The Challenges of Water Saving in Rice Irrigation: Field Assessment of Alternate Wetting and Drying Flooding and Drip Irrigation Techniques in the Lis Valley, Portugal

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Abstract. The rice irrigation by continuous flooding is highly water demanding, in comparison with most methods applied in irrigation of other crops. This is due to a significant deep percolation, and the need for surface drainage of water from the basin. Currently, rice irrigation in basins with precision land leveling requires much less water than it was used in the past; nevertheless, there are still some recognized problems, like water scarcity, environmental impacts on water quality and agroecosystems and the methane emissions to the atmosphere. Saving water in rice production becomes a priority, to safeguard its economic and environmental sustainability. This study was elaborated, under the MEDWATERICE project, aiming to experiment the alternative wetting and drying flooding (AWD), using rice cultivar "Ariete" and the drip irrigation techniques applied in three rice cultivars, "Ariete", "Teti", and "Crono". The field experiment was installed in the Lis Valley, during the 2020 campaign, on farmer's fields. The AWD results showed that there is a potential of saving 10% of irrigation water, with no significant yield impacts, allowing additional 28 days with non-flooded soil. The precise land levelling is a priority to reduce the water level above soil surface. The drip irrigation essay, innovative in this area, uncover problems with soil lateral wetting and fertilizers leaching in a light soil, explaining yield losses. However, the maximum plot yield, makes glimpse a potential good performance. In the next season experiment adjustments of the distance between row crops, position of drip lines and the fertigation plan, will allow to prove this potential.

Keywords: Rice irrigation · Oryza Sativa L. · Water saving · AWD · MEDWATERICE · www.medwaterice.org · Lis Valley · Portugal

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1 Introduction

Rice crop has an important economic and social value in several countries, like Portugal, being traditionally cultivated under continuous flooding (CF) irrigation. This practice is highly water demanding, in comparison with most methods applied in irrigation of other crops, due to a significant deep percolation, and the need for surface drainage of water from the basin. There main problems related with the CF refers to water scarcity, environmental impacts on water quality and agroecosystems and the soil methane emissions to the atmosphere. Although the common use of laser land leveling have allowed a significant reduction of water use, there are still common problems of water management to deal with, to face the climate global changes and the raising of social emergent consensus. The issue of rice irrigation water saving is challenging and intensively studied, demonstrating several irrigation management systems, such as, zero-grade fields, alternate wetting and drying, multiple-inlet, furrow, pivot irrigation and drip irrigation [1–3].

Alternate wetting and drying (AWD) consists of intermittent flooding, through a sequence of irrigation cycles with flooding for a certain period, followed by interruption of supply, until the soil dries up, creating conditions of non-saturation in the surface layer [4]. In this way, the volume of water applied to irrigation is reduced, compared to CF, as well as the reduction of greenhouse gas emissions [5] and lower arsenic accumulation in the grain [6], due to soil aeration conditions during non-saturation periods. AWD has been successfully used in several countries, as India [7], Philippines [8], and Mi-South of USA [9].

Drip irrigation is a more recent solution, taking advantage of the great potential of these systems in terms of automation and fertigation and water savings, allowing the expansion of rice cultivation to highland areas, with promising results [10–12].

This paper presents the preliminary results of research carried out on Lis Valley, Portugal, sponsored by the project MEDWATERICE (PRIMA-Sect. 2-2018; www.medwaterice.org) [13]. This project aims to explore the sustainability of innovative rice irrigation methods and technologies in the Mediterranean basin, in order to reduce rice water use and environmental impacts, and to extend rice cultivation outside of traditional paddy areas to meet the growing demand. This study, based on field experiments, had the objective to assess the actual practices of rice irrigation by CF, considered as the 'reference' irrigation method, and test two types of irrigation strategies, considered as alternative to water saving rice irrigation, the AWD and the surface drip method.

