For Guara, J. Sendra and Montsianell there were low percentages of failed panicles during the first year, while during the second year this percentage slightly increased. The V.Exp.1 cultivar exhibited the lowest proportion of failed panicles, with values close to zero. There was a lower number of panicle failure in Argila, Guara and Montsianell varieties when Sulphur was applied at any dose (Figure 24).

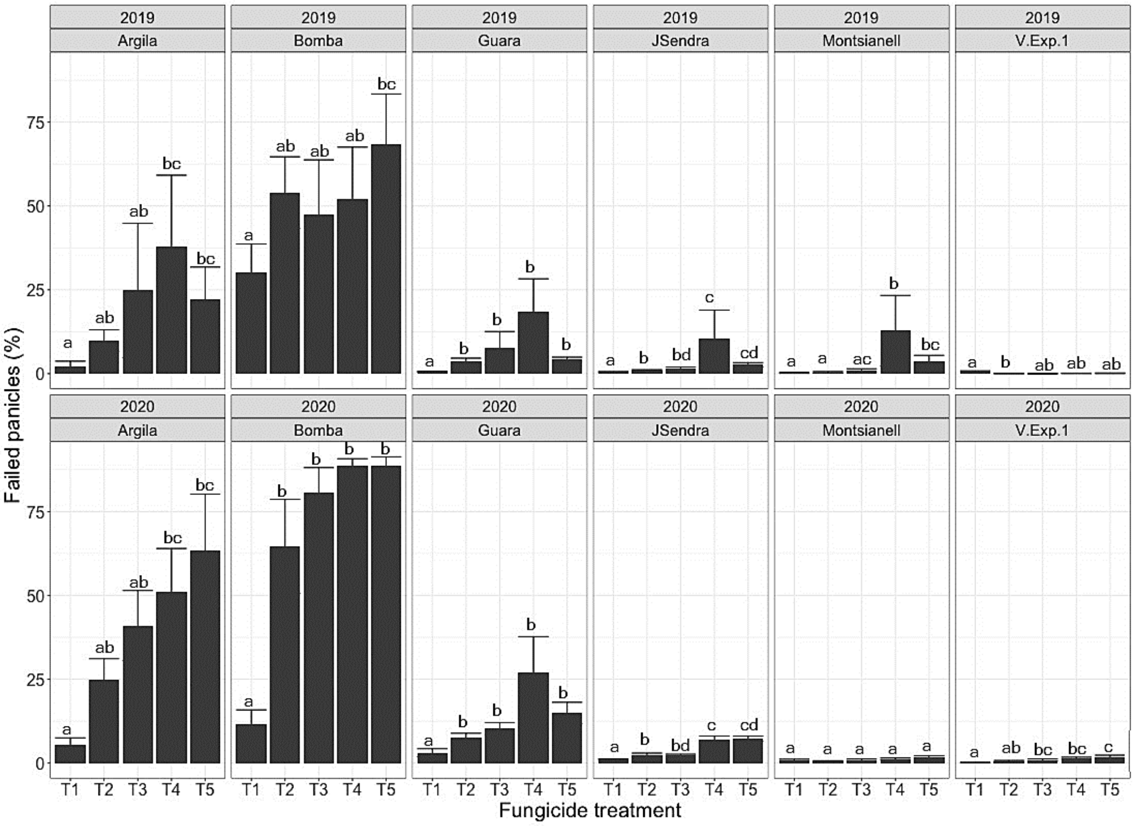


Figure 24: Percentage of rice blast failed panicles per treatment and cultivars during the first year and second year: (T1) Chemical fungicide-azoxistrobin 20 % + difenoconazol 12.5 %; (T2) high-dose Sulphur; (T3) low-dose Sulphur; (T4) diatomaceous earth and (T5) non-treated. Different letters represent significant differences at the 95% confidence interval according to the Anova LSD test.

Generally, the first-year yield was higher than the second year in all cultivars. Bomba produced the lowest yield, ranging from 538 kg·ha^{-1} with the diatomaceous earth treatment during the second year up to 4,819 kg·ha^{-1} with the synthetic fungicide control during the first year. In contrast, Argila, Guara, J. Sendra and Montsianell were the most productive, ranging from around 6,000 to 10,000 kg·ha^{-1}, while the yield of V.Exp.1 was intermediate, from 6,599 to 7,736 kg·ha^{-1}, despite it being the most blast resistant cultivar. Similar yield results were obtained from both Sulphur doses for all rice cultivars and in both years, although a trend towards increased yield was observed under higher Sulphur treatments during the second year for all the cultivars, except for the cultivar with the lowest blast sensitivity, V.Exp.1 (Figure 25).

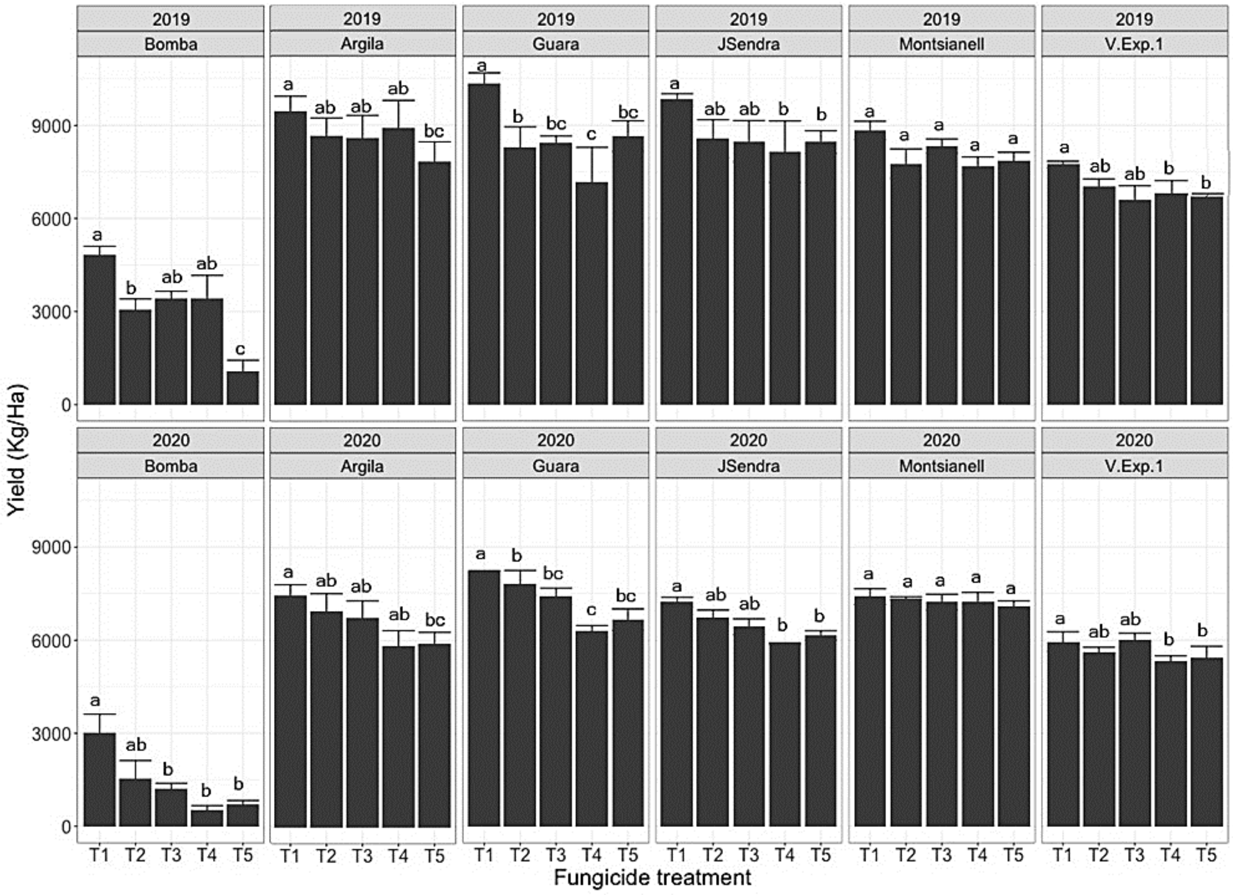


Figure 25: Grain yield (kg·ha^{-1}) per treatment and cultivars during the first year and second year: (T1) Chemical fungicide-azoxistrobin 20 % + difenoconazol 12.5 %; (T2) high-dose Sulphur; (T3) low-dose Sulphur; (T4) diatomaceous earth and (T5) non-treated. Different letters represent significant differences at the 95% confidence interval according to the Anova LSD test.

The yield was improved in the synthetic fungicide control treatment in comparison to all other strategies for all cultivars except for the second-year yield in V.Exp.1. In other words, the synthetic fungicide did not significantly improve V.Exp.1's yield relative to high-dose Sulphur during the first year. In contrast, the yield differences between the synthetic fungicide treatment and non-treated in the first year was higher than the second year. The lowest yield values were observed with the diatomaceous treatment in all cultivars and both years, except for Montsianell during the second year, where the lowest yield value occurred in the non-treated control, although there were no significant differences from the diatomaceous earth treatment (Figure 25).

4. DISCUSSION

Is it possible control de blast disease in Japonica rice with non-synthetic fungicides in Ebro Delta conditions? The most blast-sensitive cultivar was Bomba, followed by Argila, Guara, J. Sendra and Montsianell, while V.exp.1 showed the lowest blast sensibility. We conclude that Sulphur (Thiopron, 82.5 % a.i. L-1, SC, UPL Iberica) at a 7.5 l·ha^{-1} dose has potential to help organic and conventional farmers to control rice blast and the Thiopron phytosanitary yet being registered and commercialized in Spain for rice cultivation since 2022.

Our results showed differences between cultivars in the efficacy of fungicide treatments to control of rice blast. To assess the blast sensibility of the rice cultivars we focus in the non-treated plots: Bomba-Argila-Guara-J. Sendra-Montsianell-V. Exp1 (Tables 7 and 8). This factor had a high interaction with the fungicide treatment, since the efficacy was easily observed in cultivars with high sensitivity (Bomba) and medium sensitivity (Argila, Guara), being more discreetly observed in J. Sendra and practically negligible for Montsianell and V. Exp1 (Figures 23a and 23b). The explanation was very simple, when the blast tolerance of the cultivar was high, the contribution of the treatment was discreet and even undetectable. In contrast, when the cultivating blast-sensible cultivars, the treatment effect tend was more significant showing differences between non-treated and the other treatments. The levels of rice blast attack intensity for the V. Exp1 cultivar were the lowest of the 6 cultivars studied. The use of blast-resistant cultivars would be key to successful organic rice production (Namai 2011; Yamaguchi et al. 2005). Bomba has shown the highest blast sensitivity as reported by (Pineiro et al. 2000), followed by Argila and Guara. The magnitude of the yield reduction was dependent on the varietals' susceptibility to disease (Koutroubas et al. 2009).

Non-synthetic treatments couldn't protect the blast sensible Bomba cultivar in a scenario of favourable conditions for rice blast, despite the differences with respect to synthetic fungicide were less significant for Sulphur's treatments, which comes to say that despite having insufficient control, treatments with Sulphur were more effective than diatomaceous earth. The high blast incidences in the Bomba cultivar in the non-treated controls highlight its high blast sensitivity, as reported previously (Carreres et al. 1986). The wide variation in the incidence of blast-affected panicles during both years can be attributed to the reported variability dependent on climatic conditions (Marchetti and Bonman 1989; Muñoz 2008; Nasruddin and Amin 2013), although the sowing delay imposed by the second-year climatic conditions (Figure 26) might have enhanced blast severity by overlapping the most sensitive plant stages with the highest presence of blast inoculum and optimal meteorological conditions for its infection development (Shahriar et al. 2020) and it might had overlapped the most blast-favourable weather conditions with the most vulnerable rice stages: the heading and milky grain stages (Marchetti and Bonman 1989; Nasruddin and Amin 2013; Sester et al. 2014). The commonly observed later blast attack at the end of August at the ripening stage (Bonman et al. 1991) increased the level of blast effects on the panicles at the end of the rice cycle during both years, and to our knowledge, the high air humidity and high temperature favoured inoculum pressure (Marchetti and Bonman 1989; Muñoz 2008; Nasruddin and Amin 2013). The greater yield differences between synthetic and non-synthetic fungicides treated plants in terms of failed panicles were observed in Bomba due to both its varietal high blast sensitivity (Carreres et al. 1986) and the weak blast control of the assessed organic fungicides (Chakraborty et al. 2021).

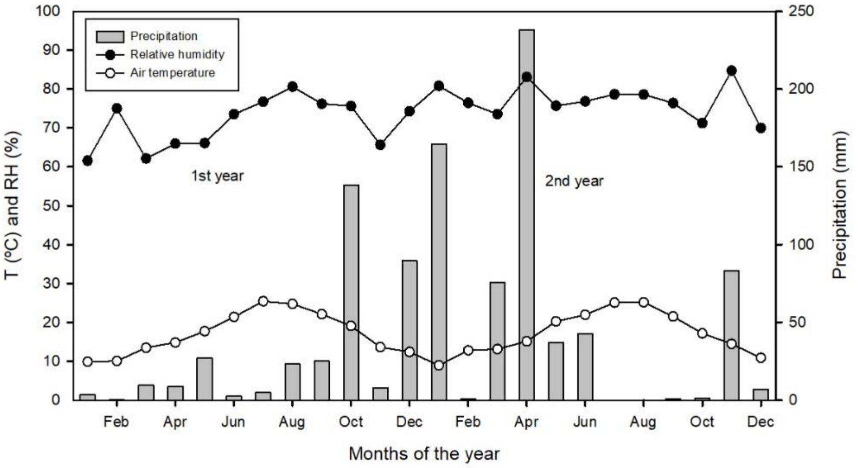


Figure 26: Data of climate conditions in Amposta station for years 2019 and 2020: (Left) temperature in ºC and relative humidity in percentage, (right) precipitation in mm.

In terms of yield, graphically the trend curves between treatments were maintained for both years. This is good news, since Sulphur treatments are closer to synthetic fungicide than to non-treated plot, and this trend is maintained in cultivars with different levels of sensitivity to rice blast. The greening effect of the strobilurin could have also contributed towards increasing yield in the synthetic fungicide control plots due to an increase in net photosynthesis, and not so much the fungicidal effect (Amaro-Blanco et al. 2021). But in the other hand, one hypothesis of the lack of efficacy of strobilurin treatments may be a fungicide resistance of blast rice strains (Valarmathi 2018). As reported in countries like India (Mohiddin et al. 2021), Italy (Kunova et al. 2021) an others (Kim et al. 2003). These could explain the close different in the yield between Sulphur based and synthetic fungicide. Indeed, other authors found that the Sulphur treatments increased the yield significantly with respect to the non-treated plots when using medium blast-tolerant cultivars (Malav et al. 2016). It may be necessary to apply four to five Sulphur or Silicon-based treatments to reach a satisfactory blast protection due to the lack of Sulphur's persistence and its mode of action, as reported by (Gopi et al. 2016).

The use of blast-resistant cultivars would be key to successful organic rice production (Namai 2011; Yamaguchi et al. 2005). Bomba has shown the highest blast sensitivity as reported by (Pineiro et al. 2000), followed by Argila and Guara. The magnitude of the yield reduction was dependent on the varietals' susceptibility to disease (Koutroubas et al. 2009).

Sulphur fungicides can be effective in blast control for moderate blast-resistant rice cultivars when applied preventively and regularly, due to their low persistence. Generally, the non-synthetic fungicide treatments are more preventive than curative, and it is important to apply those few days ahead of the synthetic fungicides. In contrast, other commercialized products could result in null or ineffective blast control for most of the rice cultivars grown under the environmental conditions of the Ebro Delta

ACKNOWLEDGEMENTS

This work was funded by the Spanish Ministry of Science and Innovation-State Research Agency (AEI) through the IMPRORICE Project entitled “Mejora de la producción ecológica de arroz de España frente a los efectos del Cambio climático” *Ministerio de Ciencia, Innovación y Universidades* (RTI2018-094487-B-I00), by the Catalan government (AGAUR) through the Alfred Palma-Guillén Industrial PhD program and by the Ebro Delta rice sector through the “Organic Delta Rice” Project. Two anonymous reviewers which comments improved the manuscript excellence.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRONTRIBUTIONS

A.P. and X.S. conceived the project and designed the experiments. A.P. and A.N. managed the field trial work, data collection and sample processing. Data was analysed by A.P. and NPM. The manuscript was written by A.P., X.S. and S.N.

DATA AVAILABILITY STATEMENT

All data used for analyses are available from the corresponding author upon requested.

CHAPTER III: Rice yield effect of organic fertilization in paddies of the Ebro Delta

Alfred Palma-Guillén, Miquel Salicrú, Ariadna Nadal,
Xavier Serrat, Salvador Nogués

Submited to:
Journal of Plant Nutrition

Rice yield effect of organic fertilizers in paddies of the Ebro Delta

Alfred Palma-Guillén[1,2], Miquel Salicrú[3], Ariadna Nadal[1], Xavier Serrat[2*], Salvador Nogués[2]

[1] AGROSERVEIS.CAT SL, Deltebre, Catalonia, Spain;

[2] Departament de Biologia Evolutiva, Ecologia i Ciències ambientals, Secció de Fisiologia Vegetal, Universitat de Barcelona, 08028 Barcelona, Catalonia, Spain;

[3] Departament de Genètica, Microbiologia i Estadística, Secció d'Estadística, Universitat de Barcelona, 08028 Barcelona, Catalonia, Spain;

*Corresponding author: e-mail: xserrat@ub.edu ; tel: +34 93 4033718

Abstract

Rice is the primary staple food for more than half of the world's population. Wetland rice systems make a major contribution to Mediterranean rice supply. Organic fertilization is a promising way to improve soil quality and sustain high yields. The main objective of this work is to find organic fertilizers for the cultivation of organic rice. Field experiments were conducted to examine the effect of organic fertilizers on the grain yield, tillering and relative chlorophyll content rates on paddy fields during years 2019 and 2020. The experimental design of the trials used a cross design of three factors arranged in a single factor with 3 replications with 6 plots. The results from chemical fertilizer control on grain yield and tillering showed the best results, followed by the organic fertilizer named OPF. The application of Plant Grow Promoting Mechanism PGPM in anaerobic conditions did not improve rice yields. The study concludes that OPF is an efficient organic fertilizer for rice cultivation in Ebro Delta, only reducing the yield by 17% when compared with the chemical fertilization control while it adapts to the application equipment's of the farmers. The outcome of these study is important since it will contribute efficiently to organic rice cultivation in Ebro Delta.

Key words: organic fertilizer, organic rice, Ebro delta, PGPM

1 INTRODUCTION

Rice (*Oryza sativa* L.) is the primary staple food for more than half of the world's population, providing up to 20% of the total calorie intake (Das 2017; Dass et al. 2017). The world's growing population is expected to exceed 9,000 million people by 2050, which poses a critical challenge to the conservation of global biodiversity while maintaining food security (Godfray et al. 2010). Rice is an important crop contributing approximately 23% of the total calories per capita for 6,000 million people worldwide. In Europe, it is an important crop covering 637,872 ha with a yearly averaged production exceeding 4 million tonnes of paddy rice (FAOSTAT 2022). Spain is the second largest European rice producer after Italy. In 2021, Spain produced 617,180 tonnes of paddy rice in more than 84,680 ha, representing about 20% of the European production (FAOSTAT 2022). However, Spain only cultivates 1,476 ha of organic rice (less than 1.8 % of paddy rice area) under organic certification in 2021 (MAPA 2021a).

Rice paddies are a major source of anthropogenic CH_4 emissions due to the severe anaerobic conditions that typically follow inundation with water (Ma et al. 2010; Zhao et al. 2023). Paddy fields account for approximately 10 % of worldwide CH_4 emissions, a number that is likely to increase in the future as the demand for rice increases along with the world's population (Naylor et al. 2005; Nazaries et al. 2013; Organization 2002).

The conventional agricultural production systems use agrochemical inputs to produce high yields. Unfortunately, this practice produces increases in costs production, dependency on non-renewable resources, biodiversity loss, water contamination, chemical-contaminated food, land degradation and risks to farmers health (De Wit and Verhoog 2007; Reganold and Wachter 2016; Suwanmaneepong et al. 2020; Willer et al. 2018; Willer et al. 2019). Agricultural intensification, at field and landscape scales, has caused a decrease in weed diversity and changes in species composition (José-María et al. 2010). The interest of organic farmers in adopting conservation agriculture principles, including minimal soil disturbance, permanent soil cover and crop rotation has been growing since the early 2000s (Peigné et al. 2016).

Organic products and organic farming technologies are more environmentally friendly (He et al. 2018) and are a move towards sustainable agriculture, but this production system requires different inputs and advanced knowledge and skills.

The Ebro Delta (NE Spain) is a 320 km^2 area with 199 km^2 of paddy fields in 2021 (Sanchez-Arcilla et al. 2023), representing 62% of the Ebro Delta's surface area (Catalonia, Spain), being the rice cultivation the main economic activity (Genua-Olmedo et al. 2022). Organic food production has been steadily increasing in Catalonia during the last 10 years (CCPAE 2020a), although organic rice production has not been increasing at the same rate. Organic production is characterised by irregular yields and substantial productivity gaps with respect to conventional systems (Delmotte et al. 2011a). In organic production system, a set of constraints including nitrogen stress at critical growth stages, unavailability of rapidly mineralizable organic amendments, lack of appropriate varieties and intense crop–weed competition pose major challenges to realize the potential yield (Hazra et al. 2018).

Some carbon sources have been available for paddy fields fertilization: organic manure, compost (Saha et al. 2007), vermicompost (Sarkar et al. 2023), rice straw (Tang et al. 2019), rice husk (Peyghambarzadeh et al. 2023), and cover crops (Weinert et al. 2023). Crop diversification (cultivar mixtures and cover crops) have been proposed as a sustainable strategy for pest control in organic cereal fields (Fandos et al. 2023). However, agricultural practices may alter the stability of the soil organic carbon stocks and thereby increase carbon mobilization in the topsoil and subsoil (Belenguer-Manzanedo et al. 2023).

Nitrogen is an important factor that affects soil ecology and limits the availability of nitrogenous organic matter in agroecological systems (Hu et al. 2023). Delayed sowing could reduce annual yield from 6.14% to 13.72%, while appropriate N application can mitigate this reduction (Fu et al. 2023). The application of 60 kg N ha^{-1} at the heading stage could effectively alleviate the reduction in grain yield attributable to elevated temperatures (Shen et al. 2023). Optimized N fertilizer management delays senescence, increasing canopy photo assimilation, higher N fertilizer use efficiency, and less N loss (Ma et al. 2023).

The main objective of this work is to find organic fertilizers for the cultivation of organic rice in paddies of the Ebro Delta.

2 MATERIALS AND METHODS

2.1 Experiment design

This study was performed in an experimental field in Ebro Delta (Tarragona, Spain), with an average annual temperature of 18º C and an annual precipitation of 500 mm. The experimental field (40º 42’ 40’’N 0º 37’ 41’’E) was a rice field with loamy texture, pH 7.9, CEC 1.13 $dS·m^{-1}$, 2.39% organic matter (OM), 14.1 N-NO_3 $mg·kg^{-1}$ and 23 P $mg·kg^{-1}$. Seeds of *Argila* Mediterranean temperate Japonica rice variety were provided by COPSEMAR (Valencia, Spain).

Three organic fertilizers systems (OPF, B+OPF and OPF+N) were compared with mineral fertilizer and non-treated plot. The size of the experimental unit was 6x15m ($90m^2$), without divisions between plots. The weeds and fungus management of the plots were done with conventional rice agriculture herbicides and fungicides. The soil levelling was performed 53 days before seeding using a Maschio MDE 50T, (Maschio Gaspardo, Padova, Italy) laser levelling.

Chemical fertilizer POLYSOL 10N-6P-10K was applied 4 days before seeding (DBS) at a concentration of 800 kg·ha^{-1}. The fertilizer incorporated 3 DBS by using a rotovator. First top-dressing application was performed manually 60 days after sowing (DAS) by using ammonium sulphate 21% 214 kg·ha^{-1}, equivalent to 45 NFU·ha^{-1}. Second top-dressing application was realized manually with ammonium sulphate 21% at 105 DAS, the doses of the fertilizer was 214 kg/hectare at 21% of richness the nitrogen, equivalent at 45 NFU/hectare.