2 Material and Methods

2.1 Study Site

The Lis Valley Irrigation District is a public irrigation district managed by a Water Users' Association (WUA), located in the Coastal Center of Portugal (coordinates, 39°51′22.1"N 8°50′56.1"W), under Mediterranean Temperate climate, belonging to the counties of Leiria and Marinha Grande (Fig. 1a). The total area is about 2000 ha, cultivated with forage corn, forage grass, vegetables, fruits and rice. The hydraulic infrastructures have the objectives of perimeter drainage defense through slope collectors and valley ditches, the irrigation water supply through a canal conveyance system and the field drainage based on a ditch network. Water is supplied by an open-channel conveyance network from weirs insalled along the Lis river and tributaries, and by pumping from drainage ditches [14]. The soils are mainly alluvial with high agricultural quality, some are poorly drained, with waterlogging and salinization risks, particularly on the downstream areas. The structure of the on-farm parcel property is characterized mainly by small parcels [15].

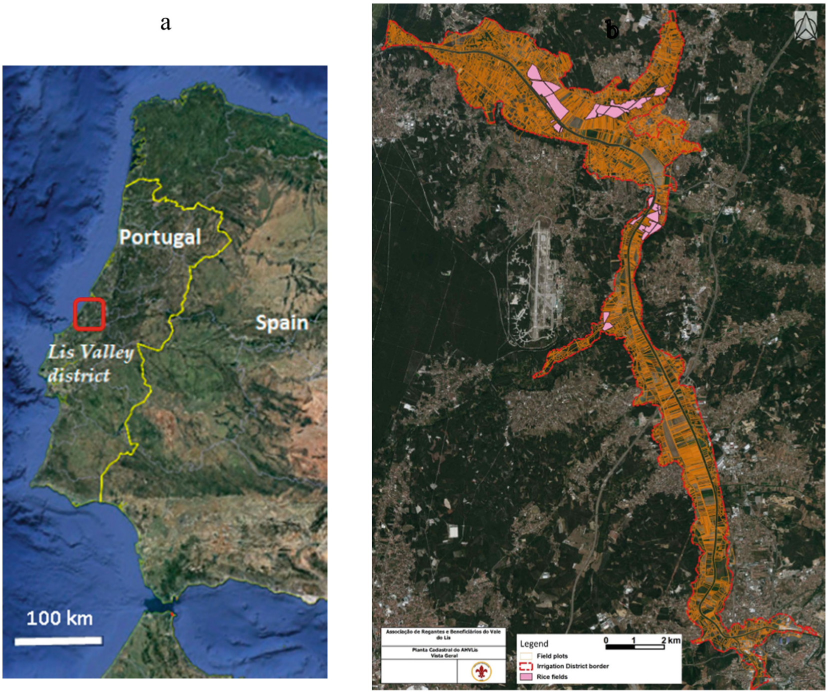

Fig. 1. (a) Location of the Lis Valley Irrigation District in Portugal (red square) (source: Google Maps, https://maps.google.pt); (b) Location of rice fields (rose color) in Lis Valley Irrigation District (source: Lis Valley Irrigation District Water Users' Association).

Rice is cultivated in traditional paddies, with ca. 10 cm of ponding depth, and an irrigation frequency varying from daily to a few days. Water in rice plays a main role in a temperature regulation and weed control. This crop is traditionally cultivated on lower soils with heavy texture, drainage problems, and a shallow groundwater table, totalizing an area of about 140 ha (Fig. 1b). A water is supplied from irrigation canals, or in some fields, by farmer's pumping from ditches. The water shortage is an endemic problem during summer months in Lis Valley, being the major constraint to rice crop sustainability and expansion. Water-saving practices on rice irrigation are welcome to mitigate a problem with water scarcity. Other constraints refer to water distribution conditions, surface water organic pollution, soil salinization, pumping energy for irrigation and economic sustainability of rice production. The essays took place in farmer fields, in a close relationship between the research team and the farmer. This proximity to the production conditions facilitated the connection and involvement with stakeholders and the dissemination activity. Meteorological observations were carried out with automatic stations installed near the experiments, being the air daily temperatures presented in Fig. 2. Daily reference evapotranspiration was calculated by Penman-Monteith method, being applied crop coefficients of 1.25 for flooding, and between 1.0 and 1.1 for dry periods and drip irrigation.

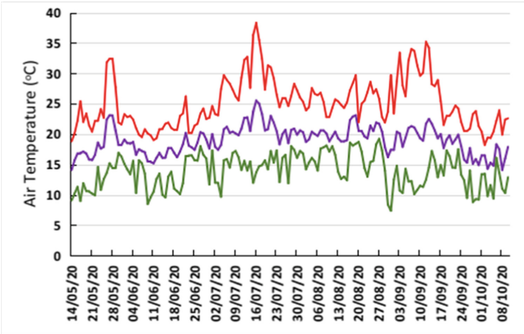

Fig. 2. Minimum (green), average (blue), and maximum (red) daily air temperatures during 2020 rice crop season.

2.2 Flooding Irrigation

The CF system essay was carried on a private farm, using two plots: i) area of 3.0 ha (215 m × 140 m), using traditional practices of flood irrigation full managed by the farmer, Lis Valley representative, used like the 'reference' irrigation method; ii) other one, with area of 0.20 ha (20 m × 100 m), contiguous to the traditional one with identical agronomic practices, applying the AWD irrigation practice. The soil has clay-loamy, neutral (pH = 7.4), with a deep profile, and with a shallow groundwater table level, between 75 cm to 85 cm below the soil surface. The agronomic practices in both plots used were soil preparation, including the ploughing and harrowing, wet sowing of the rice cultivar "Ariete", carried out on 14th May, and the fertilizer doses of 90 kg N/ha, and herbicide treatments. The monitoring system installed followed Gonçalves et al. [14]. The evaluation of crop yield, considered the sampling of aerial part at harvest time, was done in several points of the plots, with a unit sampling area of 0.5 m^2.

The AWD essay applied the following procedure based on Bouman et al. [16], with the adjustments to local agronomic practices: i) The initial flooding allowing the wet sowing, like the traditional practice (follows an initial drying event to favour the emergence); ii) Shallow ponding during the vegetative phase, considering the drying periods required for herbicide application, usually twice; iii) AWD technique applied after the flower initiation, until last irrigation; the target was a flood water depth not higher than 5–7 cm; the irrigation schedule considered was an interval between 10 to 14 days of irrigation events; ensuring that the water level should not fall to 15 cm below the soil surface, measured in a water tube; particular attention during the flowering period because it is very sensitive to water stress; iv) The last irrigation should be about 20 days before the harvest.

2.3 Drip Irrigation

The drip irrigation experiment carried out on a plot of a private farmer that usually produces horticultural crops, sown on 20th May. The soil has a light texture, very good internal drainage, acid (pH = 5.3), 1.5% of organic matter, and with a groundwater level about 3–4 m depth below soil surface. The plot had an effective area of 240 m^2 (12 m width × 25 m length), was divided into 8 strips, with two drip lines per each strip, having each strip 6 rows of plants. Three cultivars, of Portuguese rice paddies, were used: "Ariete", "Teti", and" Crono" in each third of all strips, to assess their performance to the drip irrigation condition. Spacing between rows was 20 cm, and the target plant spacing within row was 5–10 cm. The weed control was by two applications of chemical herbicide control, with the active substance Bentazona, complemented with thinning.