In this work, the effect and interactions of organic fertilizers with rice crop in Ebro Delta was study. The organic pellet fertilizer (OPF) was applied in all three organic fertilizers treatments. Then other treatments (B) and (N) were applied over the application of (OPF) to assess their possible interactions as follows:

Organic (pellet) fertilizer OPF 6% N nitrogen, 4% potassium and 4% phosphorus was applied manually at concentration 1,667 kg·ha^{-1} (100 NFU·ha^{-1}) the day before seeding, simultaneously it was incorporated in the soil was manually with a rake. A second application (1,167 kg/hectare, equivalent to 70 NFU/hectare) was performed 30 days after seeding in half of the surface of the experimental plot at concentration.

The B component in B+OPF treatment was a commercial product containing *Azotobacter vinelandii* ≥ 10^8 ufc/ml, *Bacillus megaterium* ≥ 10^8 ufc/ml, *Frateria aurantia* ≥ 10^8 ufc/ml, Zinc 2.0 % p/p, Boron 0.2 % p/p and Molybdenum 0.05 % p/p. It was applied at concentration 5 cc/ha at 22 DBS and its incorporation was performed simultaneously rotovator tractor.

The N component OPF+N treatment was a commercial product composed of: Nitrogen (N) total 2.0 % p/p, Organic nitrogen (N) total 1.2 % p/p, Free aminoacids and peptides 2.0 % p/p, Zinc 0.7 % p/p, Iron 0.5 % p/p, Potassium 6.0 / 1.2 % p/p, Alginic acid 1.5 % p/p and Manitol 0.5 % p/p. First application was applied at concentration 2 l/ha at 20 DAS. Second application was applied at concentration 2 l/ha at 38 DAS.

Chemical fertilizer, B, and N component was applied with gas back package of wide 4 meters with 8 nozzle ST-001 Albuz. The working pressure was at 2 atm and the volume of broth was 200 l/ha. A pre-emergence herbicide (oxadiazon 38%) was applied following the common agriculture practices at a concentration of 1.3 l/hectare using a FORTIS 4300 (Tecnoma) trailed sprayer equipped with 24 m width and 48 ST-001 Albuz nozzles at 2 atm working pressure. The fields were flooded 7 days after the application. The Argila rice seed was pre-hydrated for 24 hours before water-seeding at 205 kg/hectare seeding dose.

Three chemical fungicide applications were conducted., First, a mix of 1 l/ha Liseo (procloraz 45%) was applied 65 DAS. Second, a mix of the 1 l/ha Mirador (axozistrobine 25%) and 0,15 kg/ha Gazel (acetamiprid 20%) was applied 78 DAS. The third application was a mix of 0,25 kg/ha Flint (trifloxistrobine 50%) and 1,5 l/ha Am-Rice applied 101 DAS. A Maruyama Motorized Backpack Sprayer (MS735W, Maruyama, Tokio, Japan) and 4 meters width having 8 ST-001 nozzles was at 2 atm. working pressure and 300 l/hectare a broth volume was used in both treatments. The water management was common for all plots in this assay.

2.2 Data collection

The leaf chlorophyll content was measured by using a Yara N-Tester tool (Konica Minolta Ltd.). The Yara N-Tester is a handheld chlorophyll meter which measures the light across the leaf and serve as approximation of the leaf nitrogen content. The dimensionless data is used to compare the differences in “greenness” between treatments. There measurement was done after the first top-dressing 45 days after seeding.

A 0.1225 m^2 square was thrown five times randomly on each plot and number of tillers per surface was scored. The grain yield ($kg \cdot ha^{-1}$) was scored 140 after seeding by harvesting all the panicles using a Kubota RX 1050AD harvester. The grain’s percentage of moisture was recorded for all the rice samples at harvest with the use of John Deere MCXFA1873 grain moisture tester (Manufactured by AgraTronixTM Moisture Chek PlusTM, Deere and Company; Batch SW08122, U.S.A.). The rice yield at 14% moisture content was corrected in samples over 14% by subtracting 1.2% of the grain weight per 1% excess moisture above 14%. Rice impurities were also scored by running twice two samples replicates of 200 g through a high-performance AEG grain sorting machine and weighing the discarded broken grains with a scale.

2.3 Statistical analysis

A three-factor crossover design was replicated to study the effect of two fixed factors (fertilizer and year), their interaction (fertilizer-year) and a random factor (experimental row) on three responses (grain yield, number of tillers and chlorophyll concentration). The F statistic was used (Fisher-Snedecor) for both, the multiple comparison of the factor’s levels and the estimation of the variability. The variability (variance) was estimated for the random factor and contrasted with the unexplained variability (residuals). Pairwise comparisons have been performed with the Tukey test and with the observation of the overlap of the confidence intervals when significant differences have been observed in the fixed factor. The robustness of the use of the statistics employed has been ensured by checking the validity conditions of the model or by checking the unimodality of the residuals. Furthermore, the Durbin-Watson statistic was used to check the independence of the sample values.

The uncertainty in the estimation of the percentage decrease in grain yield with a fertilizer (Tx=OPF, B+OPF, OPF+N, Non-treated) in relation to the reference fertilizer or control (Tq=Chemical),

$$DEC(Tx/Tq) = \frac{Yield\ (Tq) - Yield\ (Tx)}{Yield(Tq)} \cdot 100$$

has been obtained by applying computational simulation methods. Specifically, the steps followed are detailed below:

a) both the bivariate mean µxq=(µx, µq), and the bivariate variance-covariance matrix

$$\Sigma_{xq} = \begin{pmatrix} \sigma_x^2 & \rho_{xq}\sigma_x\sigma_q \\ \rho_{xq}\sigma_x\sigma_q & \sigma_y^2 \end{pmatrix}$$

were estimated, corresponding to grain yields with Tx and Tq;

b) according to a bivariate normal distribution of parameters µxq and Σ_{xq}, 10000 pairs of values have been artificially generalized (Tx, Tq) simulating production in two paired plots ((Tx-i, Tq-i), i=1, 2, ..., 10000);

c) for each pair of artificial grain yield values, the percentage decrease in production has been calculated

$$DEC(Tx - i/Tq - i) = \frac{Yield\ (Tq-i) - Yield\ (Tx-i)}{Yield(Tq-i)} \cdot 100;$$

and d) the 10,000 regenerated values corresponding to the decrease in production have been ordered from small to large and the 250 smallest values (2.5%) and the 250 largest values (2.5%) have been discarded. In this context, the confidence interval (α=0.05) corresponding to the percentage decrease in yield is delimited by the values ordered in positions 251 and 9750.

Analysing the effect of the same factors on three response variables, it is appropriate to calculate the correlation between them (ρY,T, ρY,C and ρT,C being Y:Yield, T:Till and C: Chlorophyll concentration). If the correlation is high, the results should be very concordant and if the correlation is low, the results may be complementary. The software used was Statgraphics Centurion XVIII software (Statistical Graphics Corp., Rockville, MD, USA).

3. RESULTS

For grain yield, the statistical analysis of the experimental results has found significant differences between treatments ($p<0.0001$). No significant differences were observed between years ($p=0.5688$) or in the treatment-year interaction ($p=0.8529$). The contrast between pairs of treatments made it possible to state that the grain yield average is higher when the chemical treatment has been used and thus, in relation to this treatment, grain yield decreases by an average of 17.3% ($min_{95\%}$=-5.6%, $max_{95\%}$ =39.9%, computational confidence interval per α=0.05) when OPF treatment was used, grain yield decreases by an average of 30.3% ($CI_{0.05}$: $min_{95\%}$=-9.5%, $max_{95\%}$ =59.9%) when B+OPF treatment was used, grain yield decreases by an average of 33.0% ($CI_{0.05}$: $min_{95\%}$=12.5%, $max_{95\%}$ =57.6%) when B+OPF treatment was used, and finally grain yield decreases by an average of 64.2% ($CI_{0.05}$: $min_{95\%}$=45.2%, $max_{95\%}$ =79.7%) when the field was non-treated (Figure 27a),

$$\bar{Y}_{CHE}(7233.8) \approx \bar{Y}_{OPF}(5982.0) \approx \bar{Y}_{B+OPF}(5044.7) \approx \bar{Y}_{OPF+N}(4848.2) > \bar{Y}_{NON}(2586{,}2) \quad (1)$$

It is worth noting that (i) the non-significance of the year effect and (ii) the descriptive contrast of the grain yield between years highlighted the stability and/or robustness of the grain yield, in relation to the treatments, at different climatic conditions (Figure 27b)

$$\bar{Y}_{2020}(5234.3) \approx \bar{Y}_{2019}(5043.7) \quad (2)$$

For the number of tillers, the statistical analysis of the experimental results has also made it possible to observe significant differences between treatments ($p<0.0001$). No significant differences were observed between years ($p=0.0638$) or in the treatment-year interaction ($p=0.5293$). The contrast between pairs of treatments has allowed us to state that the average grain yield is higher when the chemical treatment has been used. Although no significant differences were found, the concentration of chlorophyll decreases by an average of 23.9% when OPF treatment is used. Further, the number of tillers decreases by an average of 46.7% with the treatments B+OPF, OPF+N and non-treated, respectively, although no significant differences were found (Figure 27c)

$$\bar{T}_{CHE}(829.8) > \bar{T}_{OPF}(631.7) > T_{NON}(479.2) \approx \bar{T}_{B+OPF}(428.0) \approx \bar{T}_{OPF+N}(418.5) \quad (3)$$

Although the differences between years have not been sufficient to state that there are significant differences, $\bar{T}_{2020}(578.7) \approx \bar{T}_{2019}(536.2)$, the percentage difference of 7.3%, the proximity of the p-value to 0.05 and the used test do not allow us to ensure the stability of the number of tillers, in relation to the treatments, in different climatic conditions (Figure 27d).

For chlorophyll measurements, the statistical analysis of the results has shown significant differences between treatments ($p=0.0002$) and between years ($p=0.0005$). On the other hand, no significant differences were observed in the treatment-year interaction ($p=0.3342$). The contrast between pairs of treatments has allowed us to affirm that the average chlorophyll concentration is higher when the chemical treatment has been used. Although no significant differences were found, the chlorophyll concentration decreases by an average of 11.3% when OPF is used, an average of 16.1% when OPF+N is used, an average of 19.9% when B+OPF is used, and an average of 20.5% when no treatment is used (Figure 27e).

$$\bar{C}_{CHE}(598.0) > \bar{C}_{OPF}(530.50) \approx \bar{C}_{OPF+N}(501.8) \approx \bar{C}_{B+OPF}(478.8) \approx \bar{C}_{NON}(475.3) \quad (4)$$

Regarding the two experimental years, the significance of differences has highlighted the non-stability of chlorophyll concentration, in relation to the treatments, at different climatic conditions (Figure 27f)

$\bar{C}_{2019}(546.7) > \bar{C}_{2020}(487.1)$ (5)

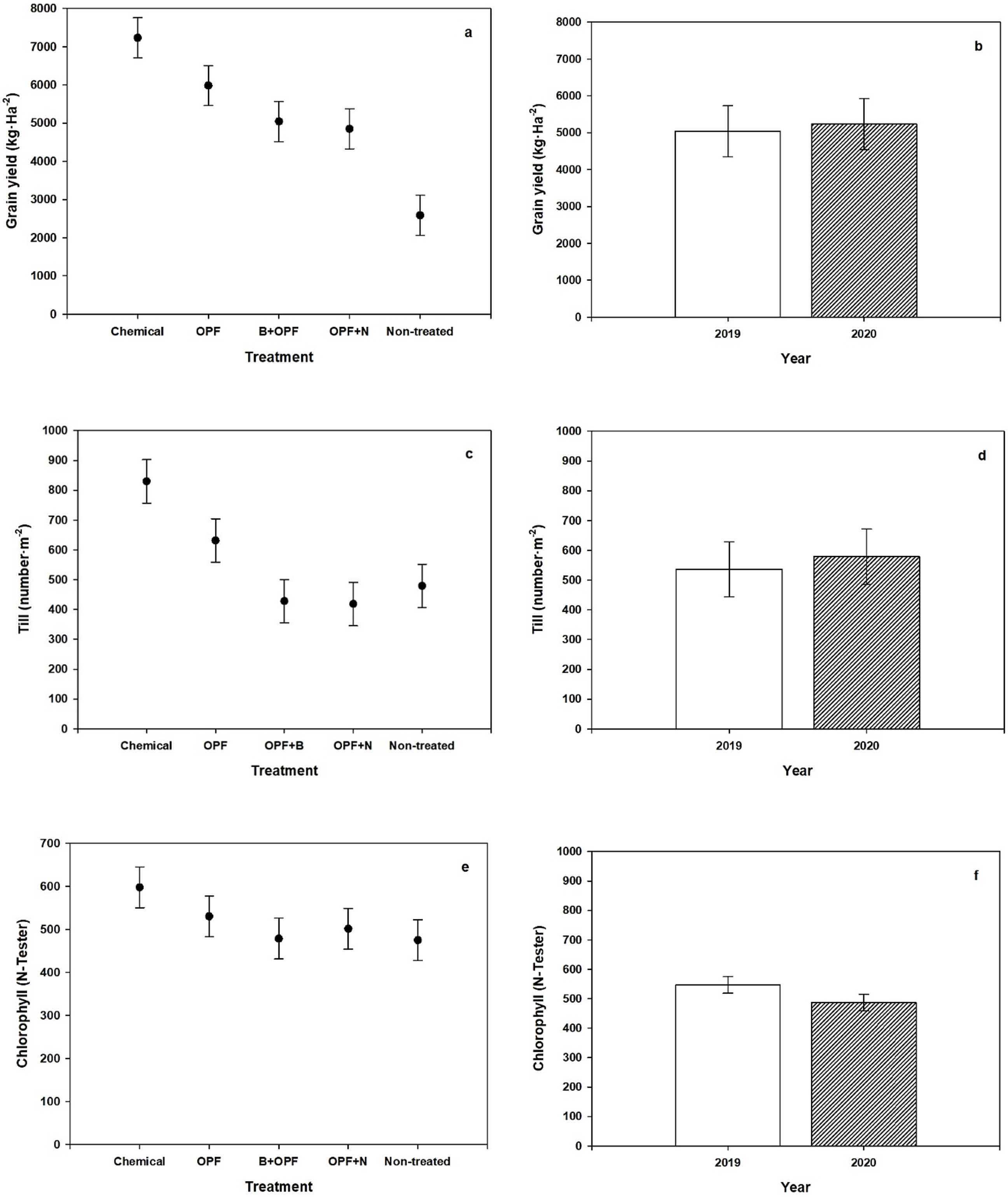


Figure 27: Results of both years: a) Grain yield per treatment: Chemical fertilizer (Chemical), organic pellet fertilizer (OPF), bacteria PGPM + organic pellet fertilizer (B+OPF), organic pellet fertilizer + nutrients (OPF+N), and control fertilizer (non-treated). b) Grain yield per year: 2019 (white) and 2020 (increasing line). c) Number of tillers per treatment. d) Number of tillers per year: 2019 (white) and 2020 (increasing line). e) Chlorophyll rates per treatment. f) Chlorophyll rates per year: 2019 (white) and 2020 (increasing line).

Furthermore, the variability due to the row effect ($s_{row,\ Yield}$=215.4, $s_{row,\ Till}$=24.3, $s_{row,\ Chlorophyll}$=10.4) represents 5.4%, 14.5% and 6.7% of the total variability yield, till and chlorophyll concentration ((s_{row}^2/s_{total}^2)·100, on $s_{total}^2 = s_{row}^2 + s_{residue}^2$). Consequently, the effect attributable to the gradients of the field is limited. In the other hand, the possible experimental column gradient has been balanced with the randomization of the treatments in the columns.

In general, the correlations between the response variables ($\rho_{Y,T}$=0.67, $\rho_{Y,C}$=0.49 i $\rho_{T,C}$=0.56, Figure 28) are compatible with the results. Regarding the treatment, significant differences are obtained for all the response variables. The chemical fertilizer is the one that obtains the best results, the OPF is in second place and the others B+OPF and OPF+N show few differences between them. Also, the treatment-year interaction is not significant in all cases.

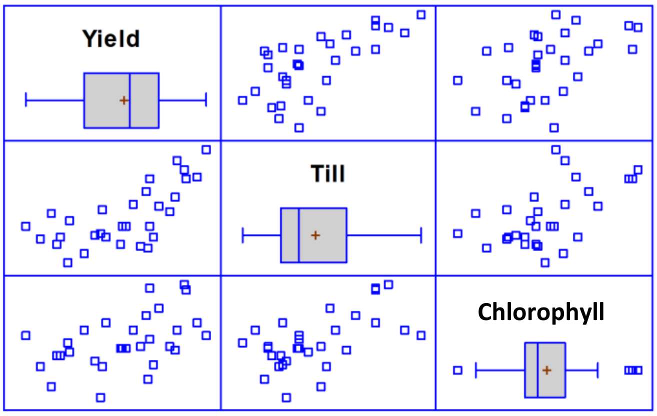


Figure 28: Correlations between the response variables (Yield, Till, Chlorophyll)

4. DISCUSSION

Rice organic fertilization is a challenge since nitrogen demand is high for this crop, especially at the vegetative stage. Further, a high percentage of inorganic nitrogen is not used by the plant due to losses (*i.e.*, leaching and volatilization). As far as we know, the effects of bio-organic fertilizers for the cultivation of organic rice in Ebro Delta has been ever published.

The response of the rice crop to the application of the OPF organic fertilizer has been observed both in the application before seeding and in the top-dressing application. The highest grain yields correspond to the treatment with chemical fertilizers, followed by the OPF organic fertilizer (with a decrease between 17 - 34%, and a very large confidence interval). This result clearly shows the effect of inorganic nitrogen in rice (Lin et al. 2009; Mohaddesi et al. 2011; Quílez y Sáez de Viteri et al. 2020; Wang et al. 2023; Zamora Laguna and Díaz Sevilla 2022). There are other stresses that are also affecting rice yield: salinity (Català et al. 2019b; Català et al. 2019a; Català et al. 2013; Litardo et al. 2023; Rodríguez Coca et al. 2023; Zheng et al. 2023), rice blast

(Agbowuro et al. 2020a; Hoosain et al. 2013), heat (Broberg et al. 2023; Guo et al. 2023), apple snail (Jiménez Tapia 2020; Rusli and Putra 2023), chironomids (Ushio et al. 2023), *Chilo suppressalis* rice borer (Sakib et al. 2022), and dry winds (Vargas 2010).

The differences between the two measuring years are not significant for grain yield and tillering, therefore the robustness of the results is solid. On the other hand, the N-tester values related to chlorophyll concentrations showed differences between years. This may be due to other factors: paddy field salinity (Zheng et al. 2023), or other environmental conditions (Chevuru et al. 2023), that affect the ability to absorb and transport nitrogen through the plant (Chen et al. 2023), directly related to the concentration of chlorophyll in the leaves (Voisin et al. 2023).

The effect of the application of the OPF fertilizer in rice cultivation has shown good results both in bottom and cover applications, although chemical fertilizer is assimilated much faster than organic fertilizer (Lin et al. 2019). Long term chemical fertilizer application leaded to the deterioration of soil fertility and environment. Partial replacement of organic materials to chemical fertilizers could significantly amend and buffer such negative effects (Gao et al. 2023). Organic fertilizer application is one of the safer alternatives with numerous benefits, such as supplying nutrients for plant growth (Alzain et al. 2023). The OPF product has been able to nitrify the organic form of nitrogen into an inorganic form so that the plant can absorb it through the root system (Xu et al. 2013). When organic fertilizers are applied to the field, only 20% is nitrified in inorganic form during the first year (*i.e.* urea, ammonium, ammonic) (Ishii et al. 2011). On the other hand, the "granulated pellet" formulation facilitates its transport and dosage for a precision application (Pocius et al. 2014). Finally, the OPF product adapts well to the application equipment of the Ebro Delta farmers and it is a good candidate to be chosen as organic fertilizer for a rice organic production but, at the same time, it can also be applied in the fields of conventional production (Lin et al. 2023).

Organic fertilizers (B+OPF and OPF+N) have not increased the grain yield, compared with OPF organic fertilizer or with the CHE chemical fertilizer. The application of bacteria to agricultural soil is a practice known as PGPM (Plant Grow Promoting Mechanism) (Rajanna et al. 2023). Usually, these applications are carried out under aerobic conditions (Dunn and Becerra-Rivera 2023). The establishment of these colonies in anaerobic conditions, as in the case of flooded rice, are not the same and do not improve rice crop response (Burgos Junco and Ramos Remache 2022), like other crops such as horticulture (Joshi et al. 2023). It is necessary to deepen the search for PGPM application techniques in rice paddy fields.

In conclusion, for the first time, an efficient bio-organic fertilizer (called OPF) for organic rice cultivation in Ebro Delta has been identified. This bio-organic fertilizer only reduced the yield by 17% compared with a chemical fertilizer. Furthermore, this OPF's granulate pellet formulation adapts to the rice farming machinery. The outcome of these study is important since it will benefit both conventional and organic systems production. Thus, this new organic OPF fertilizer will significantly contribute to efficiently organic rice farming in Ebro Delta.

ACKNOWLEDGEMENTS

This work was funded by the Spanish Ministry of Science and Innovation-State Research Agency (AEI) through the IMPRORICE Project, *Ministerio de Ciencia, Innovación y Universidades* (RTI2018-094487-B-I00), by the Catalan government (AGAUR) through the Alfred Palma-Guillén Industrial PhD program and by the Ebro Delta rice sector through the “Organic Delta Rice” Project. The authors wish to thank COPSEMAR (Valencia, Spain) for providing the rice seeds.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

A.P. and X.S. conceived the project and designed the experiments. A.P. and A.N. managed the field trial work, data collection and sample processing. Data was analysed by M.S. and A.P. The manuscript was written by A.P., M.S, X.S. and S.N.

DATA AVAILABILITY STATEMENT

All data used for analyses are available from the corresponding author upon request.

GENERAL DISCUSSION

GENERAL DISCUSSION

This thesis is focused on the major constrains of the organic rice production: weeds, in Chapter 1 (Delmotte et al. 2011b; Reddy et al. 2023); fungal diseases, in Chapter 2 (Agbowuro et al. 2020a; Hossain et al. 2005) and organic fertilization, in Chapter 3 (Hazra et al. 2018). Different non-chemical weeding techniques, rice varieties and “organic” products were assessed in field trials. Finally, an economic study of their feasibility in organic rice production systems is also presented in this Thesis.

The European policies in 2030 (The green deal) focus on the pesticides and chemical fertilizers reduction impact on the environment. In order to increase the agrarian surface devoted to the organic rice production, this thesis aims to give answers to the technical questions in relation to the new productive scenario. Other policies such as “From farm to fork” aim to reduce the carbon footprint between processes from the farm production to the consumers. The European agriculture has to be greener by consuming the lesser chemical phytosanitaries (Fetting 2020). Organic rice production is probably the most challenging among all the other cereals since it grows in flooded fields. Currently, the organic rice production in Catalonia does not reach 200 hectares, out of the 22,400 hectares under rice production. Consequently, the rice industry must import organic rice from other rice-producing areas such as Andalusia or even Italy. The COVID-19 pandemic has highlighted the importance of the countries' food sovereignty, as well as giving greater added value to market concepts such as proximity (km 0) or “carbon footprint”. It makes no sense transporting organic products long distances, since they are less sustainable than conventional products produced nearby.

Nowadays, the rice production is nearly close to its theoretical maximum yields, while the plant health problems are increasing due to pesticides resistances and new invasive pests, together with the climate change affects such as salinization of fields, and anthropogenic actions. Due to the consequences of the economy scale, there are less farmers exploiting bigger farms. In addition, the production costs are rising to the point that they compromise the benefits, being negative for many small producers. The lands of the Ebro Delta are in fewer hand of larger farmers, this produces declines of the territory. Therefore, the demand of organic rice is growing, and the production is low. Spanish, and specifically Catalan rice cannot compete in price with imported rice from Myanmar, Vietnam, or China. A viable way to differentiate the European rice products in the markets is to include an added value by having organic or sustainability certifications while packaging monovarietal quality rice avoiding the bunch. It is very important to educate the society in local and sustainable products consumption.

The first rice agronomic limitation in the Ebro Delta is the salinity of the soils. Rice is the most salt-sensitive crop, although its cultivation in constant freshwater flooding that permits lowering the salinity in the firsts layers of soil so it can grow. The salinity and the soil structure of a given field determines the cultivation strategies that can be used, from agronomic practices to water management, tillage, weed management, type of seedings and/or planting strategies and even rice varieties to be used. Selecting the right rice variety and sowing strategy can be decisive. Rustic varieties, such as Bomba, Bahia or Montsianell are more adapted to the conditions of the Ebro Delta, although they do not have the productive potential of more recent varieties such as J. Sendra, Argila or Copsemar 7.