A water was supplied using a submersible electric pump (Hidrobex, model Vetax-1000, 1 kW) and automatically controlled. The irrigation system comprised a sand-filter, complemented with two plastic mesh-filters, a fertigation injector, a water counter and two pressure gauges; a manifold of PE 50 mm, and PE drip lines of 16.2 mm diameter, brand NETAFIM, model Thyphon Plus 16150, non-regulated, dripper spacing of 0.30 m, with a flow of 1.00 L/h with pressure of 1.0 bar; the field installation had 16 drip lines with a length of 25 m, spaced of 0.60 m, working at a pressure of 1.0 bar, with a total discharge of 1.33 m^3/h. The monitoring system installed in this plot evaluated the following aspects: water use, soil moisture, crop development, yield quantity and quality. The evaluation of crop yield was considered the sampling of aerial part at harvest time, for each strip of 100 cm linear at row crop close to drip line, and identical sample on the row far from the drip line, to assess the medium and maximum yield. This procedure was applied to each of the eight strips, for every rice variety.

3 Results and Discussion

3.1 Flooding irrigation

The analysis of the water level above soil surface of flooding irrigation plots during crop season (Fig. 3) shows that the traditional CF considers four dry periods during the vegetative phase, and that after 16th July, at the end of flowering (64 DAS), the AWD technique have been applied, in five wet-dry cycles, until the final period before the harvest (Fig. 4). These cycles corresponded to a period between 12 and 14 days, with irrigation depths between 92 and 109 mm, and 5 or 6 days, with dry soil, per cycle. The irrigation water was 1292 mm and 1169 mm, for CF and AWD, respectively (Table 1), resulting in a water saving of 9.4%, corresponding to 122 mm, and a decrease of 5.6% of yield (Table 2), although the production differences were not significant (5.6%). The water productivity with CF and AWD was 0.436 kg/m^3 and 0.452 kg/m^3, respectively.

The results obtained show that the traditional practice of CF can save water if the precise levelling of the soil is improved, which in turn allows to decrease the water depth,

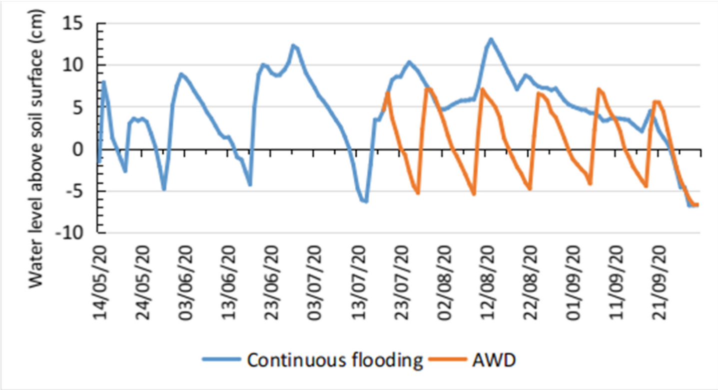

Fig. 3. Water level above soil surface (cm) of continuous flooding irrigation and alternate wetting and drying (AWD) plots, during 2020 rice crop season.

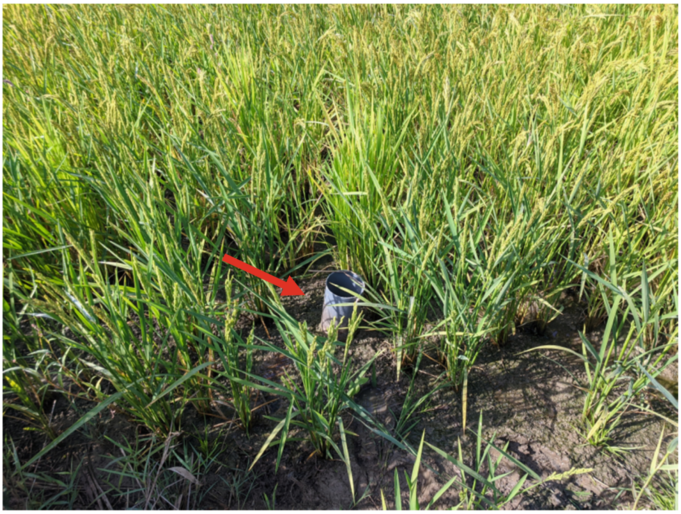

Fig. 4. Rice crop at maturation phase, during a dry period of AWD plot, with a water tube (arrow).

with the consequent decrease of the irrigation depth and percolation. However, there are some practical aspects that justify a higher value of this water level, related to the greater ease of controlling weeds and protecting the crop from the adverse effects of the strong wind that appeared during the early rice plant developing phases. The AWD practice, although it translates into a water saving of 9.4% of the total volume of the CF practice, allowed additional 28 days with non-flooded (dry) soil.

The issues to be studied in 2021 crop season experiment are: (i) continue with the CF and AWD trials; (ii) improve precise land levelling to try to reduce water level above soil surface, not to exceed 5 cm; (ii) increase the dry soil periods, elevating the critical water table threshold, closer to the 15 cm.

Table 1. Flooding irrigation plots water use (mm).

Water use (mm)	Complete crop season period		Period after flower initiation[c]	
	CF[a]	AWD[b]	CF	AWD
Evapotranspiration	674.7	656.3	347.4	329.0
Deep Percolation	587.8	488.7	330.2	249.3
Precipitation	81.8	81.8	68.4	68.4
Irrigation	1291.5	1169.3	639.2	517.0
Surface Drainage	154.8	118.2	36.5	0

[a]CF - Continuous flooding; [b]AWD - alternate wetting and drying; [c]period 16July-9October

Table 2. Irrigation trials, yield, and water productivity (rice cultivar "Ariete").

Irrigation trial	Y[c] (t/ha)	WP[d] (kg/m^3)	WG[e] (g)	SY[f] (t/ha)
CF[a]	5.993 ± 1.264	0.436	31.98 ± 1.943	4.122 ± 1.029
AWD[2]	5.659 ± 0.290	0.452	30.84 ± 0.168	3.655 ± 0.305

[a]CF - Continuous (traditional) flooding; [b]AWD - alternate wetting and drying flooding; [c]Y-Rice grain yield at 14% humidity (t/ha); [d]WP - Water Productivity = grain yield at 14% humidity/(irrigation + precipitation) (m^3/ha); [e]WG - Weight of 1000 grains at 14% humidity (g); [f]SY - Straw yield, dry matter (t/ha)

3.2 Drip Irrigation

This trial was a first experiment of aerobic drip irrigated rice (Fig. 5) applied in the Lis Region. The soil preparation included the usual practice of ploughing and harrowing. The dry sowing was manual, carried out on 20th May (Table 3).

Due to the dry and hot weather that was felt in those days (Fig. 2), the irrigation after sowing was by sprinkler solid-set, 30 min per day, during 7 days: 20th to 26th May, with a depth of 5 mm/day, to favor the seed germination and plant emergence. The drip system started from 27th May, with daily events, being the irrigation time regulated on the automatic controller. The higher daily irrigation depths were applied during the flowering and milky seed phases (19th August to 17th September), close to 14 mm/day. Two problems have occurred during vegetative and reproductive phases. First, the crop showed water stress signals on leaves, particularly in plants located on the rows far from the drip line. To overcome this problem, an over irrigation practice was applied (total of irrigation of 1114 mm, much higher than crop evapotranspiration (ETc) of 601 mm), to favour the lateral wetting, with a partial success. The second problem resulted of over irrigation on a very permeable soil, that led to an excessive deep percolation (total of 623 mm), that resulted to a significant fertilizer leaching, close to the drip line, justifying the symptoms of chlorosis on the plant leaves. Regarding the drip irrigation test, problems observed were related to the soil texture, and it was found that the lateral spacing of 20 cm between the drip line and the furthest row of plants was excessive, especially in spots with lighter soil.