The second limiting factor is the weed control, which is the main concern for both organic and conventional rice farmers. The big challenge is the integrated management of weed control in organic rice production. The lack of rice weeding manpower aggravates the current situation of the rice paddies. Weeding the paddy fields is a very hard task due to the conditions of heat, humidity, and the muddy ground environment in which it occurs. Usually, it is carried out by groups of immigrant people from other countries (India, Pakistan, etc.) and there are no people willing to work and who can support the working days in the countryside. On the other hand, the weed's seed bank in the rice paddies is the biggest reservoir of weeds. We can find species with a latency of up to 80 years in the case of the Barnyard grass weed (Papapanagiotou et al. 2023). Plant density dynamics are substantially determined by the first colonizing species that can constrain the other competitors, as described previously (Recasens et al. 2019).

Our results showed that the "Simple dry seeding" was the best treatment for dry seeding, while "false seeding" (stale seed bed) and planting was the best performing under water seeding conditions. Both treatments were as effective as chemical control in reducing the density of weeds and the weeding time for those species more abundant in Ebro Delta paddy fields (*i.e. Echinochloa oryzoides*, *Echinochloa crus-galli*, *Scirpus maritimus* and *Heteranthera reniformis*). This unexpected result highlights the applicability and economic viability of the herbicide-free dry-seeding treatments in the organic rice production system, as stated by other authors (Sullivan 2003; Torres Herrero 2021).

The diversification of weed management is the main important issue, since it can avoid the weed adaptation to the different weeding techniques in organic agriculture. In addition, if one can change the seeding system (water-seeding/dry seeding) every year, it would yet help controlling weed. The main problem of the farmers in conventional rice cultivation systems it the yearly use of the same herbicide-based strategy, displaying weeds resistance to inhibitors (ALS and ACCASA) herbicide in few years, especially in species of the genus *Echinochloa* spp. (Amaro-Blanco et al. 2021; Gavilan 2011; Gómez de Barreda et al. 2021; Romano et al. 2018; Torra et al. 2022). Despite that some authors reported that *Echinochloa* spp. exhibited weed resistance to quinclorac and atrazine herbicides inhibitors (auxins and photosystem II) (Lopez-Martinez et al. 1997; Lopez-Martinez et al. 1998; Lopez-Martinez et al. 1997), propanil herbicide (Lopez-Martinez et al. 2001) and thiocarbamates herbicide in Sacramento Valley, California (Osuna et al. 2011). Resistance to (ALS inhibitor) is widespread among *C. difformis* populations that has been evolved resistance to several herbicides (Merotto Jr et al. 2009; Osuna et al. 2002). Some authors reported that *Alisma plantago-aquatica* resistant biotypes to bensulfuron-methyl (ALS inhibitor) in Portugal (Calha et al. 2007).

Indeed, *O. sativa* f. *spontanea* is particularly problematic due to the plant's phenology and ecology, which mimics the rice crops that it grows alongside, and the ease with which it can acquire herbicide resistance through direct gene flow from herbicide-resistant rice varieties (Olofsdotter et al. 2000; Serrat et al. 2013).

Between-rows weeding rollers have not yet been adapted commercially for rice cultivation nor are they yet suited for European conditions. In contrast, small weeding rollers for small tractors have been widely used in Japan for years (Shibayama 1994, 2001). Unfortunately, the technique of water-seeding in rows created empty spaces between rows that were rapidly colonised by *H. reniformis*, probably due to the high soil temperature and the lack of competition between the stale seed bed flooding date and the planting date (Ferrero 1996).

Weed control is the main limiting factor of organic rice production in Spain. Chemical herbicides and fungicides cannot be applied in organic farming, and manual weeding is very expensive and insufficient after some years of organic production (Katsarova 2015). Thus, it is necessary to develop new agricultural techniques and specific agricultural machinery for organic rice cultivation. Smart farming for organic rice cultivation is still being developed and will aid rice farmers in weeding their fields efficiently. New specific precision tools are being designed for weeding rice crops. All of them will require GPS-guided tractors for seeding in rows and weeding between rows. These kinds of technology innovations will be key to boosting organic rice production as they will facilitate both mechanized and manual weeding and can be used in either water or dry seeding. Unfortunately, nowadays commercial rice machinery has insufficient weed control effectiveness. The adaptation and installation of digital components such as GPS and auto-guidance will allow increasing the mechanical weeding precision while increasing the rice production. The technological development of mechanized inter-row weeding should enable the agronomic management of weeds in the paddy fields of the Ebro Delta, reducing their competition and their negative impact on organic rice production. It will mean an improvement in the energetic efficiency of organic rice production which should allow to increase the added value of the entire value chain and of the final product.

Surprisingly, one of the strategies that has been proved to be successful is the use of allelopathy for weed control (Khanh et al. 2007; Kong 2008; Olofsdotter 1998; Xuan et al. 2005). Specifically, very good weed controls have been achieved using rice bran itself (Yulianto and Xuan 2018) and rice varieties have been identified that exude phytoalexins that inhibit the germination and growth of different weed species (Chen et al. 2008; Junaedi et al. 2007; Kong et al. 2011; Olofsdotter 2001). As well as other cultivated plants with a high herbicidal effect on rice weeds (Batish et al. 2007; Walia et al. 2021).

Allelopathy is a biological phenomenon by which a plant produces one or more biochemicals that influence the germination, growth, survival, and reproduction of other organisms**.** Much effort has been focused on rice allelopathy research for more than 30 years (Khanh et al. 2007). Numerous phytotoxins such as cytokinins, diterpenoids, fatty acids, flavones, glucopyranosides, indoles, momilactones (A and B), oryzalexins, phenols, phenolic acids, resorcinols and stigmastanols have been identified and determined as weeds growth inhibitors excreted by rice roots. And specific rice gene alleles determining them have been already reported (Khanh et al. 2007). These alleles have been found they are excreted by some rice varieties and wild rice species at different levels (Song et al. 2012). Thus, a wide range of new natural herbicide compounds can be developed for commercialization to control weeds in organic cultivation.

Tagetes minuta (Mexican marigold; family Asteraceae) is an aromatic essential plant with wide range of biological activity including medicinal properties (Vasudevan et al. 1997). A recent study was successfully demonstrated the potential herbicidal activity of *Tagetes minuta* leaf powder towards invasive weeds. It not only possesses excellent medicinal properties but also has strong nematicidal, insecticidal and antimicrobial activity (Tereschuk et al. 1997; Tomova et al. 2005).

Several reports have been published on rice bran allelopathy for controlling weeds in paddy fields, farmer association milling facilities produce rice bran as a waste that could be efficiently used for organic rice production. The use of rice bran compost for eco-friendly weed control in organic farming system was successfully evaluated by Khan et al. (2007) at Japan (Khan et al. 2007). Considering the above facts, the use of rice bran could be a useful way for eco-friendly and non-chemical weed control in organic farming systems (Bhuiyan et al. 2014). Furthermore, rice bran, derived from the outer layers of the caryopsis during milling, including the pericarp, seed coat, nucellus and part of the sub aleurone layer of the starchy endosperm, accounts for 5 to 8% of the rough rice weight. It is reported that rice bran contain valuable components such as oil, protein, macro and micro nutrients, vitamins some essential minerals as well as enzymes, microorganisms, natural toxicant constituent (Barber 1979).

Chapter II points that the most blast-sensitive cultivar is Bomba, followed by Argila, Guara, J. Sendra and Montsianell, while V.exp.1 was exceptionally blast tolerant. The only effective non-synthetic fungicide was Sulphur at high doses for cultivars with medium blast sensitivity. Indeed, other authors found that the Sulphur treatments increased the yield significantly with respect to the untreated plots when using medium blast-tolerant cultivars (Malav et al. 2016). We conclude that Sulphur (Thiopron, 82.5 % a.i. L-1, SC, UPL Iberica) at a 7.5 l·ha-1 dose helps organic farmers to control rice blast. It may be necessary to apply four to five Sulphur or Silicon-based treatments to reach a satisfactory blast protection due to the lack of Sulphur's persistence and its mode of action, as reported by (Gopi et al. 2016). In contrast, none of the treatments resulted in blast-tolerance improvement in either the most blast-tolerant (V.Exp.1) or the most blast-sensitive (Bomba) cultivars. The greater yield differences between synthetic and non-synthetic fungicides observed in Bomba due to both its varietal high blast sensitivity (Carreres et al. 1986) and the weak blast control of the assessed organic fungicides (Chakraborty et al. 2021). The lack of sufficiently effective blast control in Bomba when using non-synthetic fungicidal products needs to be complemented with other strategies such as reduced nitrogen fertiliser doses and reduced plant densities (Pooja and Katoch 2014). The magnitude of the yield reduction was dependent on the varietals' susceptibility to disease (Koutroubas et al. 2009).

One hypothesis is the lack of efficacy of strobilurin treatments could be because of fungicide resistance of blast rice strains (Valarmathi 2018). As reported in countries like India (Mohiddin et al. 2021), Italy (Kunova et al. 2021) an others (Kim et al. 2003). The wide variation in the incidence of blast-affected panicles during both years can be attributed to the reported variability dependent on climatic conditions (Marchetti and Bonman 1989; Muñoz 2008; Nasruddin and Amin 2013).

Our results showed an interannual variation in the proportion of failed panicles between 2019 and 2020. The delay in planting time in 2020 led to a greater intensity of rice blast attack on the panicle compared to 2019 (Figure 24 and 25). Agronomic factors such as nitrogen fertiliser doses or sowing date could influence plant health and fungus conditions (Bhat et al. 2013). These variations were due to the variation of meteorological factors (temperature, humidity, and rainfall) that affect the epidemiology of rice blast in the Ebro Delta. Indeed, the 2020-trial sowing date delay could have increased the percentage of blast failed panicles because it might had overlapped the most blast-favourable weather conditions with the most vulnerable rice stages: the heading and milky grain stages (Marchetti and Bonman 1989; Nasruddin and Amin 2013; Sester et al. 2014). The yearly variation in panicle failure is known to be highly determined by meteorology (Katsantonis et al. 2017; Shahriar et al. 2020). A 95% relative humidity and 26-27°C temperature are optimum for blast infection and substantially favour spore release (Muñoz 2008). We commonly observed later blast attack at the end of August at the ripening stage (Bonman et al. 1991) increased the level of blast effects on the panicles at the end of the rice cycle during both years, and to our knowledge, the high air humidity and high temperature favoured inoculum pressure (Marchetti and Bonman 1989; Muñoz 2008; Nasruddin and Amin 2013). Thus, one cannot directly link the apparent effects of blast on the panicles and grain yield because the impact on grain production strongly depends on the panicle stage when infection occurs (Bakar 2019).

The Blast management to avoid resistance fungicides problems it's ones of the most important points. The rotation of blast control methods can help to better results in yield. To change a cultivar every year, to change the seeding system, to change the active ingredients of fungicides, there are some of the examples of integrated pest management (Figure 29).

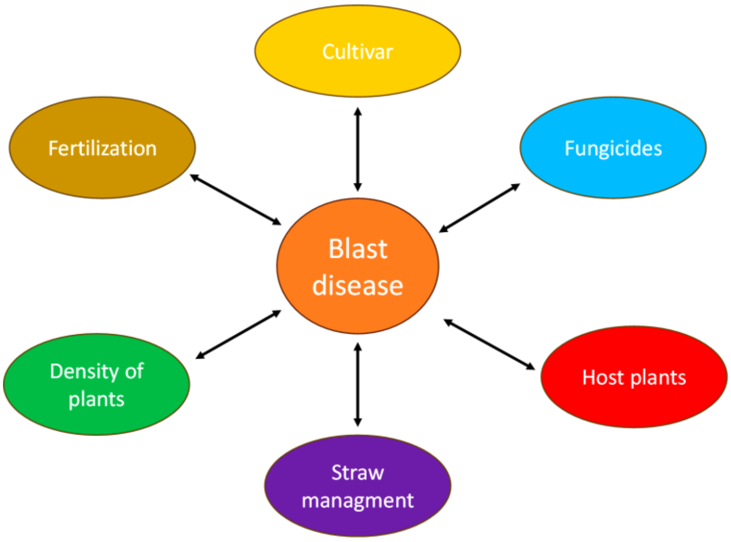


Figure 29: Integrated blast management

The results on grain yield and tillering of the chemical fertilizer showed the best results followed of the OPF fertilizer. The application of PGPM in anaerobic conditions (B and N) did not improve rice yields. The article concludes that an efficient bio-organic fertilizer (called OPF) for organic rice cultivation in Ebro Delta has been identified, only reducing the yield by 17% compared with a chemical fertilizer and it adapts perfectly to the application equipment's of the farmers. The outcome of these study is important as it will contribute efficiently to organic rice cultivation. Since organic fertilization management has been studied and it is not an limitation to organic rice production (Lin et al. 2011; Pan et al. 2009), although recent studies point that applying all the organic manure before seeding increases methane emission when compared to chemical fertilization of fractionated organic fertilization (Moreno-García et al. 2020).

Currently, rice planting is the only rice cultivation in rows that can be performed in flooded rice paddies, which greatly facilitates the mechanical control of weeds. This technique has high economic costs, and the rice plant undergoes a stress period just after transplanting, overcoming an important adaptation process. Consequently, the research and technological development of different in-row rice planting systems must be deepened, which will facilitate the subsequent mechanical weeding between rows in a more optimal and efficient way. In-rows planting permits mechanised weeding between rows and eases manual weeding (Pipeng et al. 2021)

Over flooding (OF) is a common technique of water-level management common in California. It represents an alternative to the conventional water-seeding technique that is specifically appropriate for highly salinized areas. Likewise, OF was also the one that hindered grassy weeds, accordantly to other authors (Auld and Kim 1996; Moody 1995). Simple dry seeding is the common practice when performing dry seeding in the Ebro Delta (Franquet Bernis 2018). Dry seeding in saline soils is challenging, and a specific soil moisture and texture is needed in order to facilitate rice seedling emergence (Lee et al. 2017; Yamane et al. 2018). In addition, when neighbouring fields around the experimental parcel are flooded, the saline phatic layer pushes up into the dry field (Wilson et al. 2000). Unfortunately, irrigating the fields prior to dry seeding elevated the saline water layer, which affected rice seedlings (Genua-Olmedo 2017; Sánchez-Arcilla et al. 2008). Consequently, it is necessary to isolate the field borders with drainage furrow systems to avoid this problem (Mukhopadhyay et al. 2021).

Direct seeding is commonly practiced of agriculture conservation in cereal crops, like rice. These systems have productive and economic advantages for farmers, as well as environmental ones because it is associated with the minimum tillage of the land, which improves the soil fertility and reduces the amount of nitrogen fertilizers. The main difference with water seeding is the dry seeding conditions of the soil and this strategy reduce the gas emissions (Martínez-Eixarch et al. 2021; Monaco et al. 2021) and water demand during the firstly 40 days without flooding paddies. That make them sustainable for agricultural ecosystems, in the Mediterranean region where the limiting factor is the availability of water (Cabangon et al. 2002; Mahajan et al. 2013; Zampieri et al. 2019).

Crop rotations in coastal paddy fields have failed due to high and rapid salinization of the fields when irrigation water is withdrawn. Interestingly, quinoa (*Chenopodium quinoa* Willdenow) can be used for rice crop rotation in these salinized areas, as it has shown unusually high salt tolerance; many varieties can grow in salt concentrations as high as those found in seawater (40 mS cm^{-1}). Again, it's the same problem as with the rice, weeds are the main problem with organic quinoa production. Crop rotation with rice would not only help to produce both crops in an ecological way, but would also make it possible to obtain, for the first time, two crops a year in the same paddy fields, since rice crop (summer) and quinoa crop (winter) do not overlap. It is likely that other techniques such as green mulching could also help in suppressing the weeds, as reported by Fogliatto (2021).

The agriculture conservation principles, including minimal soil disturbance, permanent soil cover and crop rotation has been growing since the early 2000s (Peigné et al. 2016). Agriculture conservation and organic farming are considered as promising sustainable agricultural system for producing food, while minimizing environmental impacts (Casagrande et al. 2016). Agriculture conservation and organic farming are two alternative strategies that aim to improve soil quality and fertility in arable cropping systems through reducing tillage intensity, maintaining soil cover and increasing nutrient recycling, using farmyard and green manures (Baldivieso-Freitas et al. 2018). Non tillage mitigates net GHG emissions in subtropical paddy rice ecosystems (Weinert et al. 2023).

However, potential weed problems often tend to discourage farmers from adopting it. Reduced tillage could thus be useful in organic cropping systems but would require proper management of perennial and monocotyledonous weeds, which are often problematic for annual crops (Sans et al. 2011). The agriculture conservation could be candidate to synergic organic rice systems, form analogous has been other crops like spelt or sunflower as reported by Sans. Optimization of the nitrogen (N) inputs and minimization of nutrient losses strongly affect yields in crop rotations (Diacono et al. 2019). Cover crops in winter season is ones of alternative technique that improve the soil fertility and the same time can reduce the weeds competence (Riemens et al. 2022; Vincent-Caboud et al. 2017). Agronomic practices taking into account the regeneration of the soil such as green manure and crop rotations, will improve the structure of the soil and their organic matter content. As far as weed infestations increase in organic rice production fields over the years, it will be necessary to plan fallows in those lands that have reached high levels of infestation, to let the land rest and be able to carry out a cultural control of weeds through false sowing and thus, reduce the seed bank of the soil. This way, the biodiversity and the rice ecosystem services will be enhanced within Ebro Delta's wetlands ecosystems.

The economic feasibility of organic rice is ones of the conflicted points with common farmers of Ebro Delta. As this we realized an economic study to know the economic sustainability of organic rice system with the increase of the production costs in 2022 (View ANNEXES I). The most relevant conclusion is that organic rice production in Ebro Delta are both agronomic and economic feasibility.

Another conflicted point is the three years conversion process towards organic certification. The farmers must use both organic products and techniques during a three year period, but their product (paddy rice) will not be certified until the third year. It implies higher production costs, and lower benefits. This factor also discourages the potential farmers to change their production system towards organic rice. There are few organic farmers, and they don't help each other. It is necessary to creation a figure of the federation that can assess and help with all problems and tramits for registration with the CCPAE.

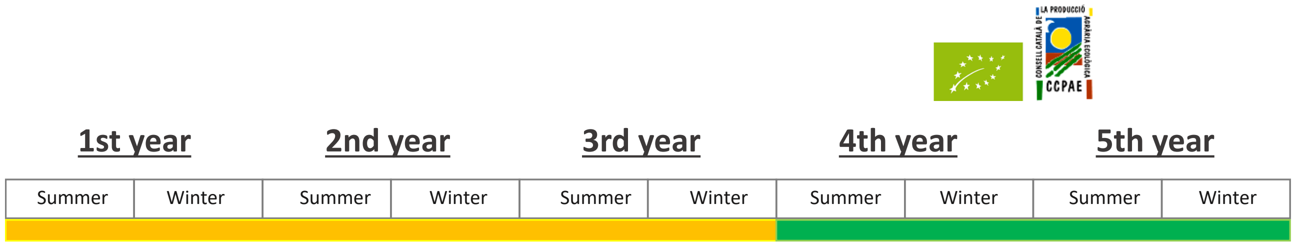


Figure 30: Period of organic certification transition following European laws.

The digitization of the organic rice cultivation will improve its production. It will permit taking better and faster technical decision. The organic production model that is proposed for the future is based on ODR (Organic + Diversify + Resilient). It will include elements such as agriculture precision, mechanical weeding, the use of organic adapted rice varieties, organic fertilizer, resistance to fungal pathologies and soil salinity. The rice cultivation in rows will facilitate the mechanical weeding.

GENERAL CONCLUSIONS

GENERAL CONCLUSIONS

1. We demonstrate for the first time the agronomic and economic viability of the organic rice production in the Ebro Delta.

2. Simple dry seeding technique was the best weeding treatment for dry seeding, while the technique of false seeding (stale seed bed) and planting, was the best performed under water seeding.

3. Dry seeding favoured grasses weeds such as *E. crus-galli*, *E. oryzoides*, while discouraging sedges and aquatic weeds. On the contrary, in water-seeding treatments, sedges and aquatic weeds (*S. maritimus*, *C. difformis* and *H. reniformis*) are favoured and grasses are still a problem in the paddy fields.

4. The use of non-chemical fungicide treatments such as Sulphur on medium-blast sensitivity such as Argila, Guara or J. Sendra is an option for organic rice production.

5. The application of non-synthetic fungicides in low blast sensitivity rice varieties is not effective.

6. An efficient bio-organic fertilizer (OPF) for organic rice cultivation has been identified, only reducing the yield by 17% compared with a chemical fertilizer. This fertilizer formulation is granulated and adapts to the farmers equipment.

FUTURE PRESPECTIVES

Mechanization and precision agriculture for the control of the weeds, especially in water rows seeding.

Studies of indirect techniques to reduce the emergence of weeds in paddy fields: rice brand, allelopathy, *Tagetes minuta*. In this sense, specific rice gene alleles that regulate the excretion of these allelopathic compounds at different levels in some rice varieties and wild rice species have been reported (Song et al. 2012). Despite these extensive efforts locating genes that determine or involve rice allelopathy, the introduction of these genes into target rice cultivars has not yet been achieved. Thus, the successful breeding of new rice cultivars with good weed-suppressing ability would not only benefit farmers, but it would also play an important role in sustainable agricultural production (Khanh et al. 2007).

Besides that, the applicability of rice bran for weed control in organic farming system has been successfully demonstrated in Japan, China, and India (Bhuiyan et al. 2014; Hoosain et al. 2013; Jabran 2017; Khan et al. 2007; Yulianto and Xuan 2018). However, no attempts have been reported in Europe, although a higher potential would be expected, as it has been reported that the rice bran from Japonica subspecies, the subspecies cultivated in Europe, is much more effective than the one from Indica subspecies, cultivated primarily in India, China, and the rest of the world. Rice bran, which account for 5 to 8 % of the rough rice weight, is derived from the outer layers of the caryopsis during milling and includes the pericarp, seed coat, nucleus, and part of the sub- aleurone layer of the starchy endosperm. Rice bran is known for its contain valuable components and natural toxins (Barber 1979). Considering the above facts, the use of rice bran could be a useful non-chemical weed control (Bhuiyan et al. 2014; Khan et al. 2007).

On the other hand, *Tagetes minuta* (Mexican marigold; family Asteraceae) is an aromatic essential plant with wide range of biological activity including medicinal properties (Vasudevan et al. 1997). A recent study successfully demonstrated the potential herbicidal activity of *T. minuta* leaf powder towards invasive weeds. It possesses not only excellent medicinal properties but also strong nematocidal, insecticidal and antimicrobial activity (Tereschuk et al. 1997; Tomova et al. 2005). The use of dry powder of *T. minuta* in India has been reported to be effective as bioherbicide in the main rice weed species (Batish et al. 2007), opening the gates for the use of this species as a bioherbicide-fertilizer cover crop, and developing new effective commercial bioherbicides.

Developing high-quality rice varieties suitable for organic cultivation, including high vigour and tillering to block weeds by light competence and having high allelopathic activity against weeds, is the challenge. This will pave the way for a new concept of rice breeding, where varietal selection focusses in cooking quality and easing organic cultivation rather than nowadays high-yielding but low-quality, low-profit rice varieties are highly pesticide-dependant.

Study of rotation of winter crops that are compatible with rice in the summer.

CITED REFERENCES

Abbott, W. S. 1925. A method of computing the effectiveness of an insecticide. J. econ. Entomol 18:265-267.

Agbowuro, G., Afolabi, M., Olamiriki, E., and Awoyemi, S. 2020a. Rice blast disease (Magnaporthe oryzae): A menace to rice production and humanity.

Agbowuro, G., Afolabi, M., Olamiriki, E., and Awoyemi, S. 2020b. Rice blast disease (Magnaporthe oryzae): A menace to rice production and humanity. International Journal of Pathogen Research 4:32-39.

Agrama, H. A., Yan, W., Jia, M., Fjellstrom, R., and McClung, A. M. 2010. Genetic structure associated with diversity and geographic distribution in the USDA rice world collection. Natural Science 2:247.

Alzain, M. N., Loutfy, N., and Aboelkassem, A. 2023. Effects of Different Kinds of Fertilizers on the Vegetative Growth, Antioxidative Defense System and Mineral Properties of Sunflower Plants. Sustainability 15:10072.

Amaro-Blanco, I., Romano, Y., Palmerin, J. A., Gordo, R., Palma-Bautista, C., De Prado, R., and Osuna, M. D. 2021. Different mutations providing target site resistance to ALS-and ACCase-inhibiting herbicides in Echinochloa spp. from paddy fields. Agriculture 11:382.

Amoghavarsha, C., Pramesh, D., Chidanandappa, E., Sharanabasav, H., Raghunandana, A., Prasanna Kumar, M., Hosahatti, R., and Saddamhusen, A. 2021. Chemicals for the management of paddy blast disease. Pages 59-81 in: Blast Disease of Cereal Crops. Springer.

Amores, A., Marcos, M., Carrió, D. S., and Gómez-Pujol, L. 2020. Coastal impacts of Storm Gloria (January 2020) over the north-western Mediterranean. Natural Hazards and Earth System Sciences 20:1955-1968.

Ampong-Nyarko, K., and De Datta, S. K. 1991. A handbook for weed control in rice. Int. Rice Res. Inst.

Auld, B. A., and Kim, K.-U. 1996. Weed management in rice. Food & Agriculture Org.

Bakar, A. 2019. Rice leaf blast (Pyricularia oryzae) cavara pathogen distribution, cultivar resistance and yield loss in Zanzibar. Sokoine University of Agriculture.

Baldivieso-Freitas, P., Blanco-Moreno, J. M., Armengot, L., Chamorro, L., Romanyà, J., and Sans, F. X. 2018. Crop yield, weed infestation and soil fertility responses to contrasted ploughing intensity and manure additions in a Mediterranean organic crop rotation. Soil and Tillage Research 180:10-20.

Barber, S. 1979. Rice bran as a potential source of food. Developments in food science.

Barreda, D. G. d. 2021. An overview of rice cultivation in Spain and the managment of Herbicide-Resistant weeds. Agronomy.

Bartlett, D. W., Clough, J. M., Godwin, J. R., Hall, A. A., Hamer, M., and Parr-Dobrzanski, B. 2002. The strobilurin fungicides. Pest Management Science: formerly Pesticide Science 58:649-662.

Batish, D. R., Arora, K., Singh, H. P., and Kohli, R. K. 2007. Potential utilization of dried powder of Tagetes minuta as a natural herbicide for managing rice weeds. Crop Protection 26:566-571.

Belenguer-Manzanedo, M., Rochera, C., Alcaraz, C., Martínez-Eixarch, M., and Camacho, A. 2023. Disentangling drivers of soil organic carbon storage in deltaic rice paddies from the Ebro Delta. Catena 228:107131.

Bhat, Z., Ahangar, M. A., Sanghera, G. S., and Mubarak, T. 2013. Effect of cultivar, fungicide spray and nitrogen fertilization on management of rice blast under temperate ecosystem. International Journal of Science, Environment and Technology 2:410-415.

Bhuiyan, K., Mridha, A., Ahmed, G., Islam, S., and Al Mamun, M. 2014. Effect of rice bran application for eco-friendly weed control, growth and yield of lowland rice in Bangladesh International Journal of Agronomy and Agricultural Research (IJAAR). 5:40-44.

Bonman, J., Estrada, B., Kim, C., Ra, D., and Lee, E. 1991. Assessment of blast disease and yield loss in susceptible and partially resistant rice cultivars in two irrigated lowland environments. Plant Disease 75:462-466.

Broberg, M., Hayes, F., Harmens, H., Uddling, J., Mills, G., and Pleijel, H. 2023. Effects of ozone, drought and heat stress on wheat yield and grain quality. Agriculture, Ecosystems & Environment 352:108505.

Brooks, M. E., Kristensen, K., Van Benthem, K. J., Magnusson, A., Berg, C. W., Nielsen, A., Skaug, H. J., Machler, M., and Bolker, B. M. 2017. glmmTMB balances speed and flexibility among packages for zero-inflated generalized linear mixed modeling. The R journal 9:378-400.

Burgos Junco, P. G., and Ramos Remache, R. A. 2022. Uso microorganismos fijadores de nitrógeno, complementario a la fertilización química del cultivo de arroz (oryza sativa l.) bajo riego.

Cabangon, R., Tuong, T. P., and Abdullah, N. 2002. Comparing water input and water productivity of transplanted and direct-seeded rice production systems. Agricultural Water Management 57:11-31.

Calha, I., Osuna, M., Serra, C., Moreira, I., De Prado, R., and Rocha, F. 2007. Mechanism of resistance to bensulfuron-methyl in Alisma plantago-aquatica biotypes from Portuguese rice paddy fields. Weed research 47:231-240.

Campagna, G., Meriggi, P., and Rapparini, G. 2022. Il contributo del diserbo chimico nella gestione integrata delle malerbe. La gestione integrata delle malerbe: un vincolo o una opportunità per una produzione economicamente e ambientalmente sostenibile?:41.

Carreres, R. 2013. Jornada técnica internacional sobre investigación en arroz. Phytoma 48:8-9.

Carreres, R., Ballesteros, R., and Sendra, J. 1986. Rice diseases in the region of Valencia and methodologies for testing varieties resistance. Cahiers Options Mediterraneennes 15:20-23.

Carretero, J. L. 2004. Flora arvense española: las malas hierbas de los cultivos españoles. MV Phytoma-España.

Casagrande, M., Peigné, J., Payet, V., Mäder, P., Sans, F. X., Blanco-Moreno, J. M., Antichi, D., Bàrberi, P., Beeckman, A., and Bigongiali, F. 2016. Organic farmers' motivations and challenges for adopting conservation agriculture in Europe. Organic Agriculture 6:281-295.

Casals, F. R., Chelleri, L., Martínez, A. J. T., and Breton, F. 2013. Sostenibilidad y resiliencia socioecológica en el delta del Ebro. Documents d'anàlisi geogràfica 59:239-263.

Castejón-Muñoz, M. 2008. The effect of temperature and relative humidity on the airborne concentration of Pyricularia oryzae spores and the development of rice blast in southern Spain. Spanish Journal of Agricultural Research 6:61-69.

Catalá Forner, M., Bria Canyes, J., Almacellas Gort, J., and Marín Sánchez, J. 2003. [Varietal reaction to Pyricularia grisea of rice commercial varieties at Ebro Delta area [Spain]]. Phytoma España (España).

Català, M. 1995. Chemical and cultural practices for red rice control in paddy fields in Ebro Delta (Spain). Crop Protection 14:405-408.

Català, M. 2011. "Chironomus vs cricotopus", ¿afectan por igual a la germinación del arroz en el Delta del Ebro? Pages 463-466 in: Agrícola vergel.

Català, M., Jardí, M., Marín, J., and Almacellas, J. 2008. Reacción varietal a "*Pyricularia grisea*" en arroz y determinación de los genes de virulencia del patògeno en el Delta del Ebro. Período 2000-2006. Phytoma España 196:48-57.

Català, M. M., Pla, E., Martínez, M., and Tomás, N. 2010. Estudio comparativo de la nascencia de cuatro variedades de arroz con diferentes manejos del agua. Agrícola Vergel 339:212-215.

Català, M. M., Domingo, C., Martínez-Eixarch, M., Tomàs, N., Pla, E., and Bertomeu, A. 2019a. Impacto de la salinidad en las principales variedades de arroz cultivadas en España. Vida Rural:36-39.

Català, M. M., Tomàs, N., Martínez, M., Forés, V., Domingo, C., Talón, M., and Pla, E. 2013. La salinidad: un factor limitante en el cultivo del arroz. Agrícola Vergel:358-362.

Català, M. M., Domingo, C., Martínez-Eixarch, M., Tomàs, N., Bertomeu, A., Montero, P., Cabanes, P., and Pla, E. 2019b. Tolerancia varietal del arroz a la salinidad. Agrícola vergel:83-87.

Caton, B. 2010. A practical field guide to weeds of rice in Asia. Int. Rice Res. Inst.

CCPAE. 2020a. Estadistiques 2000-2020.

CCPAE. 2020b. Estadistiques 2000-2020. in: Estadístiques completes. Estadístiques Catalunua 2000-2021 Consell Català de la Producció Agrària Ecològica.

Chakraborty, M., Mahmud, N. U., Ullah, C., Rahman, M., and Islam, T. 2021. Biological and biorational management of blast diseases in cereals caused by Magnaporthe oryzae. Critical Reviews in Biotechnology 41:994-1022.

Chang, T.-T., and Bardenas, E. A. 1965. The morphology and varietal characteristics of the rice plant. Int. Rice Res. Inst.

Charpentier, A., Grillas, P., and Thompson, J. D. 2000. The effects of population size limitation on fecundity in mosaic populations of the clonal macrophyte Scirpus maritimus (Cyperaceae). American Journal of Botany 87:502-507.

Chauhan, B. S., Jabran, K., and Mahajan, G. 2017. Rice production worldwide. Springer.

Chen, S., Elrys, A. S., Zhao, C., Cai, Z., Zhang, J., and Müller, C. 2023. Global patterns and controls of yield and nitrogen use efficiency in rice. Science of The Total Environment:165484.

Chen, X., Hu, F., and Kong, C. 2008. Varietal improvement in rice allelopathy. Allelopathy J 22:379-384.

Chevuru, S., de Wit, A., Supit, I., and Hutjes, R. 2023. Copernicus global crop productivity Indicators: An evaluation based on regionally reported yields. Climate Services 30:100374.

Crafts, A. S., and Robbins, W. W. 1963. Weed control. Soil Science 95:287.

Csurhes, S., and Zhou, Y. 2008. Pest plant risk assessment. Stinkwort (Dittrichia graveolens).

Das, S. K. 2017. Rice cultivation under changing climate with mitigation practices: a mini review. Universal Journal of Agricultural Research 5:333-337.

Das, T., Sen, S., Raj, R., Ghosh, S., Behera, B., and Roy, A. 2021. Economic threshold concept for weed management in crops: Usefulness and limitation.

Dass, A., Shekhawat, K., Choudhary, A. K., Sepat, S., Rathore, S. S., Mahajan, G., and Chauhan, B. S. 2017. Weed management in rice using crop competition-a review. Crop protection 95:45-52.

De Wit, J., and Verhoog, H. J. N.-w. j. o. l. s. 2007. Organic values and the conventionalization of organic agriculture. 54:449-462.

Degiovanni Beltramo, V. M., Berrío Orozco, L. E., and Charry Mercado, R. E. 2010. Origen, taxonomía, anatomía y morfología de la planta de arroz (Oryza sativa L.).

Delmotte, S., Tittonell, P., Mouret, J. C., Hammond, R., and Lopez-Ridaura, S. 2011a. On farm assessment of rice yield variability and productivity gaps between organic and conventional cropping systems under Mediterranean climate. European Journal of Agronomy 35:223-236.

Delmotte, S., Tittonell, P., Mouret, J.-C., Hammond, R., and Lopez-Ridaura, S. 2011b. On farm assessment of rice yield variability and productivity gaps between organic and conventional cropping systems under Mediterranean climate. European Journal of Agronomy 35:223-236.

Deng, Y. Z., and Naqvi, N. I. 2019. Metabolic Basis of Pathogenesis and Host Adaptation in Rice Blast. Annual Review of Microbiology 73:601-619.

Diacono, M., Baldivieso-Freitas, P., and Sans Serra, F. X. 2019. Nitrogen utilization in a cereal-legume rotation managed with sustainable agricultural practices. Agronomy 9:113.

Dunn, M. F., and Becerra-Rivera, V. A. 2023. The biosynthesis and functions of polyamines in the interaction of plant growth-promoting rhizobacteria with plants.

Ebbole, D. J. 2007. Magnaporthe as a model for understanding host-pathogen interactions. Annu. Rev. Phytopathol. 45:437-456.

Egea-Fernández, J. M., and Egea-Sánchez, J. M. 2006. Lugares de interés agroecológico como espacio potencial para la producción ecológica. Agroecología 1:99-104.

Eixarch, M. T. M. 2010. Caracterización y optimización del ahijado del arroz en el Delta del Ebro.

Fahad, S., Adnan, M., Noor, M., Arif, M., Alam, M., Khan, I. A., Ullah, H., Wahid, F., Mian, I. A., and Jamal, Y. 2019. Major constraints for global rice production. Pages 1-22 in: Advances in rice research for abiotic stress tolerance. Elsevier.

Fandos, A. T., Chamorro-Lorenzo, L., Caballero-López, B., Blanco-Moreno, J. M., Bragg, D., Casiraghi, A., Pèrez-Ferrer, A., and Sans, F. X. 2023. The Role of Cultivar Mixtures and Intercropping on Cereal Aphid Populations and Crop Yield in Mediterranean Organic Winter Wheat.

FAOSTAT. 2022. Crops and livestock products. Food and Agriculture Organization of the United Nations.

FAOSTAT, F. 2016. Statistical Databases (2013) Food and agriculture organization of the United Nations, statistics division.

FAOSTAT, F. 2023. Statistical Databases (2023) Food and agriculture organization of the United Nations, statistics division.

Farooq, M. S., Fatima, H., Rehman, O. U., Yousuf, M., Kalsoom, R., Fiaz, S., Khan, M. R., Uzair, M., and Huo, S. 2023. Major challenges in widespread adaptation of aerobic rice system and potential opportunities for future sustainability. South African Journal of Botany 159:231-251.

Ferrero, A. 1996. Prediction of Heteranthera reniformis competition with flooded rice using day–degrees. Weed Research 36:197-201.

Ferrero, A. 2005. Ecological and economic sustainability of rice cultivation in Europe and the Mediterranean region. SUMAPOL

Fetting, C. 2020. The European green deal. ESDN report 53.

FiBL-IFOAM. 2022. FiBL & IFOAM. Organics International. The World of Organic Agriculture Statistics & Emerging Trends 2022.

Fogliatto, S., Patrucco, L., De Palo, F., Moretti, B., Milan, M., and Vidotto, F. 2021. Cover crops as green mulching for weed management in rice. Italian Journal of Agronomy.

Foster, S. D., and Bravington, M. V. 2013. A Poisson–Gamma model for analysis of ecological non-negative continuous data. Environmental and ecological statistics 20:533-552.

Fraga, H., Guimarães, N., and Santos, J. A. 2019. Future changes in rice bioclimatic growing conditions in Portugal. Agronomy 9:674.

Franquet Bernis, J. M. 2018. El nuevo sistema de siembra en seco del arroz. 1st ed., Spain.

Franquet Bernis, J. M., and Borràs Pàmies, C. 2004. Variedades y mejora del arroz (Oryza sativa, L.).

Fu, Z., Zhang, K., Zhang, J., Zhang, Y., Cao, Q., Tian, Y., Zhu, Y., Cao, W., and Liu, X. 2023. Optimizing nitrogen application and sowing date can improve environmental sustainability and economic benefit in wheat-rice rotation. Agricultural Systems 204:103536.

Galimany, G., Almacelles, J., Marin, J., and Català, M. 2006. Estrategias para la optimización del control de las enfermedades del arroz en el Delta del Ebro. Phytoma 178:15.

Gao, J., Zhang, X., Luo, J., Zhu, P., Lindsey, S., Gao, H., Li, Q., Peng, C., Zhang, L., and Xu, L. 2023. Changes in soil fertility under partial organic substitution of chemical fertilizer—A 33-year trial. Journal of the Science of Food and Agriculture.

Garris, A. J., Tai, T. H., Coburn, J., Kresovich, S., and McCouch, S. 2005. Genetic structure and diversity in Oryza sativa L. Genetics 169:1631-1638.

Gavilan, A. C. G. 2011. Resistencia a herbicidas inhibidores de ALS y ACCasa en malas hierbas en arroz. Universidad de Córdoba (ESP).

Genua-Olmedo, A. 2017. Modelling sea level rise impacts and the management options for rice production: the Ebro Delta as an example. Universitat Rovira i Virgili.

Genua-Olmedo, A., Alcaraz, C., Caiola, N., and Ibáñez, C. 2016. Sea level rise impacts on rice production: The Ebro Delta as an example. Science of The Total Environment 571:1200-1210.

Genua-Olmedo, A., Temmerman, S., Ibáñez, C., and Alcaraz, C. 2022. Evaluating adaptation options to sea level rise and benefits to agriculture: The Ebro Delta showcase. Science of The Total Environment 806:150624.

Gharsallah, O., Rienzner, M., Mayer, A., Tkachenko, D., Corsi, S., Vuciterna, R., Romani, M., Ricciardelli, A., Cadei, E., and Trevisan, M. 2023. Economic, environmental, and social sustainability of Alternate Wetting and Drying irrigation for rice in northern Italy. Frontiers in Water 5:1213047.

Godfray, H. C. J., Beddington, J. R., Crute, I. R., Haddad, L., Lawrence, D., Muir, J. F., Pretty, J., Robinson, S., Thomas, S. M., and Toulmin, C. 2010. Food security: the challenge of feeding 9 billion people. science 327:812-818.

Gómez de Barreda, D., Pardo, G., Osca, J. M., Catala-Forner, M., Consola, S., Garnica, I., López-Martínez, N., Palmerín, J. A., and Osuna, M. D. 2021. An overview of rice cultivation in Spain and the management of herbicide-resistant weeds. Agronomy 11:1095.

Gopi, R., Avasthe, R., Kalita, H., and Kapoor, C. 2016. Management of rice blast caused by Magnaporthe oryzae using botanicals, biocontrol agents and organically permitted fungicides. Indian Phytopath 69:10-15.

Guo, S., Mu, L., Sun, S., Hou, X., Yao, M., and Hu, X. 2023. Concurrence of microplastics and heat waves reduces rice yields and disturbs the agroecosystem nitrogen cycle. Journal of Hazardous Materials 452:131340.

Gussev, C., Georgiev, V., Tsoneva, S., and Tzonev, R. 2020. New floristic and syntaxonomic data from paddy fields in Bulgaria. Botanica Serbica 44:95-100.

Hartig, F. 2020. DHARMa: residual diagnostics for hierarchical (multi-level/mixed) regression models. R package version 0.3 3.

Hazra, K., Swain, D., Bohra, A., Singh, S., Kumar, N., and Nath, C. 2018. Organic rice: Potential production strategies, challenges and prospects. Organic agriculture 8:39-56.

He, X., Qiao, Y., Liang, L., Knudsen, M. T., and Martin, F. 2018. Environmental life cycle assessment of long-term organic rice production in subtropical China. Journal of Cleaner Production 176:880-888.

Hermoso, V., Carvalho, S., Giakoumi, S., Goldsborough, D., Katsanevakis, S., Leontiou, S., Markantonatou, V., Rumes, B., Vogiatzakis, I., and Yates, K. 2022. The EU Biodiversity Strategy for 2030: Opportunities and challenges on the path towards biodiversity recovery. Environmental Science & Policy 127:263-271.

Hoosain, S. T., Sugimoto, H., Asagi, N., Araki, T., and Ueno, H. 2013. the use of desalinated-dried jellyfish and rice brand for controlling weeds and rice yield. Jornal of Organic Systems 8:28-37.

Hori, K., Yamamoto, T., and Yano, M. 2017. Genetic dissection of agronomically important traits in closely related temperate Japonica rice cultivars. Breeding science 67:427-434.

Horie, T., Karahara, I., and Katsuhara, M. 2012. Salinity tolerance mechanisms in glycophytes: An overview with the central focus on rice plants. Rice 5:1-18.

Hossain, S. T., Sugimoto, H., Ahmed, G. J. U., and Islam, M. 2005. Effect of integrated rice-duck farming on rice yield, farm productivity, and rice-provisioning ability of farmers. Asian Journal of Agriculture and Development 2:79-86.

Hu, C., Shi, J., Quan, S., Cui, B., Kleessen, S., Nikoloski, Z., Tohge, T., Alexander, D., Guo, L., and Lin, H. 2014. Metabolic variation between Japonica and Indica rice cultivars as revealed by non-targeted metabolomics. Scientific reports 4:5067.

Hu, Q., Liu, T., Ding, H., Li, C., Tan, W., Yu, M., Liu, J., and Cao, C. 2023. Effects of nitrogen fertilizer on soil microbial residues and their contribution to soil organic carbon and total nitrogen in a rice-wheat system. Applied Soil Ecology 181:104648.

Ibáñez, C., Prat, N., Canicio, A., and Curcó, A. 1999. El delta del Ebro, un sistema amenazado. Fundación Nueva Cultura del Agua/Bakeaz.

Ishiguro, K. 2001. Review of research in Japan on the roles of Silicon in conferring resistance against rice blast. Studies in plant science 8:277-291.

Ishii, S., Ikeda, S., Minamisawa, K., and Senoo, K. 2011. Nitrogen cycling in rice paddy environments: past achievements and future challenges. Microbes and environments 26:282-292.

Ito, V. C., and Lacerda, L. G. 2019. Black rice (Oryza sativa L.): A review of its historical aspects, chemical composition, nutritional and functional properties, and applications and processing technologies. Food chemistry 301:125304.

Jabran, K. 2017. Rice Allelopathy for Weed Control. Pages 35-47.

Jang, S., Jung, H., Yun, Y., Hyun, K., Kim, D., Mallory-Smith, C., and Kuk, Y. 2015. Use of emulsifiers for control of rice blast and sheath blight in organic rice cultivation. Journal of Food, Agriculture & Environment 13:213-217.

Jiménez Tapia, E. M. 2020. Paisajes de agua: propuesta de adaptación del Delta del Ebro frente al cambio climático. Universitat Politècnica de Catalunya.

José-María, L., Armengot, L., Blanco-Moreno, J. M., Bassa, M., and Sans, F. X. 2010. Effects of agricultural intensification on plant diversity in Mediterranean dryland cereal fields. Journal of Applied Ecology 47:832-840.

Joshi, B., Jena, S. N., Joshi, S., and Bhau, B. S. 2023. Recent Advances in PGPRs and Their Application in Imparting Biotic and Abiotic Stress Tolerance in Plants. Industrial Microbiology and Biotechnology: Emerging concepts in Microbial Technology:431-472.

Junaedi, A., Jung, W.-S., Chung, I.-M., and Kim, K.-H. 2007. Differentially expressed genes of potentially allelopathic rice in response against barnyardgrass. Journal of Crop Science and Biotechnology 10:231-236.

Katsantonis, D., Kadoglidou, K., Dramalis, C., and Puigdollers, P. 2017. Rice blast forecasting models and their practical value: a review. Phytopathologia Mediterranea:187-216.

Katsarova, I. 2015. Organic food: Helping EU consumers make an informed choice. | European Parliamentary Research Service.

Kellogg, E. A. 2009. The evolutionary history of Ehrhartoideae, Oryzeae, and Oryza. Rice 2:1-14.

Kendig, A., Williams, B., Smith, C. W., and Dilday, R. 2003. Rice weed control. Rice: Origin, history, technology, and production 3:457-472.

Khan, M., K, U., S, H., F, K., K, T., and Y, O. 2007. Evaluation of the Use of Rice Bran Compost for Eco-friendly Weed Control in Organic Farming Systems. American Journal of Environmental Sciences 3.

Khandagave, R. 2023. Organic Farming for Sustainable Production of Sugarcane. Organic Crop Production Management: Focus on India, with Global Implications.

Khanh, T., Dang Xuan, T., and Chung, I. M. 2007. Rice allelopathy and the possibility for weed management. Annals of Applied Biology 151:325-339.

Kim, Y.-S., Dixon, E. W., Vincelli, P., and Farman, M. L. 2003. Field resistance to strobilurin (QoI) fungicides in Pyricularia grisea caused by mutations in the mitochondrial cytochrome b gene. Phytopathology 93:891-900.

Kong, C. 2008. Rice allelopathy. Allelopathy Journal 22:261-273.

Kong, C. H., Chen, X. H., Hu, F., and Zhang, S. Z. 2011. Breeding of commercially acceptable allelopathic rice cultivars in China. Pest Manag Sci 67:1100-1106.

Kongcharoen, N., Kaewsalong, N., and Dethoup, T. 2020. Efficacy of fungicides in controlling rice blast and dirty panicle diseases in Thailand. Scientific Reports 10:1-7.

Koutroubas, S. D., Katsantonis, D., Ntanos, D. A., and LUPOTTO, E. 2009. Blast disease influence on agronomic and quality traits of rice varieties under Mediterranean conditions. Turkish Journal of Agriculture and forestry 33:487-494.

Kraehmer, H., Thomas, C., and Vidotto, F. 2017. Rice production in Europe. Rice production worldwide:93-116.

Kraehmer, H., Jabran, K., Mennan, H., and Chauhan, B. S. 2016. Global distribution of rice weeds–a review. Crop Protection 80:73-86.

Kumar, V., Mahajan, G., Sheng, Q., and Chauhan, B. S. 2023. Weed management in wet direct-seeded rice (Oryza sativa L.): Issues and opportunities. Advances in Agronomy 179:91-133.