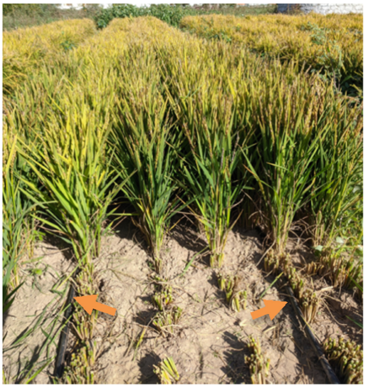

Fig. 5. Drip irrigation experiment, at harvest, showing the drip lines (orange arrows).

Table 3. Crop development phases, fertigation, and irrigation depths of drip experiment.

Phases	Vegetative	Panicle D[a]	Flowering	Milky	Maturation	Final	Total
Start date	20 May	28 Jul	19 Aug	30 Aug	18 Sep	2 Oct	18 Oct
Start DAS[b]	0	69	91	103	121	135	150
N (kg/ha)	175	25					200
K_2O (kg/ha)	39	20	27	15			101
P_2O_5 (kg/ha)	25		25				50
DI[c] (mm/d)	6.1	10.3	14.5	14.0	5.0	0	
I[d] (mm)	415	216	160	238	85	0	1114
Etc[e]	320.7	89.0	51.5	72.2	36.1	32.0	601.5
P[f]	10.4	1.4	17.0	0.4	49.4	12.8	91.4
DP[g]	104.7	128.4	125.5	166.2	98.3	0	623.1

[a]Panicle D. - Panicle Differentiation; [b]DAS - Days After Sowing, at 20th May; [c]DI - Daily Irrigation depth, average value, mm/day; [d]I - Phase Irrigation depth, mm; [e]ETc - crop evapotranspiration (mm); [f]P - precipitation (mm); [g]DP

These problems led to high water consumption and very significant production losses (Table 4). However, in the three cultivars ("Ariete", "Teti", and "Crono"), control areas with high production were identified and yield assessed.

Table 4. Drip irrigation trial yield and water productivity, in three rice cultivars.

Rice cultivar	Ymed[a] (t/ha)	Ymax[b] (t/ha)	WPmed[c] (kg/m^3)	WPmax[c] (kg/m^3)	WG[d] (g)	SY[e] (t/ha)
Ariete	4.218 ± 1.646	7.138 ± 2.544	0.379	0.641	25.475 ± 0.883	10.96 ± 2.845
Teti	3.306 ± 1.850	6.341 ± 2.401	0.297	0.569	23.729 ± 0.969	8.483 ± 3.363
Crono	2.545 ± 2.408	8.129 ± 2.432	0.228	0.730	22.273 ± 4.564	8.290 ± 6.147

[a]Ymed - Medium plot rice grain yield at 14% humidity (t/ha); [b]Ymax - Maximum plot rice grain yield at 14% humidity (t/ha); [c]WP - Water Productivity = grain yield at 14% humidity (kg/ha)/(irrigation + precipitation) (m^3/ha); [d]WG - Medium Weight of 1000 grains at 14% humidity (g); [e]SY - Medium Straw yield, dry matter (t/ha)

4 Final Considerations

The experimental results obtained in the 2020 season concerning rice irrigation water saving techniques show that this issue is complex and challenging. Regarding the AWD technique, the results seem to be in accordance with several published studies [4, 7, 8], showing that there is a relative potential for saving water. The 10% of irrigating water was saved, with a negative impact of 5.6% on the production. AWD allowed a 28 days period of dry soil, expecting lower levels of greenhouse gas emissions and the arsenic content in the rice grain, in the future studies. It is considered a priority to improve the precise land levelling to optimize the water level above the soil surface, aiming water saving. On the other hand, the need to carry out frequent and planned irrigation events in the AWD period (after mid-July), makes the inflow control devices more demanding, making place for its automation.

Regarding the drip irrigation test, in 2021 the crop row distance and the drip lines position will be adjusted, reducing the spacing, to try to achieve more yield uniformity and decrease the water use.

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