Kunova, A., Palazzolo, L., Forlani, F., Catinella, G., Musso, L., Cortesi, P., Eberini, I., Pinto, A., and Dallavalle, S. 2021. Structural investigation and molecular modeling studies of Strobilurin-Based fungicides active against the rice blast pathogen Pyricularia oryzae. International Journal of Molecular Sciences 22:3731.

Laborte, A. G., Gutierrez, M. A., Balanza, J. G., Saito, K., Zwart, S. J., Boschetti, M., Murty, M. V. R., Villano, L., Aunario, J. K., Reinke, R., Koo, J., Hijmans, R. J., and Nelson, A. 2017. RiceAtlas, a spatial database of global rice calendars and production. Scientific Data 4:170074.

Labrada, R., Caseley, J. C., and Parker, C. 1996. Manejo de malezas para países en desarrollo. Food & Agriculture Org.

Laha, G., Singh, R., Ladhalakshmi, D., Sunder, S., Prasad, M. S., Dagar, C., and Babu, V. R. 2017. Importance and management of rice diseases: a global perspective. Rice production worldwide:303-360.

Lancashire, P. D., Bleiholder, H., Boom, T. V. D., Langelüddeke, P., Stauss, R., Weber, E., and Witzenberger, A. 1991. A uniform decimal code for growth stages of crops and weeds. Annals of applied Biology 119:561-601.

Lee, H.-S., Sasaki, K., Kang, J.-W., Sato, T., Song, W.-Y., and Ahn, S.-N. 2017. Mesocotyl elongation is essential for seedling emergence under deep-seeding condition in rice. Rice 10:1-11.

Lenth, R., Buerkner, P., Herve, M., Love, J., Riebl, H., and Singmann, H. 2020. emmeans: estimated marginal means, aka least-squares means, v1. 5.1. Vienna: R Core Team.

Lillebø, A. I., Pardal, M. A., Neto, J. M., and Marques, J. C. 2003. Salinity as the major factor affecting Scirpus maritimus annual dynamics: evidence from field data and greenhouse experiment. Aquatic Botany 77:111-120.

Lin, M., Yang, S., Chen, H., Letuma, P., Khan, M. U., Huang, J., Shen, L., and Lin, W. 2023. Optimally combined application of organic and chemical fertilizers increases grain yield and improves rhizosphere microecological properties in rice ratooning. Crop Science 63:764-783.

Lin, W., Lin, M., Zhou, H., Wu, H., Li, Z., and Lin, W. 2019. The effects of chemical and organic fertilizer usage on rhizosphere soil in tea orchards. PloS one 14:e0217018.

Lin, X.-q., Zhu, D.-f., Chen, H.-z., and Zhang, Y.-p. 2009. Effects of plant density and nitrogen application rate on grain yield and nitrogen uptake of super hybrid rice. Rice Science 16:138-142.

Lin, X., Zhu, D., and Lin, X. 2011. Effects of water management and organic fertilization with SRI crop practices on hybrid rice performance and rhizosphere dynamics. Paddy and Water Environment 9:33-39.

Litardo, R. C. M., Bendezú, S. J. G., Zenteno, M. D. C., Mora, F. C., and Rivas, L. L. P. 2023. Sistema de producción del cultivo de arroz en zonas con alta salinidad en suelos y agua. Ciencia y Tecnología Agropecuaria 24.

Liu, C., Yang, K., Chen, Y., Gong, H., Feng, X., Tang, Z., Fu, D., and Qi, L. 2023. Benefits of mechanical weeding for weed control, rice growth characteristics and yield in paddy fields. Field Crops Research 293:108852.

Lobo, V. L. 2008. Effects of chemical treatment of rice seeds on leaf blast control and physiological and sanitary quality of treated seeds. Tropical Plant Pathology 33:162-166.

Londo, J. P., Chiang, Y.-C., Hung, K.-H., Chiang, T.-Y., and Schaal, B. A. 2006. Phylogeography of Asian wild rice, Oryza rufipogon, reveals multiple independent domestications of cultivated rice, Oryza sativa. Proceedings of the National Academy of Sciences 103:9578-9583.

Lopez-Martinez, N., Shimabukuro, R. H., and De Prado, R. 1998. Effect of quinclorac on auxin-induced growth, transmembrane proton gradient and ethylene biosynthesis in Echinochloa spp. Functional Plant Biology 25:851-857.

Lopez-Martinez, N., Finch, R., Marshall, G., and De Prado, R. 1997. Molecular Characterization of Herbicide Resistance in Echinochloa Spp. Pages 199-205 in: Weed and Crop Resistance to Herbicides. Springer.

Lopez-Martinez, N., Marshall, G., and De Prado, R. 1997. Resistance of barnyardgrass (Echinochloa crus-galli) to atrazine and quinclorac. Pesticide Science 51:171-175.

Lopez-Martinez, N., Gonzalez-Gutierrez, J., and De Prado, R. 2001. Propanil activity, uptake and metabolism in resistant Echinochloa spp. biotypes. Weed Research 41:187-196.

Lopez, M. A., Altaba, C. R., Andree, K. B., and Lopez, V. 2010. First invasion of the apple snail Pomacea insularum in Europe. Tentacle 18:26-28.

Ma, S.-C., Li, F.-M., Xu, B.-C., and Huang, Z.-B. 2010. Effect of lowering the root/shoot ratio by pruning roots on water use efficiency and grain yield of winter wheat. Field Crops Research 115:158-164.

Ma, S., Wang, G., Su, S., Lu, J., Ren, T., Cong, R., Lu, Z., Zhang, Y., Liao, S., and Li, X. 2023. Effects of optimized nitrogen fertilizer management on the yield, nitrogen uptake, and ammonia volatilization of direct-seeded rice. Journal of the Science of Food and Agriculture.

Ma Xu, Q. L., Liang Bai, et al. 2011. Present status and propects of mechanical weeding equipment and technology in paddy field. Transactions of the CSAE 27:162-169.

Maclean, J., Hardy, B., and Hettel, G. 2013. Rice Almanac: Source book for one of the most important economic activities on earth. IRRI.

Mahajan, G., Chauhan, B., and Gill, M. 2013. Dry-seeded rice culture in Punjab State of India: lessons learned from farmers. Field Crops Research 144:89-99.

Maimunah, M. A., Kautsar, V., Bimantara, P. O., Kimani, S. M., Torita, R., Tawaraya, K., Murayama, H., Utami, S. N. H., Purwanto, B. H., and Cheng, W. 2021. Weeding frequencies decreased rice–weed competition and increased rice n uptake in organic paddy field. Agronomy 11:1904.

Malav, J. K., Ramani, V., SAJID, M., and PATEL, K. 2016. Yield and nutrient content of rice as influenced by Silicon and nitrogen application. Annals of Plant and Soil Research 18:413-417.

Mañosa, S., Mateo, R., Guitart, R. J. E. M., and Assessment. 2001. A review of the effects of agricultural and industrial contamination on the Ebro delta biota and wildlife. 71:187-205.

MAPA. 2020. ESYRCE. Enquesta de superficies y rendimientos de cultivo.

MAPA. 2021a. Producción ecológica. Estadísticas 2020.

MAPA. 2021b. ESYRCE. Encuesta sobre superficies y rendimientos en España.

MAPA. 2022. Informe del consumo alimentario de España 2022.

MAPAMA. 2017. MAPAMA Dash board: arroz (mayo 2017).

MAPAMA. 2018. Distribución de la superfície y producción de arroz en España por Comunidades Autónomas. S. g. d. A. y. alimentación, ed. Dirección general de producciones y mercados agrarios, Madrid.

Marchetti, M., and Bonman, J. 1989. Rice blast disease management. Rice Farming Systems: New Directions:175-184.

Marín, J., Segarra, J., and Almacellas, J. 1992. Enfermedades de los cereales en Cataluña durante 1988-90.[Cereal diseases in Cataluña during 1988-90 period]. Investigación agraria. Producción y protección vegetales-INIA (España) 7:261-275.

Martínez-Eixarch, M., Curcó, A., Ibáñez, C. J. P., and Environment, W. 2017. Effects of agri-environmental and organic rice farming on yield and macrophyte community in Mediterranean paddy fields. 15:457.

Martínez-Eixarch, M., Alcaraz, C., Viñas, M., Noguerol, J., Aranda, X., Prenafeta-Boldú, F.-X., Català-Forner, M., Fennessy, M. S., and Ibáñez, C. 2021. The main drivers of methane emissions differ in the growing and flooded fallow seasons in Mediterranean paddy fields. Plant and Soil 460:211-227.

Masseroni, D., Moller, P., Tyrell, R., Romani, M., Lasagna, A., Sali, G., Facchi, A., and Gandolfi, C. 2018. Evaluating performances of the first automatic system for paddy irrigation in Europe. Agricultural Water Management 201.

Masum, S., Hasanuzzaman, M., Malek, M., Jalal, M., and Razzaque, M. 2022. Morphological and phenological variability of Echinochloa accessions and their herbicide sensivity

Meharg, C., and Meharg, A. A. 2015. Silicon, the silver bullet for mitigating biotic and abiotic stress, and improving grain quality, in rice? Environmental and Experimental Botany 120:8-17.

Merotto Jr, A., Jasieniuk, M., Osuna, M. D., Vidotto, F., Ferrero, A., and Fischer, A. J. 2009. Cross-resistance to herbicides of five ALS-inhibiting groups and sequencing of the ALS gene in Cyperus difformis L. Journal of agricultural and food chemistry 57:1389-1398.

Mohaddesi, A., Abbasian, A., Bakhshipour, S., and Aminpanah, H. 2011. Effect of different levels of nitrogen and plant spacing on yield, yield components and physiological indices in high-yield rice (number 843). American-Eurasian Journal of Agricultural & Environmental Sciences 10:893-900.

Mohiddin, F. A., Bhat, N. A., Wani, S. H., Bhat, A. H., Ahanger, M. A., Shikari, A. B., Sofi, N. R., Parveen, S., Khan, G. H., and Bashir, Z. 2021. Combination of Strobilurin and Triazole Chemicals for the Management of Blast Disease in Mushk Budji-Aromatic Rice. Journal of Fungi 7:1060.

Monaco, S., Volante, A., Orasen, G., Cochrane, N., Oliver, V., Price, A. H., Teh, Y. A., Martínez-Eixarch, M., Thomas, C., and Courtois, B. 2021. Effects of the application of a moderate alternate wetting and drying technique on the performance of different European varieties in Northern Italy rice system. Field Crops Research 270:108220.

Moody, K. 1995. Sustainability in rice weed management. Pages 93-103 in: Proc. Asian Pacific Weed Sci. Soc. Conf. 15th. Vol. IA.

Moreno-García, B., Guillén, M., and Quílez, D. 2020. Greenhouse gas emissions as affected by fertilization type (pig slurry vs. mineral) and soil management in Mediterranean rice systems. Agronomy 10:493.

Morillo, I. 2023. Sequía| El drástico recorte de riego en el Guadalquivir hace inviable la próxima siembra de arroz.

Mouret, J., Hammond, R., Dreyfus, F., Desclaux, D., Marnotte, P., and Mesleard, F. 2004. An integrated study of the development of organic rice cultivation in the Camargue (France).

Mukhopadhyay, R., Sarkar, B., Jat, H. S., Sharma, P. C., and Bolan, N. S. 2021. Soil salinity under climate change: Challenges for sustainable agriculture and food security. Journal of Environmental Management 280:111736.

Munnoli, S., Rajakumar, D., and Thavaprakaash, N. 2023. Influence of Weed Management Practices on Growth and Yield of Aerobic Rice. International Journal of Plant & Soil Science 35:394-403.

Munns, R., and Tester, M. 2008. Mechanisms of salinity tolerance. Annu. Rev. Plant Biol. 59:651-681.

Muñoz, M. C. 2008. The effect of temperature and relative humidity on the airbone concentration of" Pyricularia oryzae" spores and the development of rice blast in southern Spain. Spanish journal of agricultural research:61-69.

Nakashima, S., Calrao, E., De Andrade, L., Sanzonowicz, C., and Spera, S. 2001. The effect of silicic materials application to cerrado oxisol on field crops in the middle-west region of Brasil. Japanese Journal of Soil Science and Plant Nutrition (Japan).

Nalley, L., Tsiboe, F., Durand-Morat, A., Shew, A., and Thoma, G. 2016. Economic and environmental impact of rice blast pathogen (Magnaporthe oryzae) alleviation in the United States. PloS one 11:e0167295.

Namai, T. 2011. Race differentiation of the rice blast fungus, Pyricularia oryzae, and environmentally friendly control of rice blast disease. Journal of General Plant Pathology 77:350-353.

Nasruddin, A., and Amin, N. 2013. Effects of cultivar, planting period, and fungicide usage on rice blast infection levels and crop yield. Journal of Agricultural Science 5:160.

Navarro, A. L. 2007. El arroz en España y en el mundo. Distribución y Consumo:112-120.

Naylor, R., Steinfeld, H., Falcon, W., Galloway, J., Smil, V., Bradford, E., Alder, J., and Mooney, H. 2005. Losing the links between livestock and land. Science 310:1621-1622.

Nazaries, L., Murrell, J. C., Millard, P., Baggs, L., and Singh, B. K. 2013. Methane, microbes and models: fundamental understanding of the soil methane cycle for future predictions. Environmental microbiology 15:2395-2417.

Negrão, S., Courtois, B., Ahmadi, N., Abreu, I., Saibo, N., and Oliveira, M. M. 2011. Recent Updates on Salinity Stress in Rice: From Physiological to Molecular Responses. Critical Reviews in Plant Sciences 30:329-377.

Ntantos, P., and Karpouzos, D. 2010. Application of data envelopment analysis and performance Indicators to irrigation systems in Thessaloniki Plain (Greece). International Journal of Agricultural and Biosystems Engineering 4:714-720.

OECD, Food, and Nations, A. O. o. t. U. 2022. OECD-FAO Agricultural Outlook (Edition 2022).

Olofsdotter, M. 1998. Allelopathy in rice. Int. Rice Res. Inst.

Olofsdotter, M. 2001. Getting closer to breeding for competitive ability and the role of allelopathy—an example from rice (Oryza sativa). Weed Technology 15:798-806.

Olofsdotter, M., Valverde, B., and Madsen, K. 2000. Herbicide resistant rice (Oryza sativa L.): Global implications for weedy rice and weed management. Annals of Applied Biology 137:279-295.

Organization, W. H. 2002. Food and Agriculture Organization of the United Nations. Living well with HIV/AIDS, a manual on nutritional care and support for people living with HIV. AIDS, Rome.

Osca Lluch, J. M., and Gómez De Barreda Ferraz, D. 2016. Guía gráfica de cultivos herbáceos. Colección Académica. Editorial UPV.

Osuna, M. D., Romano, Y., and Quiles, J. 2012. Principales malas hierbas y métodos de control en el cultivo de arroz en España. Vida Rural 339:74-77.

Osuna, M. D., Okada, M., Ahmad, R., Fischer, A. J., and Jasieniuk, M. 2011. Genetic diversity and spread of thiobencarb resistant early watergrass (Echinochloa oryzoides) in California. Weed Science 59:195-201.

Osuna, M. D., Vidotto, F., Fischer, A. J., Bayer, D. E., De Prado, R., and Ferrero, A. 2002. Cross-resistance to bispyribac-sodium and bensulfuron-methyl in Echinochloa phyllopogon and Cyperus difformis. Pesticide Biochemistry and Physiology 73:9-17.

Ou, S. 1985. Rice Diseases: Commonwealth Mycological Institute. Kew, Surrey, England:109-200.

Pacanoski, Z., and Mehmeti, A. 2023. Different POST-em Herbicide Programs for Weed Management in Lowland Flooded Rice System in North Macedonia. Yuzuncu Yıl University Journal of Agricultural Sciences 33:150-162.

Pak, D., You, M. P., Lanoiselet, V., and Barbetti, M. J. 2017. Azoxystrobin and propiconazole offer significant potential for rice blast (Pyricularia oryzae) management in Australia. European Journal of Plant Pathology 148:247-259.

Pan, G., Zhou, P., Li, Z., Smith, P., Li, L., Qiu, D., Zhang, X., Xu, X., Shen, S., and Chen, X. 2009. Combined inorganic/organic fertilization enhances N efficiency and increases rice productivity through organic carbon accumulation in a rice paddy from the Tai Lake region, China. Agriculture, ecosystems & environment 131:274-280.

Pandey, S., Byerlee, D., Dawe, D., Dobermann, A., Mohanty, S., Rozelle, S., and Hardy, B. 2010. Rice in the global economy. Los Banos, Phillipines: International Rice Research Institute.

Papapanagiotou, A., Vasilakoglou, I., Dhima, K., and Eleftherohorinos, I. 2023. Growth rate and competitive ability of susceptible and multiple-resistant late watergrass (Echinochloa phyllopogon) biotypes to rice. Phytoparasitica:1-18.

Peigné, J., Casagrande, M., Payet, V., David, C., Sans, F. X., Blanco-Moreno, J. M., Cooper, J., Gascoyne, K., Antichi, D., and Bàrberi, P. 2016. How organic farmers practice conservation agriculture in Europe. Renewable Agriculture and Food Systems 31:72-85.

Pérez Lotz, J. 2016. Análisis genético de la resistencia parcial a Magnaporthe oryzae en arroz (Oryza sativa) en varias poblaciones y ambientes. Universitat Politècnica de València.

Pérez Pons, M. 2012. El caracol manzana ya coloniza mil hectáreas en el delta del Ebro. in: El País Grupo Prisa, Tarragona, Spain.

Peyghambarzadeh, S., Babaeinejad, T., Hadian, J., Fallah, A., and Ghanavati, N. 2023. Growth and Phytochemical Properties of Horsetail Plant affected by Organic and Mineral Fertilization. Silicon:1-9.

Pineiro, F., García-Cebolla, J., and Giménez-Ejarque, J. 2000. La Pyriculariosis en el arroz valenciano. Comunitat Valenciana Agraria:43-47.

Pipeng, X., Jinhai, L., Haowen, L., Rifang, L., Longxin, H., Hua, T., Meiyang, D., Shenggang, P., Zhaowen, M., and Xiangru, T. 2021. Effects of Different Mechanical Planting Methods on Yield, Quality and Aroma of Fragrant Rice under Organic Cultivation Conditions. China Rice 27:41.

Pocius, A., Jotautiene, E., Mieldazys, R., Jasinskas, A., and Kucinskas, V. 2014. Investigation of granulation process parameters influence on granulated fertilizer compost properties. Pages 296-300 in: Engineering for rural development: 13th international scientific conference: proceedings.

Pooja, K., and Katoch, A. 2014. Past, present and future of rice blast management. Plant Science Today 1:165-173.

Primack, R., Rozzi, R., Massardo, F., and Feinsinger, P. 2001. VI. Destrucción y degradación del hábitat. Fundamentos de Conservación Biológica Perspectivas Latinoamericanas. México DF: Fondo de Cultura Económica:183-221.

Quílez y Sáez de Viteri, D., Moreno García, B., Guillén Castillo, M., Bruna Lavilla, P., Vallés Pérez, M., and Iguácel Soteras, F. 2020. Fertilización nitrogenada orgánica y mineral del cultivo de arroz en Aragón.

Rajanna, G. A., Suman, A., and Venkatesh, P. 2023. Mitigating Drought Stress Effects in Arid and Semi-Arid Agro-Ecosystems through Bioirrigation Strategies—A Review. Sustainability 15:3542.

Rajkhowa, D., Mahanta, K., Kumar, M., Das, A., Sharma, A., Rangappa, K., and Saikia, U. S. 2023. Effect of herbicides on weed dynamics, soil fertility, energetics and productivity of upland rice in an acidic subtropical soil of the Eastern Himalayas, India. Archives of Agronomy and Soil Science 69:2552-2568.

Ramos de Fuentes, E. 2018. Developing of new stress-tolerant rice varieties for the Mediterranean region.

Recasens, J., Conesa, J., and Juárez-Escario, A. 2019. Las invasiones vegetales en sistemas agrícolas. Retrospectiva de los últimos 40 años en Cataluña. Inf. Tec. Econ. Agrar.

Reddy, B. M., Naseeruddin, R., Kumar, S. V., Prathima, T., and Leelavathy, G. 2023. Consequences of climate change in weed species in the rice ecosystem.

Reganold, J. P., and Wachter, J. M. J. N. p. 2016. Organic agriculture in the twenty-first century. 2:1-8.

Riemens, M., Sønderskov, M., Moonen, A.-C., Storkey, J., and Kudsk, P. 2022. An integrated weed management framework: a pan-European perspective. European Journal of Agronomy 133:126443.

Rodrigo, A., and Ribeiro, D. 2023. Report on the national GHG emissions from rice straw.

Rodríguez Coca, L. I., García González, M. T., Gil Unday, Z., Jiménez Hernández, J., Rodríguez Jáuregui, M. M., and Fernández Cancio, Y. 2023. Effects of Sodium Salinity on Rice (Oryza sativa L.) Cultivation: A Review. Sustainability 15:1804.

Roma-Burgos, N., San Sudo, M. P., Olsen, K. M., Werle, I., and Song, B.-K. 2021. Weedy rice (Oryza spp.): what’s in a name? Weed Science 69:505-513.

Romano, Y., Mendoza, F., Palmerín, J., Quiles, J., Amaro, I., and Osuna, M. 2018. Distribution of resistant populations of Echinochloa spp. to ALS and ACCase inhibitors herbicides in Extremadura. Pages 269-273 in: XVI Congreso de la Sociedad Española de Malherbología, SEMh 2017, Pamplona-Iruña, España, 25-27 octubre, 2017 Universidad Pública de Navarra.

Rossman, A. Y., Howard, R. J., and Valent, B. 1990. Pyricularia grisea the correct name for the rice blast disease fungus. Mycologia 82:509-512.

Rusli, R., and Putra, R. 2023. Golden apple snail management (Pomacea canaliculata Lamarck) using integrated pest management (IPM) and non-integrated pest management (non-IPM) on paddy cultivation. Page 012048 in: IOP Conference Series: Earth and Environmental Science IOP Publishing.

SAFA, F. 2023. Sustainability of assessment of food and agriculture systems.

Saha, S., Pandey, A., Gopinath, K., Bhattacharaya, R., Kundu, S., and Gupta, H. 2007. Nutritional quality of organic rice grown on organic composts. Agronomy for sustainable development 27:223-229.

Sakib, N., Hossain, M., Islam, A., and Amin, M. 2022. Efects of new generation insecticides on the infestation os stem borers and yield of rice. Bangladesh Entomological Society:89.

Sakulkoo, W., Osés-Ruiz, M., Oliveira Garcia, E., Soanes, D. M., Littlejohn, G. R., Hacker, C., Correia, A., Valent, B., and Talbot, N. J. 2018. A single fungal MAP kinase controls plant cell-to-cell invasion by the rice blast fungus. Science 359:1399-1403.

Sales, E., García-Romeral, J., and Domingo, C. 2023. Bioinformatics approach for developing a minimum set of SNP markers for identification of temperate Japonica rice varieties cultivated in Spain. Plos one 18:e0286839.

Samyor, D., Das, A. B., and Deka, S. C. 2017. Pigmented rice a potential source of bioactive compounds: A review. International Journal of Food Science & Technology 52:1073-1081.

Sanchez-Arcilla, A., Ibañez, C., Gracia, V., Garrote, L., CaceresS, I., Lopez, D., De la peña, J., Caiola, N., Munne, A., and Espanya, A. 2023. Nature based solutions for sediment starved deltas. The Ebro case in the Spanish mediterranean coast. Pages 2307-2320 in: Coastal Sediments 2023: The Proceedings of the Coastal Sediments 2023. World Scientific.

Sánchez-Arcilla, A., Jiménez, J. A., Valdemoro, H. I., and Gracia, V. 2008. Implications of climatic change on Spanish Mediterranean low-lying coasts: The Ebro delta case. Journal of Coastal Research 24:306-316.

Sans, F., Berner, A., Armengot, L., and Mäder, P. 2011. Tillage effects on weed communities in an organic winter wheat–sunflower–spelt cropping sequence. Weed Research 51:413-421.

Sarkar, L., Hoque, A., and Pal, S. 2023. Effect of Vermicompost, Municipal Compost and Inorganic Fertilization on Growth Attributes on Plant Growth of Wet Season Rice. International Journal of Plant & Soil Science 35:105-112.

Schebesta, H., Bernaz, N., and Macchi, C. 2020. The European Union Farm to Fork Strategy. European Food and Feed Law Review 15:420-427.

Scott, B., Norsworthy, J., Barber, T., Hardke, J., and Hardke, T. 2013. Rice weed control.

Sella, L., Vu, V. V., Quarantin, A., Caracciolo, R., Govind, R., Bolzonello, A., Tundo, S., Zotti, M. D., Favaron, F., and Nguyen, H. D. 2021. Sustainable methods to control Pyricularia oryzae, the causal agent of rice blast disease. Pages 67-82 in: Innovations in Land, Water and Energy for Vietnam’s Sustainable Development. Springer.

Serrat, X., Esteban, R., Peñas, G., Català, M., Melé, E., and Messeguer, J. 2013. Direct and reverse pollen-mediated gene flow between GM rice and red rice weed. AoB Plants 5.

Sester, M., Raveloson, H., Tharreau, D., and Dusserre, J. 2014. Conservation agriculture cropping system to limit blast disease in upland rainfed rice. Plant Pathology 63:373-381.

Shahriar, S. A., Imtiaz, A. A., Hossain, M. B., Husna, A., and Eaty, M. N. K. 2020. Rice blast disease. Annual Research & Review in Biology:50-64.

Shen, Y., Wang, K., Zhao, Y., Yang, L., Liu, W., Yin, T., Wang, X., Ran, X., Guo, H., and Ma, Y. 2023. Nitrogen fertilizer alleviates rice yield loss without increasing global warming potential under elevated temperatures. Field Crops Research 298:108972.

Shibayama, H. 1994. Integrated management of paddy weeds in Japan. Pages 78-87 in: Integrated management of paddy and aquatic weeds in Asia”; proc. int. seminar “biological control and integrated management of paddy and aquatic weeds in Asia”, Food and Fertilizer Technology Center, Taiwan.

Shibayama, H. 2001. Weeds and weed management in rice production in Japan. Weed biology and management 1:53-60.

Smith, R. J. 1977. Weed control in US rice production. Agricultural Research Service, US Department of Agriculture.

Song, Y., Wang, R., Zhao, M., Yan, X., Su, Y., and Zeng, R. 2012. Differential allelopathic potential of wild rice (Oryza rufipogon W. Griffith) biotypes. Allelopathy Journal 30:189-196.

Strasburger, E., Noll, F., Schenck, H., and SCHIMPER, A. 2004. Tratado de botánica. Barcelona. Omega.

Sullivan, P. 2003. Organic rice production. ATTRA.

Suwanmaneepong, S., Kerdsriserm, C., Lepcha, N., Cavite, H. J., and Llones, C. A. 2020. Cost and return analysis of organic and conventional rice production in Chachoengsao Province, Thailand. Organic Agriculture 10:369-378.

Talbot, N. J. 1995. Having a blast: exploring the pathogenicity of Magnaporthe grisea. Trends in Microbiology 3:9-16.

Talbot, N. J. 2003. On the trail of a cereal killer: exploring the biology of Magnaporthe grisea. Annual Reviews in Microbiology 57:177-202.

Tan, B. L., Norhaizan, M. E., and Chan, L. C. 2023a. Rice Bran: From Waste to Nutritious Food Ingredients. Nutrients 15:2503.

Tan, J., Zhao, H., Li, J., Gong, Y., and Li, X. 2023b. The Devastating Rice Blast Airborne Pathogen Magnaporthe oryzae—A Review on Genes Studied with Mutant Analysis. Pathogens 12:379.

Tang, H., Xiao, X., Xu, Y., Li, C., Cheng, K., Pan, X., and Li, W. 2019. Utilization of carbon sources in the rice rhizosphere and nonrhizosphere soils with different long-term fertilization management. Journal of basic microbiology 59:621-631.

Tereschuk, M. a. L., Riera, M. V., Castro, G. R., and Abdala, L. R. 1997. Antimicrobial activity of flavonoids from leaves of Tagetes minuta. Journal of Ethnopharmacology 56:227-232.

Tomova, B. S., Waterhouse, J. S., and Doberski, J. 2005. The effect of fractionated Tagetes oil volatiles on aphid reproduction. Entomologia Experimentalis et Applicata 115:153-159.

Tony Cisse, K. 2005. Techniques for organic paddy cultivation. Indigenous Agriculture News 4:1-4.

Torra, J., Montull, J. M., Calha, I. M., Osuna, M. D., Portugal, J., and de Prado, R. 2022. Current status of herbicide resistance in the Iberian Peninsula: Future trends and challenges. Agronomy 12:929.

Torres Herrero, J. 2021. Análisis ambiental y social de agricultura ecológica en el Ebro. Universitat Politècnica de Catalunya.

Ushio, M., Saito, H., Tojo, M., and Nagano, A. J. 2023. Detecting and validating influential organisms for rice growth: An ecological network approach. bioRxiv:2023.2002. 2019.529115.

Valarmathi, P. 2018. Dynamics of fungicidal resistance in the agro eco-system: A review. Agricultural Reviews 39.

van Bruggen, A. H., Gamliel, A., and Finckh, M. R. 2016. Plant disease management in organic farming systems. Pest Management Science 72:30-44.

Vargas, J. P. 2010. Capítulo 6.-El arroz y su medio ambiente. Producción eco-eficiente del arroz en América Latina:83-99.

Vasudevan, P., Kashyap, S., and Sharma, S. 1997. Tagetes: a multipurpose plant. Bioresource Technology 62:29-35.

Vigar, V., Myers, S., Oliver, C., Arellano, J., Robinson, S., and Leifert, C. 2019. A systematic review of organic versus conventional food consumption: is there a measurable benefit on human health? Nutrients 12:7.

Vincent-Caboud, L., Peigné, J., Casagrande, M., and Silva, E. M. 2017. Overview of organic cover crop-based no-tillage technique in Europe: Farmers’ practices and research challenges. Agriculture 7:42.

Voisin, A.-S., Denimal, E., De-Yparraguirre, M., Dujourdy, L., and Gée, C. 2023. Potential of the dark green color index for dynamic monitoring of N requirements in wheat crop. Pages 351-358 in: Precision agriculture'23. Wageningen Academic Publishers.

Volpe, V., Magurno, F., Bonfante, P., Ghignone, S., and Lumini, E. 2023. Diversity of Arbuscular Mycorrhizal Fungi Associated with Six Rice Cultivars in Italian Agricultural Ecosystem Managed with Alternate Wetting and Drying. Rice Science 30:348-358.

Walia, S., Banerjee, T., and Kumar, R. 2021. Efficacy of Weed Management Techniques on Weed Control, Biomass Yield, and Soil Herbicide Residue in Transplanted Wild Marigold (Tagetes minuta L.) under High Rainfall Conditions of Western Himalaya. Agronomy 11:2119.

Wang, Y., Li, Y., Xie, Y., Yang, X., He, Z., Tian, H., Duan, M., Tang, X., and Pan, S. 2023. Effects of Nitrogen Fertilizer Rate Under Deep Placement on Grain Yield and Nitrogen Use Efficiency in Mechanical Pot-seedling Transplanting Rice. Journal of Plant Growth Regulation 42:3100-3110.

Wei, X., and Huang, X. 2019. Origin, taxonomy, and phylogenetics of rice. Pages 1-29 in: Rice. Elsevier.

Weinert, C., de Sousa, R. O., Bortowski, E. M., Campelo, M. L., da Silva Pacheco, D., dos Santos, L. V., Deuner, S., Valente, G. B., Matos, A. B., and Vargas, V. L. 2023. Legume winter cover crop (Persian clover) reduces nitrogen requirement and increases grain yield in specialized irrigated hybrid rice system. European Journal of Agronomy 142:126645.

Wickham, H., Averick, M., Bryan, J., Chang, W., McGowan, L. D. A., François, R., Grolemund, G., Hayes, A., Henry, L., and Hester, J. 2019. Welcome to the Tidyverse. Journal of open source software 4:1686.

Willer, H., Lernoud, J., Huber, B., and Sahota, A. 2018. The world of organic agriculture.

Willer, H., Moeskops, B., Busacca, E., and De La Vega, N. 2019. Organic in Europe: recent developments. The World of Organic Agriculture: Statistics and Emerging Trends 2019:208-216.

Willer, H., Trávníček, J., Meier, C., and Schlatter, B. 2021. The world of organic agriculture: statistics and emerging trends 2021. Frick/Bonn: Research Institute of Organic Agriculture (FiBL)/IFOAM-Organics International.

Wilson, C., Keisling, T., Miller, D., Dillon, C., Pearce, A., Frizzell, D., and Counce, P. 2000. Tillage influence on soluble salt movement in silt loam soils cropped to paddy rice. Soil Science Society of America Journal 64:1771-1776.

Wilson, R. A., and Talbot, N. J. 2009. Under pressure: investigating the biology of plant infection by Magnaporthe oryzae. Nature Reviews Microbiology 7:185-195.

Xu, C.-m., Wang, D.-y., Song, C., Chen, L.-p., and Zhanz, X.-f. 2013. Effects of aeration on root physiology and nitrogen metabolism in rice. Rice Science 20:148-153.

Xuan, T. D., Shinkichi, T., Khanh, T. D., and Chung, I. M. 2005. Biological control of weeds and plant pathogens in paddy rice by exploiting plant allelopathy: an overview. Crop protection 24:197-206.

Yamaguchi, M., Yokogami, N., Kataoka, T., Nakagomi, K., Takita, T., Higashi, T., Kato, H., Tamura, Y., Kowata, H., and Oyamada, Z. 2005. Breeding of a new rice cultivar," Churahikari", with blast resistance and excellent eating quality. Bulletin of the National Agricultural Research Center for Tohoku Region (Japan).

Yamane, K., Garcia, R., Imayoshi, K., Mabesa-Telosa, R., Banayo, N., Vergara, G., Yamauchi, A., Sta. Cruz, P., and Kato, Y. 2018. Seed vigour contributes to yield improvement in dry direct-seeded rainfed lowland rice. Annals of Applied Biology 172:100-110.

Yang, C.-c., Kawahara, Y., Mizuno, H., Wu, J., Matsumoto, T., and Itoh, T. 2012. Independent domestication of Asian rice followed by gene flow from Japonica to Indica. Molecular biology and evolution 29:1471-1479.

Yulianto, R., and Xuan, T. D. 2018. Antioxidant and allelopathic activities of rice (Oryza sativa L.) Bran. Journal of Horticulture and Plant Research 1:26-34.

Zaidan, Ú. R., Motta, L. M., de Souza, W. M., Faria, R. M., Paiva, M. C., Mendes, K. F., and de Freitas, F. C. L. 2021. Multi-mixture herbicides provide management strategies in the control of the aquatic weed Heteranthera reniformis. Journal of Crop Science and Biotechnology 24:137-144.

Zamora Laguna, E. J., and Díaz Sevilla, O. G. 2022. Evaluación de cuatros niveles de nitrógeno y tres dosis de siembra en arroz (Oryza sativa L.) var. NutreZinc en el Valle de Sébaco, 2020-2021. Universidad Nacional Agraria.

Zampieri, M., Ceglar, A., Manfron, G., Toreti, A., Duveiller, G., Romani, M., Rocca, C., Scoccimarro, E., Podrascanin, Z., and Djurdjevic, V. 2019. Adaptation and sustainability of water management for rice agriculture in temperate regions: The Italian case-study. Land Degradation & Development 30:2033-2047.

Zhang, S., Rasool, G., Guo, X., Wang, R., Zhao, Z., and Altaf, A. 2021. Response of weeds in paddy fields to different water saving irrigation treatments. Pakistan Journal of Agricultural Sciences 58.

Zhao, T.-c., He, A.-b., Khan, M. N., Yin, Q., Song, S.-k., and Nie, L.-x. 2023. Coupling of reduced inorganic fertilizer with plant-based organic fertilizer as a promising fertilizer management for colored rice in tropical regions. Journal of Integrative Agriculture.

Zheng, C., Liu, C., Liu, L., Tan, Y., Sheng, X., Yu, D., Sun, Z., Sun, X., Chen, J., and Yuan, D. 2023. Effect of salinity stress on rice yield and grain quality: A meta-analysis. European Journal of Agronomy 144:126765.

Zhiyu, L., Hong, Y., Feng-Xiang, L., Qiang, F., and Yang, H. 2011. Occurrence and Population Dynamics of Chironomids in the Early Rice Field.

ANNEXES

ANNEXES

ANNEX 1. Economical study of organic rice cultivation in the Ebro Delta

Table 1: Comparison of cost per hectare between Organic crop system and Conventional crop system. Prices for the Ebro Delta in 2022.

	Operations	Concept	Cost (€/Ha)		Differences between Organic & Conventional
			Organic	Conventional	
CROP EXPENSES	**Preparation of the soil**	Machinery	263	217	Organic needs more preparation
	Fertilization	Machinery - F1 Deep	68	34	The chicken manure is cheap and it's necessary large quantitties
		Fertilizer - F1 Deep	108	368	
		Machinery - F2 Cover	41	82	Organic fertilizers is more expensive than conventional, in change, the conventional needs more nitrogen quantity
		Fertilizer - F2 Cover	651	364	
	Seeding	Machinery	41	41	Organic needs more seeding doses and conventional must to seed-treatment
		Seed	376	239	
	Weeds control	Non-chemical - product	-	-	Organic has only non-chemical techniques to weeding
		Non-chemical - work	200	-	
		Chemical control - product	-	347	Conventional needs products and three chemical-herbicides aplications
		Chemical control - work	-	150	
		Manual weeding	900	100	Organic needs more work-hours to keep out the weeds manually
	Diseases control	Non-chemical - product	146		Organic needs four fungicides applications
		Non-chemical - work	199		
		Chemical control - product		153	Conventional needs three chemical-fungicides applications
		Chemical control - work		150	
	Pest control	Non-chemical - product	74	74	Booth systems needs the saponin treatments to minnor the apple snail pest
		Non-chemical - work	50	50	
	Crop following	Worker	500	300	Organic needs more attentation
	Harvest	Machinary	456	456	
	Post harvest	Machinary	97	97	
	Water	Waste	214	214	
		Worker	120	120	
	Crop insurance	Taxes	75	75	
	ADV	Taxes	48	48	
	Treatments book	IPM Advisor	100	100	
	AMOUNT CROP EXPENSES		**4,727**	**3,779**	
CROP INCOME	**Grant**	PAC	586	586	There are not differences between grants
		Unic payment	345	345	
		Agro-enviromental payment	316	316	
		Rice specific payment	200	200	
	AMOUNT GRANT		**1,447**	**1,447**	
	Rice production	Grain yield (Kg/Ha)	4,500	8,000	Organic rice price has 270 % upper than conventional
		Price (€/kg)	1.30	0.48	
		Benefits	5,850	3,840	
	AMOUNT RICE PRODUCTION		**5,850**	**3,840**	
Total expenses			4,727	3,779	Organic expenses are higher than conventional
Total income			7,297	5,287	Organic has more income than conventional
PROFITS (€/Ha)			**3,274**	**2,328**	Organic wins 29% more profits than conventional

Table 2: Differences between Organic crop system and Conventional crop system. Prices for the Ebro Delta in 2022.

Concept	Organic	Conventional
Rice production (kg/Ha)	4,500	8,000
Price sale (€/kg)	1.30	0.48
Expenses (€/Ha)	4,727	3,779
Benefits (€/Ha)	5,850	3,840
Profits (€/Ha)	1,827	881
Ratio P/E (%)	38.65	23.31
Final price for consumers (€/Kg)	2	6

Table 3: Economical study for 5 years between Organic crop system and Conventional crop system. Prices for the Ebro Delta in 2022.

Rice production (kg/Ha)		Price sale (€/kg)	Benefits					Profits (€)	Expenses (€)	Net benefits without grant (€)	Net benefits with grant (€)
			1st year	2nd year	3rd year	4th year	5th year				
Organic	4,500	0.38	1,710	1,710	1,710	-	-	16,830	23,635	-6,805	430
	4,500	1.32	-	-	-	5,850	5,850				
Conventional	8,000	0.38	3,040	1,710	3,040	3,040	3,040	15,200	18,895	3,695	10,930

ANNEX 2. OTHER SUBMITTED PAPERS (Journals)

plants

Article

Physiological, anatomical and biochemical salt-stress responses of two quinoa varieties

Xavier Serrat[1,*], Antony Quello[1], Gladys Lino[1,2], Alfred Palma-Guillén[1,3] and Salvador Nogués [1]

[1] Departament Biologia Evolutiva, Ecologia i Ciències Ambientals, Universitat de Barcelona, Barcelona, Catalonia Spain
[2] Facultad de Ciencias Ambientales, Universidad Científica del Sur, Lima, Perú
[3] AGROSERVEIS.CAT SL, Deltebre, Catalonia, Spain
[*] Correspondence: xserrat@ub.edu; Tel+34-934033718

Abstract: Soil salinization is an important stress factor that limits plant growth and yield. Increased salinization is projected to affect more than 50 % of all arable land by 2050. In addition, the growing demand for food, together with the increase in the world population, forces the need to seek salt-tolerant crops. Quinoa (*Chenopodium quinoa* Willd.) is an Andean crop of high importance, due to its nutritional characteristics and high tolerance to different abiotic stresses. The aim of this work is to determine the physiological, anatomical and biochemical salt-tolerance mechanisms of a salt-tolerant (Vikinga) and a salt-sensitive (Regalona) quinoa varieties. Plants were subjected to salinity stress for 15 days, starting at 100 mM NaCl until progressively reaching 400 mM NaCl. Growth parameters, chlorophyll content, quantum yield of photosystem II (ϕ_{PSII}), gas exchange, stomatal density, stomatal size and lipid peroxidation (*i.e.* malondialdehyde, MDA) were evaluated. Results show that chlorophyll content, ϕ_{PSII} and MDA were not significantly reduced under saline stress in both varieties. The most stress-affected process was the CO_2 net assimilation, with an up to 60 % reduction in both varieties. The stomatal densities increased under salinity for both varieties, with Regalona the one showing higher values. The averaged stomatal size was also reduced under salinity in both varieties. The capacity of Vikinga to generate higher dry weight is a function of the capacity to generate greater amounts of leaves and roots in any condition. The stomatal control is a key mechanism in quinoa's salinity tolerance, acquiring higher densities with smaller sizes for efficient management of water loss and carbon assimilation.

Keywords: Quinoa; abiotic stress; halophyte; salinity

Citation: To be added by editorial staff during production.

Academic Editor: Firstname Lastname

Received: date
Revised: date
Accepted: date
Published: date

1. Introduction

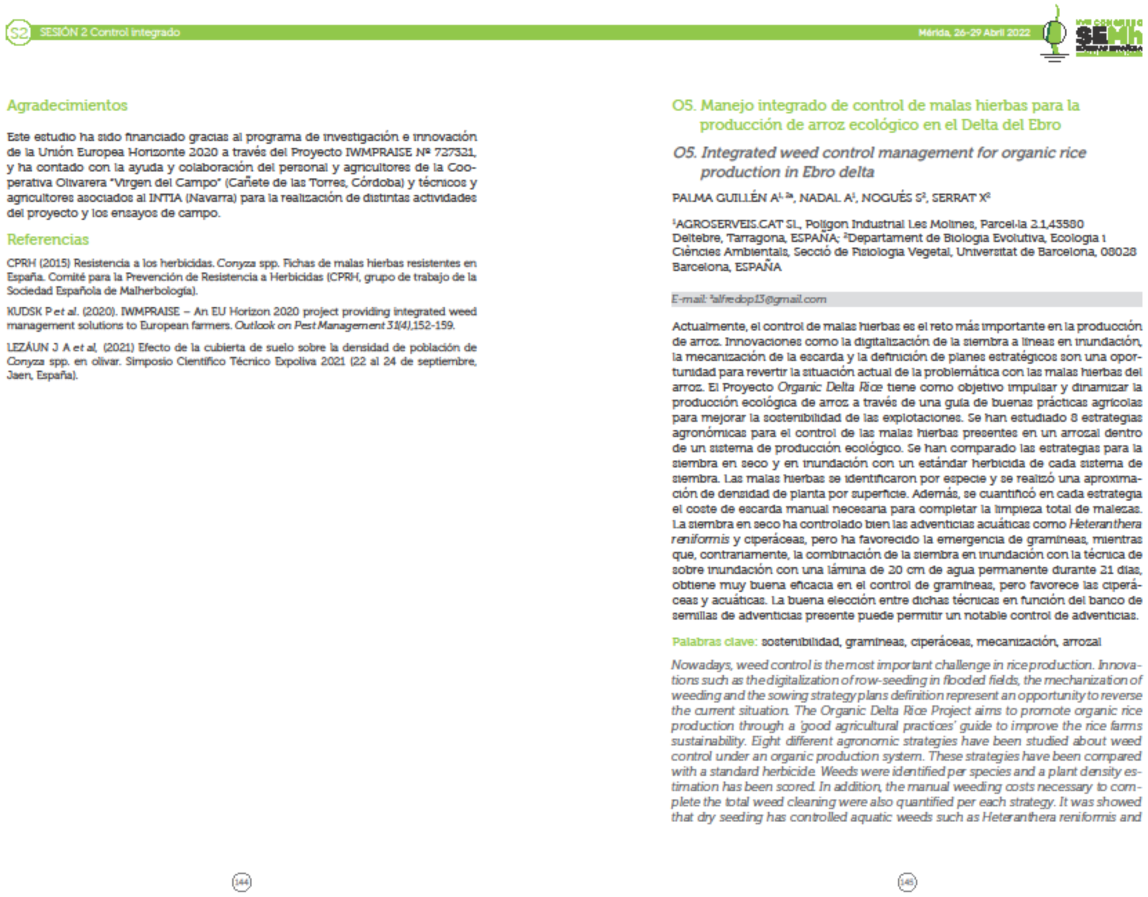
Soil salinization is one of the worst and ancient environmental problems [1]. More than 6 % of the world land surface is affected by the excess of salts and a high rate of arable land is becoming saline due to the human-induced deforestation, inadequate watering and other factors related with the climate change such as the sea water intrusion in coastal areas as a result of the sea level increase and the higher frequency of strong tempests [2,3]. Indeed, it is expected that 50 % of the arable land will be affected by salinization by 2050 [4].

The world population expansion is increasing the food demand and the water competition between domestic and agricultural use, which compromises food security [5]. Agriculture is now focussing on the search of alternative crops and cultivation methods to keep food security and thus, renewed interest has arose in stress-tolerant crop species [6]. Quinoa (*Chenopodium quinoa* Willd.) belongs to the Amaranthaceae family which was

ANNEX 3. DISSEMINATION

(1) **XVIII Congres SEMh –** April 2021

https://semh.net/wp-content/uploads/2022/07/LibroActasSEMh2022-Meridabr.pdf



Agradecimientos

Este estudio ha sido financiado gracias al programa de investigación e innovación de la Unión Europea Horizonte 2020 a través del Proyecto IWMPRAISE Nº 727321, y ha contado con la ayuda y colaboración del personal y agricultores de la Cooperativa Olivarera "Virgen del Campo" (Cañete de las Torres, Córdoba) y técnicos y agricultores asociados al INTIA (Navarra) para la realización de distintas actividades del proyecto y los ensayos de campo.

Referencias

CPRH (2015) Resistencia a los herbicidas. *Conyza* spp. Fichas de malas hierbas resistentes en España. Comité para la Prevención de Resistencia a Herbicidas (CPRH, grupo de trabajo de la Sociedad Española de Malherbología).

KUDSK P *et al.* (2020). IWMPRAISE – An EU Horizon 2020 project providing integrated weed management solutions to European farmers. *Outlook on Pest Management 31(4)*,152-159.

LEZÁUN J A *et al*, (2021) Efecto de la cubierta de suelo sobre la densidad de población de *Conyza* spp. en olivar. Simposio Científico Técnico Expoliva 2021 (22 al 24 de septiembre, Jaen, España).

O5. Manejo integrado de control de malas hierbas para la producción de arroz ecológico en el Delta del Ebro

O5. Integrated weed control management for organic rice production in Ebro delta

PALMA GUILLÉN A[1, 2a], NADAL A[1], NOGUÉS S[2], SERRAT X[2]

[1]AGROSERVEIS.CAT SL, Polígon Industrial Les Molines, Parcel·la 2.1,43580 Deltebre, Tarragona, ESPAÑA; [2]Departament de Biologia Evolutiva, Ecologia i Ciències Ambientals, Secció de Fisiologia Vegetal, Universitat de Barcelona, 08028 Barcelona, ESPAÑA

E-mail: [a]alfredop13@gmail.com

Actualmente, el control de malas hierbas es el reto más importante en la producción de arroz. Innovaciones como la digitalización de la siembra a líneas en inundación, la mecanización de la escarda y la definición de planes estratégicos son una oportunidad para revertir la situación actual de la problemática con las malas hierbas del arroz. El Proyecto *Organic Delta Rice* tiene como objetivo impulsar y dinamizar la producción ecológica de arroz a través de una guía de buenas prácticas agrícolas para mejorar la sostenibilidad de las explotaciones. Se han estudiado 8 estrategias agronómicas para el control de las malas hierbas presentes en un arrozal dentro de un sistema de producción ecológico. Se han comparado las estrategias para la siembra en seco y en inundación con un estándar herbicida de cada sistema de siembra. Las malas hierbas se identificaron por especie y se realizó una aproximación de densidad de planta por superficie. Además, se cuantificó en cada estrategia el coste de escarda manual necesaria para completar la limpieza total de malezas. La siembra en seco ha controlado bien las adventicias acuáticas como *Heteranthera reniformis* y ciperáceas, pero ha favorecido la emergencia de gramíneas, mientras que, contrariamente, la combinación de la siembra en inundación con la técnica de sobre inundación con una lámina de 20 cm de agua permanente durante 21 días, obtiene muy buena eficacia en el control de gramíneas, pero favorece las ciperáceas y acuáticas. La buena elección entre dichas técnicas en función del banco de semillas de adventicias presente puede permitir un notable control de adventicias.

Palabras clave: sostenibilidad, gramíneas, ciperáceas, mecanización, arrozal

Nowadays, weed control is the most important challenge in rice production. Innovations such as the digitalization of row-seeding in flooded fields, the mechanization of weeding and the sowing strategy plans definition represent an opportunity to reverse the current situation. The Organic Delta Rice Project aims to promote organic rice production through a 'good agricultural practices' guide to improve the rice farms sustainability. Eight different agronomic strategies have been studied about weed control under an organic production system. These strategies have been compared with a standard herbicide. Weeds were identified per species and a plant density estimation has been scored. In addition, the manual weeding costs necessary to complete the total weed cleaning were also quantified per each strategy. It was showed that dry seeding has controlled aquatic weeds such as Heteranthera reniformis and

(2) Award: The best oral communication of Doctorate student – April 2021

https://www.phytoma.com/noticias/noticias-de-actualidad/un-estudio-sobre-control-de-malas-hierbas-en-arroz-ecologico-xiii-premio-semh-phytoma

https://doctoratsindustrials.gencat.cat/un-projecte-di-sobre-control-de-males-herbes-en-arros-ecologic-xiii-premi-semh-phytoma/

PREMIO PHYTOMA
XVIII CONGRESO SEMh 2022

OTORGADO AL TRABAJO

MANEJO INTEGRADO DE CONTROL
DE MALAS HIERBAS PARA LA
PRODUCCIÓN DE ARROZ
ECOLÓGICO EN EL DELTA DEL EBRO

ALFRED PALMA

FDO. M.ª DOLORES OSUNA RUIZ
Presidenta de la Sociedad Española de Malherbología

XVIII CONGRESO
SEMh
SOCIEDAD ESPAÑOLA
DE MALHERBOLOGÍA
Mérida, 26-29 Abril 2022

(3) II Congres PAE and conference – May 2021

https://www.youtube.com/watch?v=dNMnsNuGxOQ

II Congrés de
Producció
Agroalimentària
Ecològica

UNIVERSITAT DE BARCELONA
agroserveis.cat

Universitat de Barcelona
Agroserveis.cat

Qui som?

La Universitat de Barcelona i Agroserveis.cat impulsen projectes de recerca en matèria ecològica al Delta de l'Ebre. Realitzem recerca aplicada (I+D) al cultiu de l'arròs, especialment en Producció ecològica. Acompanyats del sector arrosser del Delta, hem iniciat diversos projectes de recerca, col·laborant amb centres com l'IRTA i el DAAC.

(www.ub.edu/web/portal/ca/ www.agroserveiscat.com)

Què fem en relació a la producció agroalimentària ecològica?

Projecte Organic Delta Rice (Doctorat Industrial) + **Projecte Impro-rice**

Objectiu: Estudi de fertilitzants orgànics, fortificants, varietats d'arròs, tècniques pel control de males herbes i rotació de cultiu amb Quinoa per producció ecològica d'arròs al Delta de l'Ebre.
Termini: 2019 – 2022
Actors: Universitat de Barcelona, Agroserveis.cat, Sector arrosser del Delta de l'Ebre, associació d'arrossers PRODELTA, cooperatives, comunitats de regants, IRTA, ADV, DAAC, empreses de fitosanitaris i llavors.

Grup Operatiu d'arròs ecològic

Objectiu: Estudi del control de males herbes dels arrossars amb tècniques de sembra i adaptació de la maquinaria pel desherbatge mecànic
Termini: 2021 – 2022
Actors: Sector arrosser del Delta de l'Ebre, associació d'arrossers PRODELTA, cooperatives, comunitats de regants, ADV, DAAC, IRTA i Agroserveis.cat

Ajut de recerca PAE: Cobertes vegetals als marges i desaigües per la producció ecològica d'arròs

Objectiu: Gestió de males herbes en cursos d'aigua de reg, desaigües i marges de cultiu per a la producció ecològica d'arròs al Delta de l'Ebre
Termini: 2022 – 2023
Actors: Universitat de Barcelona i Agroserveis.cat

Formació Escola Agrària: Cultiu ecològic de l'arròs al Delta de l'Ebre

Objectiu: Proporcionar coneixements i eines pràctiques als agricultors en la presa de decisions del maneig d'una finca de producció ecològica d'arròs.
Termini: 04/2022 – 10/2022
Actors: Escola agrària d'Amposta, Agroserveis.cat

XVIII Congrés de Malherbologia (Divulgació)

Objectiu: Comunicació oral dels resultats de control de males herbes en producció ecològica al XVIII Congrés de la Societat Espanyola de Malherbologia (Mèrida)
Data: 28/04/2022
Actors: Universitat de Barcelona i Agroserveis.cat

*** Premi Semh-Phytoma a la millor comunicació**

PLA D'ACCIÓ PER AL
Desenvolupament de la
Producció ecològica
2023-2027

Generalitat de Catalunya
Departament d'Acció Climàtica, Alimentació i Agenda Rural

(4) Journal BROTS №25 – September 2021

http://www.agrifor.org/ca/actualitat/revista

Mirades del sector

EL PERSONATGE

Screening de varietats d'amics per a producció ecològica.

El Projecte Organic Delta Rice (ODR)

El Projecte Organic Delta Rice va néixer l'any 2019, impulsat per un doctorat industrial (Alfred Palma), l'empresa Agroserveis.cat, SL, la Universitat de Barcelona i el sector arrosser del delta de l'Ebre.

Alfred Palma va néixer a Barcelona l'any 1984. Alumne de l'Escola de Capacitació Agrària d'Amposta, va fer el salt a Escola Tècnica Superior d'Enginyeria Agrària de Lleida en cursar Enginyeria Tècnica Forestal. Posteriorment, va treballar durant tres anys a l'estació experimental de l'IRTA a Amposta i va continuar la formació amb un màster de Protecció Integrada de Cultius (UDL). El 2017 va entrar a treballar com a director tècnic a l'empresa Agroserveis.cat, SL, de Deltebre, on va poder iniciar el doctorat industrial a la Facultat de Biologia de la Universitat de Barcelona, amb el catedràtic Salvador Nogués.

Per **Alfred Palma Guillén**
Col·legiat 4.947
Doctorand de la Universitat de Barcelona (doctorat industrial)
Director tècnic (Agroserveis.cat)

Se sent profundament agraït perquè ha anat adquirint experiència al llarg d'aquests anys, cosa que li està facilitant desenvolupar-se professionalment com a investigador en una zona d'altíssim valor mediambiental com és el delta de l'Ebre.

Projecte Organic Delta Rice (ODR)

La situació actual de la producció d'arròs és cada vegada més complexa des del punt de vista de la sostenibilitat i viabilitat de les explotacions. El model actual de producció d'arròs ha tocat sostre i l'agricultor s'afronta cada campanya a més problemes de sanitat vegetal (resistències als pesticides, plagues invasores, etc.), que s'afegeixen als fenòmens derivats de l'acció antròpica i el canvi climàtic (falta de sediments, regressió i subsidència de la plataforma deltaica,

(5) Journal AGROCULTURA Nº89 – October 2021

https://botiga.associaciolera.org/revista-agrocultura/683-revista-agrocultura-num-89-tardor-2022.html

agrocultura

La revista de la producció ecològica i l'agroecologia

núm. 89 | 4,80 euros

noves tècniques

La tracció animal pren embranzida a Catalunya

reportatge

El Delta de l'Ebre es vol inundar d'arròs eco

biodiversitat

Le Biau Germe: multiplicació de varietats locals en col·lectivitat

horta

Fauna i flora espontània a l'hort de tardor

amb el peu al tros

Joan Raventós: resiliència i equilibri en fruita eco

Eduardo Aguilera, coautor de 'La urgencia de una transición agroecológica en España':

"Per fer la transició agroecològica necessitem canviar també la dieta"

(6) **Journal PHYTOMA Nº344 –** December 2021

https://www.phytoma.com/la-revista/phytohemeroteca/344-diciembre-2022

Premio SEMh-Phytoma

Figura 1. Campo experimental del Proyecto Organic Delta Rice – 2019 (Jordi Tomas).

Palma Guillén, A[1,2*]
Nadal, A[1], Nogués, S[2]
Serrat X[2]

[1] AGROSERVEIS.CAT SL, Polígon Industrial Les Molines, Parcel·la 2.1, 43580 Deltebre, Tarragona, España;[2]

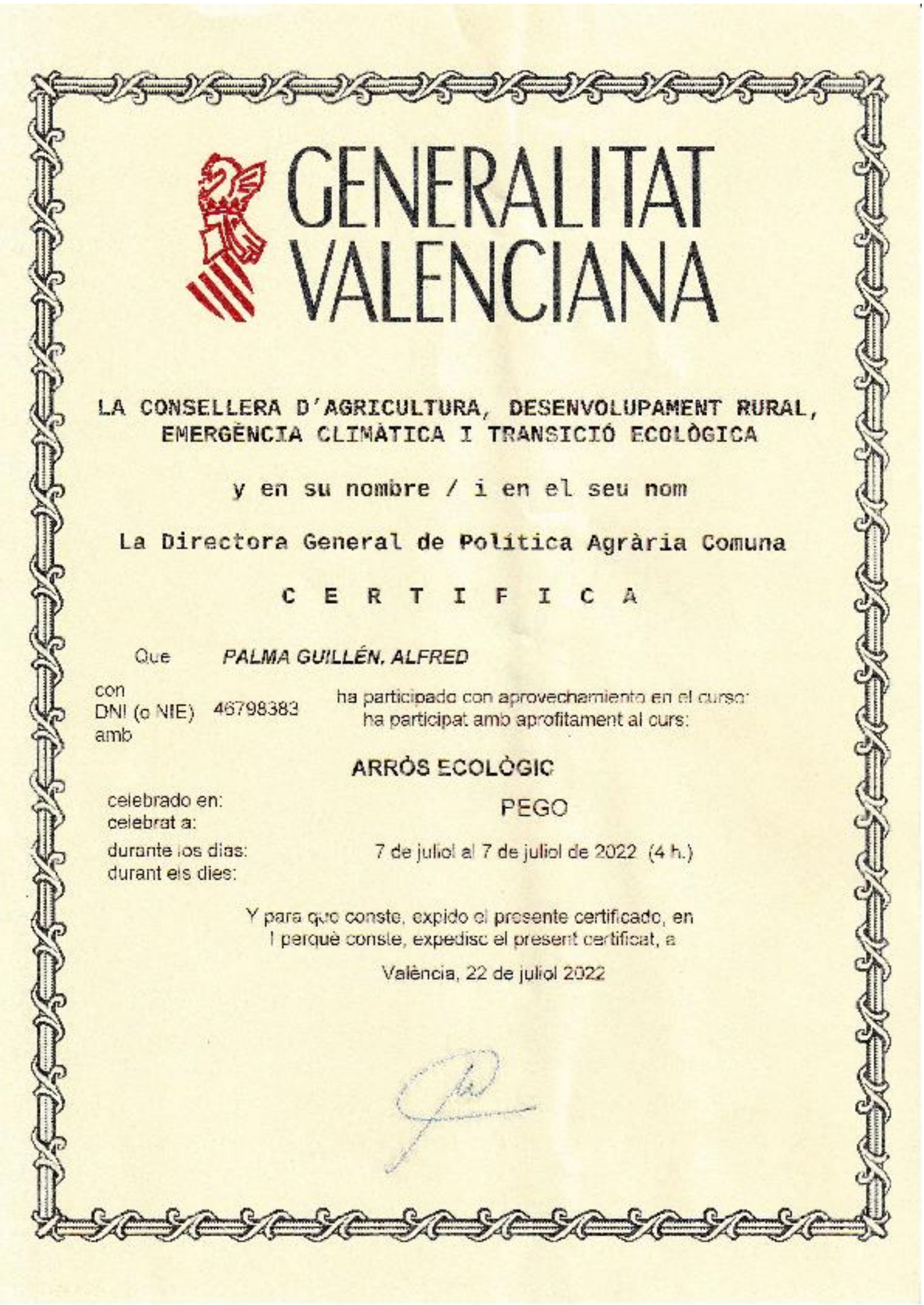
Departament de Biologia Evolutiva, Ecologia i Ciències Ambientals, Secció de Fisiologia Vegetal, Universitat de Barcelona

Manejo integrado de control de malas hierbas para la producción de arroz ecológico en el Delta del Ebro

El control de malas hierbas es el reto más importante en la producción de arroz. El Proyecto Organic Delta Rice tiene como objetivo impulsar y dinamizar la producción ecológica de arroz a través de una guía de buenas prácticas agrícolas para promover la biodiversidad asociada al ecosistema del arrozal y mejorar la sostenibilidad de las explotaciones. Innovaciones como la digitalización de la siembra a líneas en inundación, la mecanización de la escarda y la definición de planes estratégicos son una oportunidad para revertir la situación actual de la problemática con las malas hierbas del arroz. Se han estudiado ocho estrategias agronómicas para el control de las malas hierbas presentes en un arrozal dentro de un sistema de producción ecológico. La siembra en seco ha controlado bien las adventicias acuáticas y ciperáceas, pero ha favorecido la emergencia de gramíneas, mientras que, contrariamente, la combinación de la siembra en inundación con la técnica de sobre inundación con una lámina de 20 cm de agua permanente durante 21 días, obtiene muy buena eficacia en el control de gramíneas, pero favorece las ciperáceas y acuáticas. La buena elección entre dichas técnicas en función del banco de semillas de adventicias presente puede permitir un notable control de adventicias.

Palabras clave: Sostenibilidad, gramíneas, ciperáceas, mecanización, arrozal

(7) Farmers training in Valencia – July, 2022



GENERALITAT
VALENCIANA

LA CONSELLERA D'AGRICULTURA, DESENVOLUPAMENT RURAL,
EMERGÈNCIA CLIMÀTICA I TRANSICIÓ ECOLÒGICA

y en su nombre / i en el seu nom

La Directora General de Política Agrària Comuna

CERTIFICA

Que *PALMA GUILLÉN, ALFRED*

con DNI (o NIE) amb 46798383 ha participado con aprovechamiento en el curso:
ha participat amb aprofitament al curs:

ARRÒS ECOLÒGIC

celebrado en:
celebrat a: PEGO

durante los días:
durant els dies: 7 de juliol al 7 de juliol de 2022 (4 h.)

Y para que conste, expido el presente certificado, en
I perquè consle, expedisc el present certificat, a

València, 22 de juliol 2022

(8) Journal AGROECOLOGIA Nº48 – Summer, 2022

https://www.agroecologia.net/producto/revista-ae-no48/

Plaza • Pública

■ AGRICULTORES NO ÁGRAFOS

Todas las personas tienen formada una opinión sobre los agricultores y esta suele estar cargada de prejuicios y estereotipos: son seres primarios, aculturales, carentes de formación; que se dedican a esta profesión porque están incapacitados para desarrollar otra.

Como agricultora y ganadera ecológica, tengo dos opciones: mostrar mi enfado o analizar la causa de tales ideas preconcebidas. Decido optar por la segunda opción, pienso que el error que hemos cometido ha sido: Ceder la divulgación y el discurso a los demás (opiniónamos, políticos…).

Voy a aprovechar esta oportunidad para hacer una aproximación a la realidad de la agricultura y ganadería ecológica:

Es una actividad muy compleja porque se trabaja con parámetros infinitos e impredecibles, los que aporta la naturaleza.

Tener un enfoque naturcentrista, para obtener un producto de máxima calidad, implica: mucha dedicación, conocimiento y en ocasiones capacidad para manejar la contrariedad.

Una vez obtenido un alimento de calidad excepcional, su comercialización es difícil, ya que las personas priorizan el consumo barato, con independencia de sus características, procedencia y propiedades organolépticas (color, olor, sabor).

Por último tenemos que escuchar constantemente peroratas en defensa del clima y la naturaleza que solo son ecopostureo.

Isabel González Díaz de Villegas - Socia de SEAE

■ IMPULSAR LA PRODUCCIÓN ECOLÓGICA DE ARROZ EN EL DELTA DEL EBRO

El Delta del Ebro es un agroecosistema con una alta biodiversidad que es necesario proteger y preservar. La salinidad de la capa freática es el factor limitante a nivel agronómico que frena la diversificación del monocultivo del arroz. El modelo actual de producción de arroz es insostenible debido a la alta competencia de adventicias, plagas invasoras, enfermedades fúngicas y costes de producción elevados.

El Proyecto Organic Delta Rice impulsado por un Doctorado industrial entre la Universidad de Barcelona y la empresa de servicios Agroserveis.cat está generando la información y experiencias necesarias para potenciar e impulsar la producción ecológica de arroz en el Delta del Ebro. El sector arrocero (cooperativas, comunidad de regantes y asociación de arroceros) están dando apoyo económico para la realización de experimentos que sirvan para enriquecer el conocimiento necesario para que los agricultores puedan realizar una transición del sistema de producción convencional al sistema de producción ecológica.

4 Ae · nº48 · verano 2022

(9) Journal BROTS Nº26 – September, 2022

http://www.agrifor.org/repositori/documents/documentacio/ca/BROTS%20n%C2%BA26(MITJA-pagxpag).pdf

Món agrícola i forestal
PRODUCCIÓ D'ARRÒS

Grup Operatiu ECO-DE. Producció ecològica d'arròs en zones amb limitacions naturals com el Delta de l'Ebre.

Identificació i caracterització de males herbes.

Augmentar la competitivitat en el sector arrosser i en la seva producció ecològica en zones amb certes limitacions.

El Grup Operatiu ECO-DE pretén donar un impuls al cultiu ecològic d'arròs per preservar i millorar la biodiversitat en un ecosistema agrari d'alt valor natural i paisatgístic al Delta de l'Ebre. Aquest projecte ha estat impulsat pel sector arrosser del Delta de l'Ebre (cooperatives, federació d'entitats PRODELTA, comunitats de regants, ADV, IRTA). El projecte s'ha cofinançat a través de l'Associació Europea per la Innovació (AEI), Departament d'Acció Climàtica, Alimentació i Agenda rural i sector arrosser del Delta de l'Ebre. Aquest finançament forma part del programa de desenvolupament rural de Catalunya 2014-2020 a través de l'operació 16.01.01 de cooperació per la innovació.

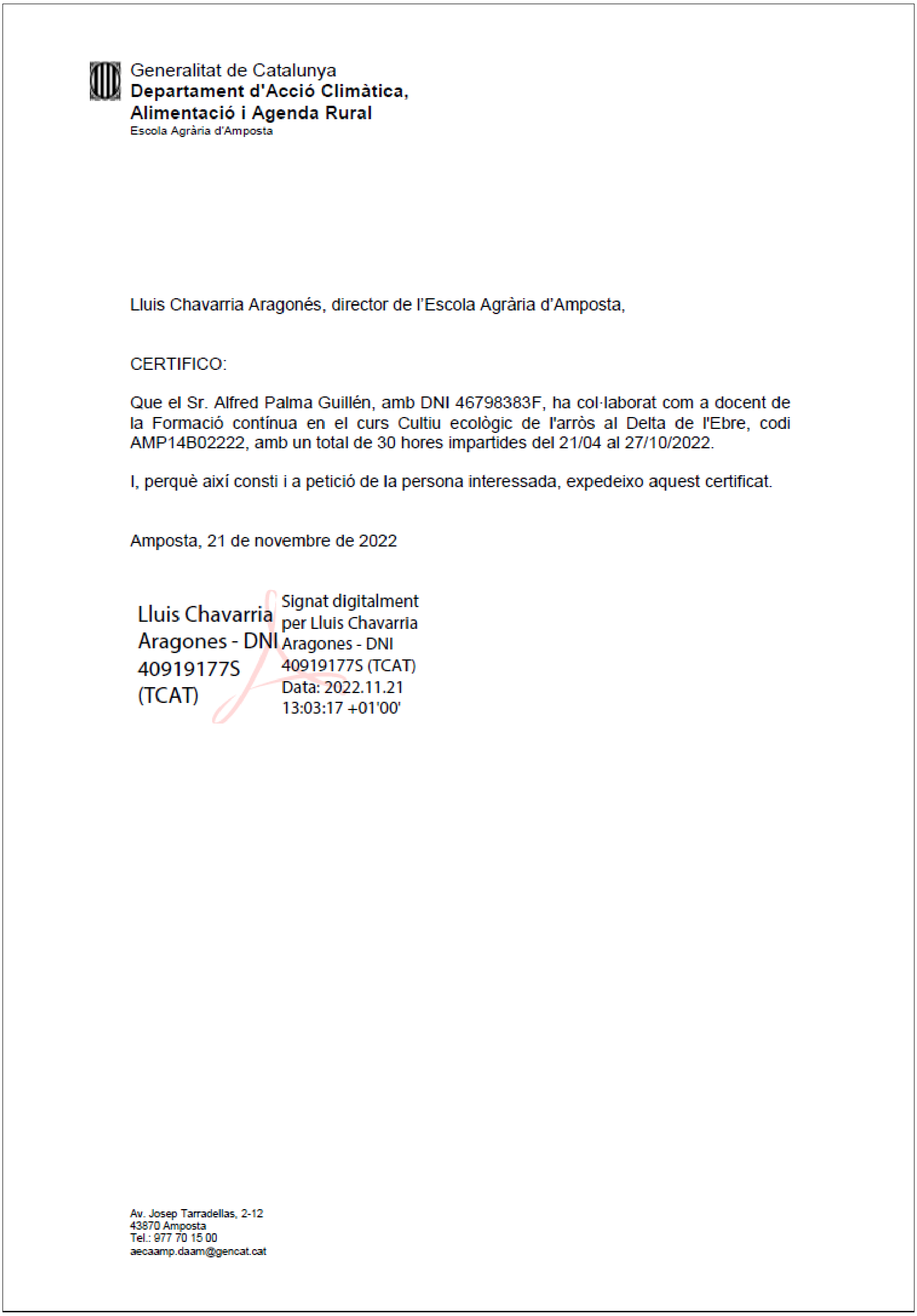
Per **Alfred Palma Guillén**
Col·legiat 4.947
Doctorand de la Universitat de Barcelona (Doctorat Industrial)
Director Tecnic (AGROSERVEIS.CAT)

El projecte dona continuïtat al Projecte Organic Delta Rice on gràcies a l'impuls de tot el sector arrosser, l'any 2019 es va obrir una línia de recerca específica pel cultiu ecològic de l'arròs al Delta de l'Ebre. Les línies d'investigació estan encaminades a donar resposta als aspectes agronòmics més limitants per la producció ecològica d'arròs. El principal limitant és el control de les males herbes que suposa el principal mal de cap dels arrossers tant d'ecològic com del sistema de producció convencional. L'execució dels assajos els realitza Agroserveis.cat SL, una empresa de serveis agraris focalitzada al cultiu de l'arròs i especialitzada en assajos d'experimentació. S'estan estudiant diferents estratègies pel control de les males herbes amb el sistema de sembra en inundació i sembra en sec. Aquestes estratègies integren pràctiques culturals, amb tècniques innovadores de sembra com "la goma d'esborrar" i diferents màquines pel desherbatge amb diferents modes d'acció mecànica.

L'estació experimental I.R.T.A.

38 | BROTS 9/2022

(10) Farmers training in Ebro Delta – November, 2022



Generalitat de Catalunya
Departament d'Acció Climàtica,
Alimentació i Agenda Rural
Escola Agrària d'Amposta

Lluis Chavarria Aragonés, director de l'Escola Agrària d'Amposta,

CERTIFICO:

Que el Sr. Alfred Palma Guillén, amb DNI 46798383F, ha col·laborat com a docent de la Formació contínua en el curs Cultiu ecològic de l'arròs al Delta de l'Ebre, codi AMP14B02222, amb un total de 30 hores impartides del 21/04 al 27/10/2022.

I, perquè així consti i a petició de la persona interessada, expedeixo aquest certificat.

Amposta, 21 de novembre de 2022

Lluis Chavarria
Aragones - DNI
40919177S
(TCAT)

Signat digitalment
per Lluis Chavarria
Aragones - DNI
40919177S (TCAT)
Data: 2022.11.21
13:03:17 +01'00'

Av. Josep Tarradellas, 2-12
43870 Amposta
Tel.: 977 70 15 00
aecaamp.daam@gencat.cat

(11) Newsletter EXTENSIUS.CAT – February 2023

https://extensius.cat/2023/02/27/practiques-per-afavorir-la-biodiversitat-als-arrossars/

PRÀCTIQUES PER AFAVORIR LA BIODIVERSITAT ALS ARROSSARS

La font de riquesa que suposen els arrossars per a la societat és molt gran, tant des del punt de vista agrícola com mediambiental i social. Els serveis ecosistèmics dels arrossars van des d'una font d'alimentació bàsica fins a un reservori de biodiversitat (aus, amfibis, artròpodes) i representen una font de treball per a la gent que treballa la terra. Revertir la pèrdua de biodiversitat dels arrossars és un factor clau per a la preservació dels ecosistemes a les zones humides, però l'equilibri amb la rendibilitat de les explotacions d'arròs no és feina fàcil.

EUROPA: LA NOVA PAC 2023-2027

Entre els objectius de la nova política agrària comunitària d'Europa en destaca un bloc específic per al medi ambient, on es posa èmfasi en l'acció contra el canvi climàtic, la protecció del medi ambient, ~~i~~ la conservació del paisatge i la **biodiversitat**.

Les pràctiques agrícoles van orientades cap a una agricultura més verda, més ecològica i amb menys ús de fitosanitaris i fertilitzants químics. El conreu de l'arròs és probablement el cultiu més sensible per la manca d'alternatives i de recerca aplicada en aquesta direcció. Rotació de cultius, guarets, producció ecològica, etc. són les alternatives agronòmiques cap on camina la nova PAC, però en el cas del Delta de l'Ebre, el **principal factor limitant és la salinitat** dels terrenys on es cultiva arròs, i aquest no és un escull fàcil de salvar, per tal d'assolir els objectius proposats per Europa.

Els arrossars són un reservori molt important d'espècies de fauna i flora a preservar i conservar, però també són un punt calent d'espècies invasores que suposen una greu amenaça per al territori i la seva biodiversitat.

CONVIVÈNCIA

La biodiversitat associada al conreu de l'arròs està representada per un nombre molt gran d'animals per als quals l'arrossar representa una font d'aliment, refugi o nidificació. Inevitablement, aquest fet té un impacte en les produccions que a vegades pot causar pèrdues del 100% de la collita d'arròs. Des del punt de vista de l'agricultor, aquesta situació és insostenible a tots els nivells,

(12) Journal AGRICULTURA Nº1072 – May 2023

https://archivo.revistaagricultura.com/revista/agricultura/revista-agricultura_31_1_ap.html

El gran reto DEL CULTIVO DEL ARROZ

Un grupo operativo de producción ecológica de arroz en el Delta del Ebro ha estudiado métodos no químicos para el control de las malas hierbas, cuyos resultados ayudarán a diversificar las técnicas actuales en la gestión integrada de malas hierbas en los arrozales. De estas prácticas para producción ecológica se pueden beneficiar las fincas de arroz que producen en un sistema convencional.

ALFRED PALMA GUILLÉN
Universidad de Barcelona

El grupo operativo ECO-de quiere impulsar el cultivo ecológico del arroz para preservar y mejorar la biodiversidad en un sistema agrario de alto valor natural y paisajístico en el Delta del Ebro. Este proyecto ha estado impulsado por el sector arrocero del Delta del Ebro (cooperativas, federación arrocera PRODELTA, comunidades de regantes, ADV y IRTA). El proyecto se ha cofinanciado a través de la Agencia Europea para la Innovación (AEI), Departament d'Acció Climàtica, Alimentación y Agenda rural y el sector arrocero del Delta del Ebro para generar conocimiento científico aplicable al campo. Este financiamiento forma parte del Programa de desarrollo rural de Cataluña 2014-2020 a través de la operación 16.01.01 de cooperación para la innovación.

El proyecto da continuidad al proyecto *Organic Delta Rice* donde, gracias al impulso de todo el sector arrocero, en el año 2019 se abrió una línea de investigación específica para el cultivo ecológico de arroz en el Delta del Ebro. La ejecución de los ensayos de campo para el control de las malas hierbas los ha realizado Agroserveis.cat SL, una empresa de servicios agrarios especializada en ensayos de experimentación. La estación experimental IRTA (Amposta) es la otra empresa ejecutora de los ensayos y sus trabajos de investigación se focalizan en el estudio de variedades de arroz que tienen una mayor capacidad de competir con las malas hierbas, así como el estudio de estrategias de fertilización orgánica y control de patologías (Piriculariosis).

Las resistencias a los modos de acción herbicida y la falta de materias activas registradas para el cultivo están dejando al agricultor sin herramientas para afrontar esta problemática. Las especies con mayor dificultad de control son las del género *Echinochloa* spp. A pesar de que especies invasoras como la *Heteranthera reniformis* tienen una alta capacidad de colonización, las guías de gestión integrada de plagas plantean los métodos químicos como la última herramienta para resolver un problema de sanidad vegetal.

Los ensayos se han realizado durante los años 2021 y 2022 en fincas experimentales del Delta del Ebro. El diseño experimental ha sido con cuatro repeticiones con los bloques fijos y las parcelas distribuidas al azar.

Las estrategias para controlar las malas hierbas plantean dos escenarios distintos en función del sistema de siembra: siembra en inundación y siembra en seco. La variedad de arroz utilizada fue Argila.

Estrategias para la siembra en inundación

La máxima es tener el cultivo del arroz alineado para poder controlar mecánicamente las malas hierbas. *A priori*, lo primero que nos viene a la cabeza sería un trasplante del arroz mecanizado. Pero esta técnica funciona bien a pequeña escala, ya que tiene la dificultad logística de los invernaderos para producir el plantel, el transporte para llevar el plantel al campo y por último la dificultad que las líneas de plantación sean precisas. Por lo que se descartó está estrategia por la complejidad de poderla aplicar a gran escala.

Esta alineación del cultivo se consigue de dos maneras; (i) sembrando el arroz a líneas en inundación o (ii) sembrando el arroz a voleo y generar las líneas una vez el cultivo está establecido. En la primera opción (i), no existe maquinaria tecnificada en el mercado que esté preparada para

(13) Conference in Salon Gourmets MADRID 2023 – May 2023

https://www.youtube.com/watch?v=v9QnK6xXb7E

NOMEN | NOMEN FOODS

Certified B Corporation

Deltebre, 15 de maig de 2023

Sr. Alfred Palma
C/. Illa de Gràcia, 11 1º- 6ª
43877 Sant Jaume d'Enveja

Benvolgut Sr. Alfred Palma,

Amb aquestes ratlles, et vull agrair la participació als **Diàlegs al Chester de Bayo**, que van tenir lloc al Saló Gurmets. Fou un honor i un plaer comptar amb la teva presència. No tots els dies podem dedicar un temps a la reflexió i a l'intercanvi d'opinions, per la qual cosa creiem que l'experiència va resultar molt enriquidora, i segur que la repetirem.

A Nomen Foods, creiem fermament en l'excel·lència i en el rigor. Per això, fou molt enriquidor comptar amb les teves aportacions. Compartir coneixements ens sembla una manera encertada de poder continuar avançant com a societat i fer entre tots que el sector avanci cap a unes quotes encara més altes de qualitat i d'eficiència.

Amb el desig que tu també poguessis gaudir de l'acte, et fem arribar un petit obsequi com a mostra del nostre agraïment.

Ben afectuosament,

Enric Batlle
CEO

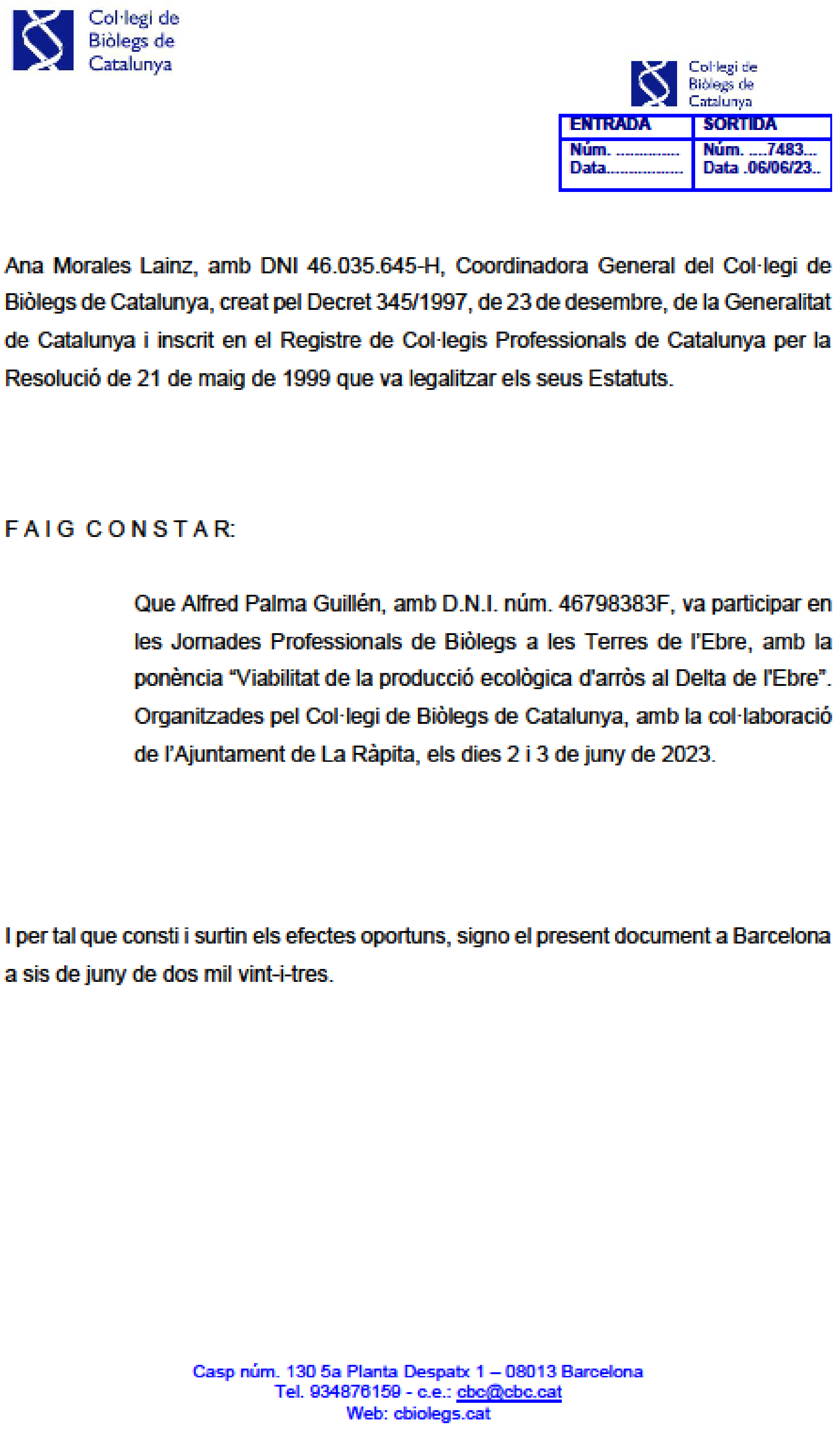
Gracies!

Ctra. Camarles - Deltebre, km 6.5 | 43580 Deltebre, Tarragona (Spain)
T: (+34) 977 487 800 | info@nomenfoods.com | www.nomenfoods.com

1 de 1

(14) Biologists Journey’s (La Ràpita) – June 2023

https://www.youtube.com/watch?v=XMv2wodMMJs&t=4s



Col·legi de
Biòlegs de
Catalunya

Col·legi de
Biòlegs de
Catalunya

ENTRADA	SORTIDA
Núm.	Núm. ....7483...
Data..................	Data .06/06/23..

Ana Morales Lainz, amb DNI 46.035.645-H, Coordinadora General del Col·legi de Biòlegs de Catalunya, creat pel Decret 345/1997, de 23 de desembre, de la Generalitat de Catalunya i inscrit en el Registre de Col·legis Professionals de Catalunya per la Resolució de 21 de maig de 1999 que va legalitzar els seus Estatuts.

FAIG CONSTAR:

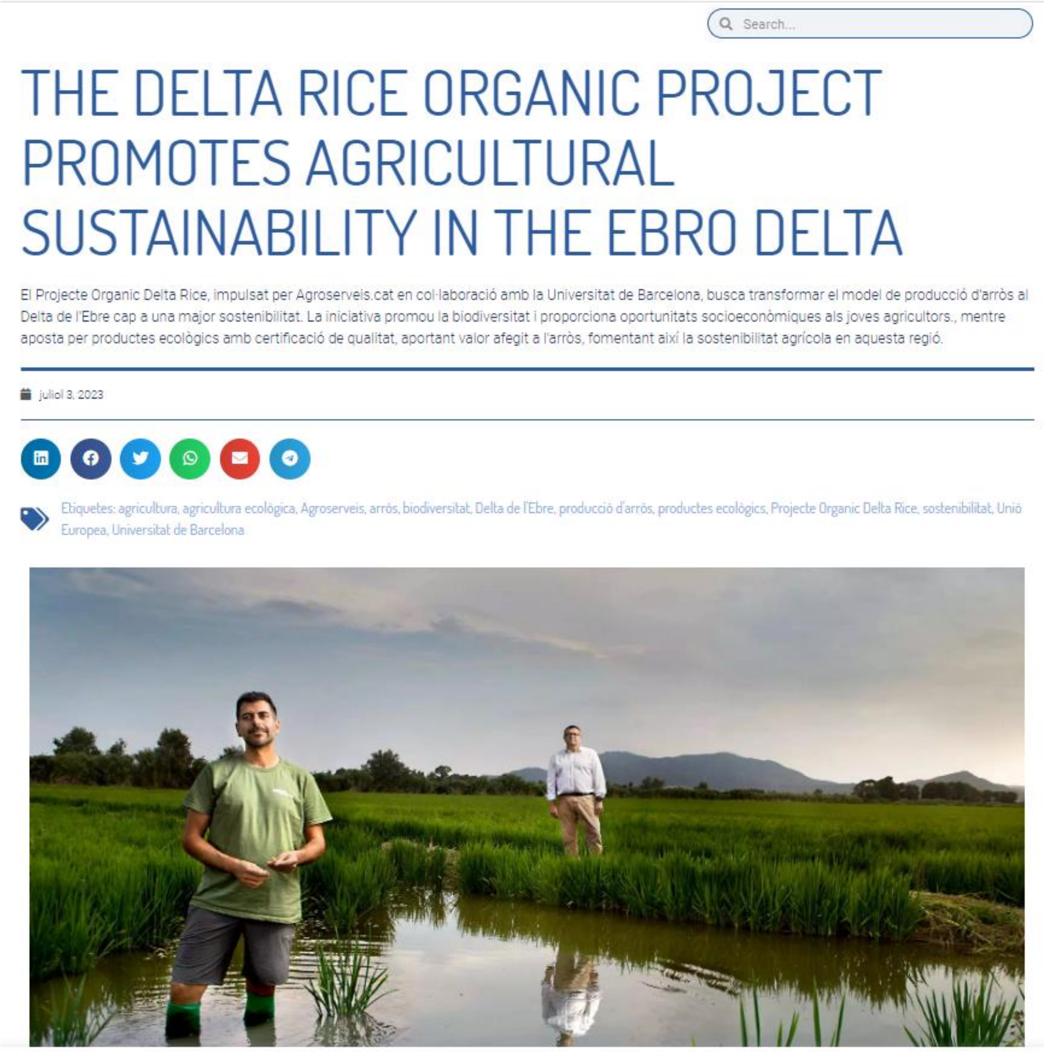
Que Alfred Palma Guillén, amb D.N.I. núm. 46798383F, va participar en les Jornades Professionals de Biòlegs a les Terres de l’Ebre, amb la ponència “Viabilitat de la producció ecològica d'arròs al Delta de l'Ebre”. Organitzades pel Col·legi de Biòlegs de Catalunya, amb la col·laboració de l’Ajuntament de La Ràpita, els dies 2 i 3 de juny de 2023.

I per tal que consti i surtin els efectes oportuns, signo el present document a Barcelona a sis de juny de dos mil vint-i-tres.

Casp núm. 130 5a Planta Despatx 1 – 08013 Barcelona
Tel. 934876159 - c.e.: cbc@cbc.cat
Web: cbiolegs.cat

(15) Website AGAUR – July 2023

https://doctoratsindustrials.gencat.cat/en/projecte-organic-delta-rice-sostenibilitat-agricola-delta-de-lebre/



THE DELTA RICE ORGANIC PROJECT PROMOTES AGRICULTURAL SUSTAINABILITY IN THE EBRO DELTA

El Projecte Organic Delta Rice, impulsat per Agroserveis.cat en col·laboració amb la Universitat de Barcelona, busca transformar el model de producció d'arròs al Delta de l'Ebre cap a una major sostenibilitat. La iniciativa promou la biodiversitat i proporciona oportunitats socioeconòmiques als joves agricultors., mentre aposta per productes ecològics amb certificació de qualitat, aportant valor afegit a l'arròs, fomentant així la sostenibilitat agrícola en aquesta regió.

juliol 3, 2023

Etiquetes: agricultura, agricultura ecològica, Agroserveis, arròs, biodiversitat, Delta de l'Ebre, producció d'arròs, productes ecològics, Projecte Organic Delta Rice, sostenibilitat, Unió Europea, Universitat de Barcelona

ANNEX 4. OTHER PUBLISHED PAPERS (TV and Newspapers)

https://www.ccma.cat/tv3/alacarta/telenoticies-comarques/el-sector-arrosser-avalua-la-viabilitat-del-conreu-ecologic-al-delta-de-lebre/video/6023356/

TELENOTÍCIES COMARQUES

El sector arrosser avalua la viabilitat del conreu ecològic al Delta de l'Ebre

Telenotícies comarques - 05/05/2021

Telenotícies comarques - 04/05/2021

Telenotícies comarques - 03/05/2021

Telenotícies comarques - 30/04/2021

Telenotícies comarques - 29/04/2021

Telenotícies comarques -

https://www.ccma.cat/catradio/alacarta/el-primer-sector/arros-ecologic-al-delta-de-lebre-molt-minoritari-tot-i-que-nhi-ha-demanda-i-es-paga-be/audio/1095563/

EL PRIMER SECTOR

Arròs ecològic al delta de l'Ebre, molt minoritari tot i que n'hi ha demanda i es paga bé

15/03/2021 | Sabeu quin percentatge d'arròs ecològic es produeix al Delta? No arriba al 2%. De ganes no en falten, però queden moltes qüestions per resoldre. Per exemple, les males herbes. Ara s'estudia com lluitar-hi. I a "La veu del camp", anirem al Vallès per descobrir com es treballa per recuperar varietats locals de tomàquets, més gustosos, però menys productius.

https://www.ccma.cat/tv3/alacarta/telenoticies-comarques/assagen-el-cultiu-de-quinoa-al-delta-de-lebre/video/6034283/

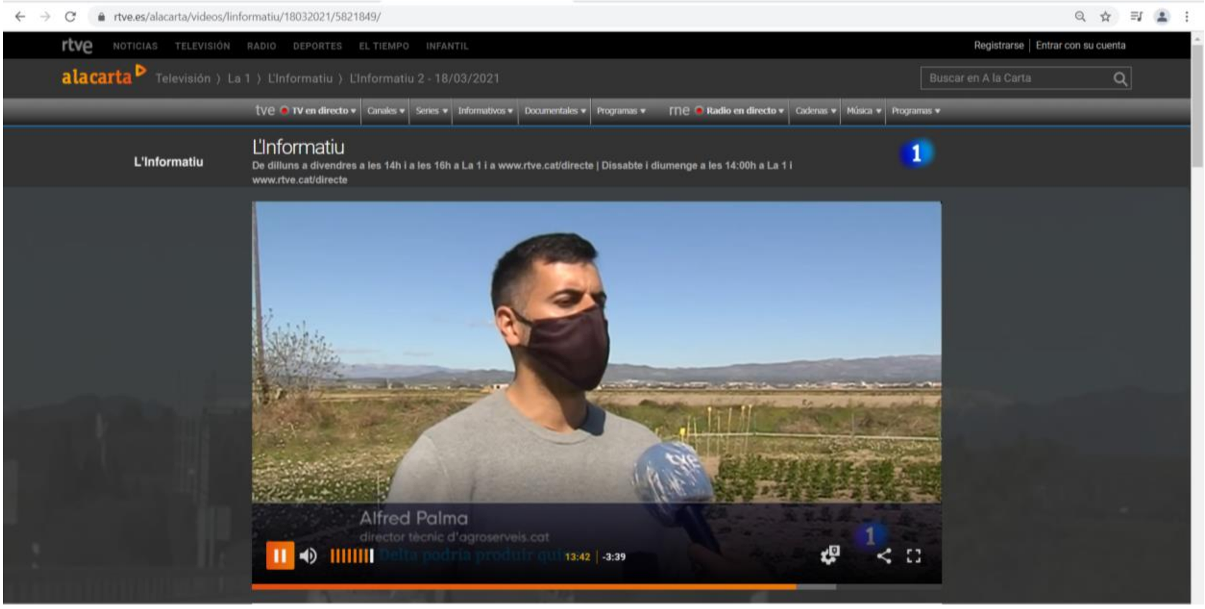
Assagen el cultiu de quinoa al delta de l'Ebre

https://ebredigital.cat/2021/03/16/la-rotacio-del-cultiu-darros-amb-quinoa-permetria-frenar-les-males-herbes-i-diversificar-el-sector-al-delta/

La rotació del cultiu d'arròs amb quinoa permetria frenar les males herbes i diversificar el sector al Delta

16 de març de 2021 | Medi Ambient| Deltebre | Agroserveis_cat, arròs, cultiu, Delta de l'Ebre, estudi, Improrice, IRTA, males herbes, Quinoa, rotació, secà, UB

https://www.rtve.es/alacarta/videos/linformatiu/18032021/5821849/



L'Informatiu

De dilluns a divendres a les 14h i a les 16h a La 1 i a www.rtve.cat/directe | Dissabte i diumenge a les 14:00h a La 1 i www.rtve.cat/directe

https://www.rtve.es/play/videos/aqui-la-tierra/15-09-2021/6096362/

https://doctoratsindustrials.gencat.cat/un-projecte-de-doctorat-industrial-posa-les-bases-per-a-impulsar-la-produccio-darros-ecologic-al-delta-de-lebre/

UN PROJECTE DE DOCTORAT INDUSTRIAL POSA LES BASES PER A IMPULSAR LA PRODUCCIÓ D'ARRÒS ECOLÒGIC AL DELTA DE L'EBRE

febrer 3, 2020

NOTÍCIA ORIGINAL – www.setmanarilebre.cat – 02/02/2019

El projecte de doctorat industrial "Viabilitat del cultiu ecològic de l'arròs al Delta de l'Ebre" entre l'empresa de Deltebre Agroserveis.cat i la Universitat de Barcelona ha iniciat assajos per a elaborar una guia agronòmica per als pagesos.

La producció d'arròs ecològic al delta de l'Ebre és actualment testimonial i no arriba ni a l'1% de la superfície conreada (150ha), malgrat que hi ha una demanda creixent d'arròs ecològic per part del consumidor. Davant esta realitat, l'empresa de Deltebre Agroserveis.cat ha signat un conveni amb la Universitat de Barcelona per a impulsar el projecte Organic Delta Rice, que té com a objectiu establir les bases tècniques per a impulsar la producció d'arròs ecològic al Delta.

El projecte, que té el suport del sector –Cambra Arrossera del Montsià, Nomen Foods, Prodelta i els regants de l'Esquerra-, es va presentar este dimecres a

ellevant recordant les vostres preferències i visites repetides. En fer clic a "Acceptar-ho tot", accepteu l'ús de totes les cookies. Tanmateix, podeu visitar "Configuració de les galetes" per proporcionar un consentiment controlat.