Alternate wetting and drying in the Center of Portugal: field assessment toward rice sustainability

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Abstract: Rice cultivation has an important economic and social value in Portugal, being traditionally cultivated under continuous flooding irrigation. High-water demand, water resources pollution and methane emissions are environmental problems of rice agroecosystems that claim effective agronomic changes to safeguard its sustainable production, facing the climate global changes and the raising of a social emergent consensus. Therefore, solutions in rice production that save water and environmentally friendly becomes a priority, to safeguard its sustainability. Alternate wetting and drying (AWD) consists of intermittent flooding irrigation through a sequence of flooding cycles with very thin water depths, followed by drying periods. The recession is only due to infiltration and evaporation, leaving the soil surface layer in a non-saturated condition for a few days until the next reflooding cycle. The soil is kept dry until hairline cracks are visible, or the decrease in the soil water potential does not cause significant crop stress (AWD mild option). This communication presents a field study in farmer's paddies carried out for three consecutive years, from 2019 to 2021 with the objectives of: i) assessing the current rice irrigation practices, through a field monitoring, ii) testing AWD, and iii) preparing a AWD knowledge base to support its extension to rice farmers. The field experiments were carried out on the Lower Mondego and Lis Valley Irrigation Districts, Portugal, under Mediterranean Temperate climate, sponsored by the project MEDWATERICE (www.medwaterice.org). The field measurements included the soil hydrodynamics, water table level, field water level, irrigation scheduling and depths, agronomic operations, and rice productivity. This study confirmed the interest of the AWD irrigation of rice paddies in this region. It should be applied from the reproductive phase to the end of the season, through 2 to 4 wet-drying cycles with a dry period of 4-5 days, allowing water savings in relation to the traditional continuous flooding about 10%, an additional of 10-20 days with dry soil, being however expected a decrease in production about 5%. Furthermore, the need to carry out frequent and planned irrigation events during the AWD period, demands for more accurate inflow control devices, making place for its automation, and leading towards rice modernization through smart flooding irrigation systems. In Portuguese conditions, AWD should be applied from the beginning of the reproductive stage. The traditional practice of waterlogging in the early stages of the crop should be kept, due to the particularly sensitive agronomic criteria, such as thermal control, weeds, wind, or phytosanitary treatments.

1. Introduction

Rice (*Oryza sativa* L.) has an important economic and social value in several regions, namely in Mediterranean countries [1]. In Portugal, rice is cultivated in about 30 thousand ha, especially in the Mondego, Tagus and Sado Valleys, in lowland areas and coastal wetlands, with a particular role in the preservation of the biodiversity and soil conservation [2]. In these valleys, rice is cultivated in traditional paddies, on lower soils with heavy texture and poor drainage, with a shallow and relatively saline groundwater table. Paddies are irrigated by continuous flooding (CF), with *ca.* 10 cm of ponding depth, and a frequency varying from daily to a few days. Paddies are highly water demanding due to a significant deep percolation, and surface drainage [3]. The flooding of paddies plays several determinant roles, namely, temperature regulation during the first weeks of crop development due to microclimatic imperatives, particularly during night-time in the initial phase of the cycle and during flowering; after sowing, to avoid seed collecting by wild birds; to control of weeds development; to control of the crop damage due to the strong wind; and the soil salt leaching in susceptible areas. In its turn, the initial drainage periods enable the application of phytopharmaceuticals, especially herbicides and fungicides, a good rooting of the seedlings, while avoiding soil hardening, and a reduction of algal proliferation on surface water.

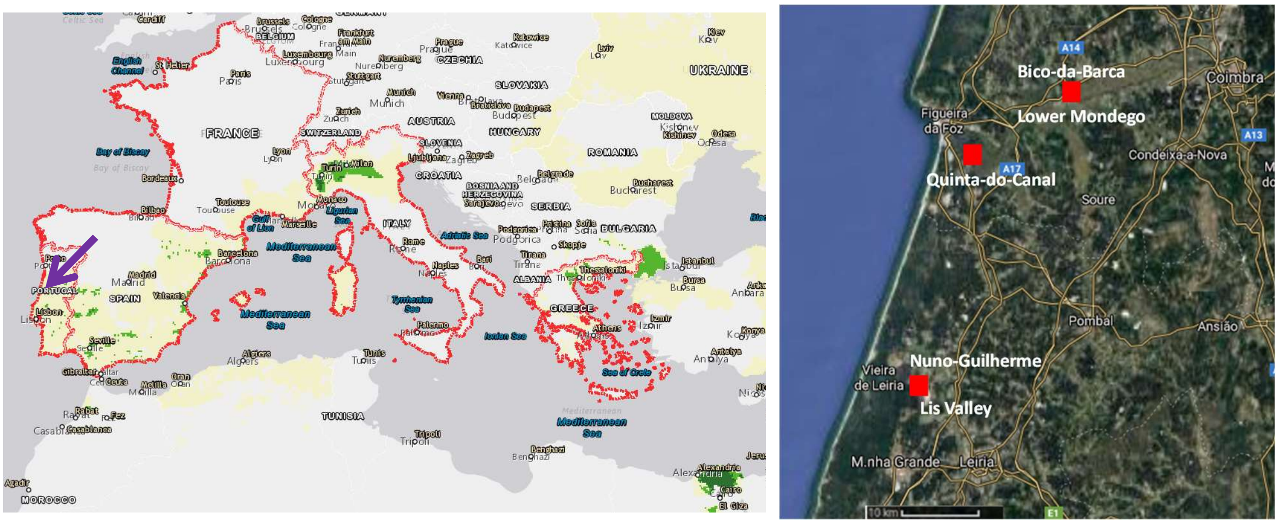
Alternate wetting and drying irrigation (AWD) consists of intermittent flooding, through a sequence of flooding cycles with water depths of about 5 cm, followed by drying periods. The recession is only due to infiltration and evaporation, leaving the soil surface layer in a non-saturation condition for a few days (a condition called “dry soil”, in contrast to “flooded soil”), until the next reflooding cycle [4,5]. The soil is kept dry until hairline cracks are visible, or the decrease of the soil water potential does not cause significant crop stress. The management of AWD must consider the referred the water thermoregulatory effect and weed control, to avoid compromising production. The benefits of AWD, when compared with CF, include the: i) irrigation water savings, by up to 30% [6], due to the decrease of deep percolation, facing a lower soil water pression, and a decrease of the soil evaporation.; ii) reduction of greenhouse gas emissions (methane plus nitrous oxide) by 45–90% [7]; iii) reduction of the arsenic accumulation in the grain by 50% [8], and iv) reduction of methylmercury concentrations in rice grain by 38–60% and in the soil [9]. The AWD management is based on two parameters: timing and threshold [6,10]: i) the timing is when in the growing season the drying cycles are imposed, namely by the vegetative, reproductive, or ripening phases, or then throughout the crop season; the crop sensitivity to water stress is a major factor to determine this timing; ii) the AWD threshold is the value of a soil water content that refers a limit condition of water deficit used to determine the time for reflood.

This research aimed to provide knowledge to outline the guidelines to promote the development of AWD by rice farmers, by studying the effects of AWD on rice yield and water use relative to the actual practice of CF in the Central Region of Portugal.

2. Materials and Methods

The experimental study was carried out from 2019 to 2021 in the Lower-Mondego and in the Lis Valley Irrigation Districts, located in Coastal Center of Portugal, with a total irrigated area of about 14,000 ha, and a rice area of about 6,000 ha [2] (Figure 1a). This region has a Mediterranean climate, Csb and Csa of Köppen classification, with an annual average precipitation of about 800 mm to 900 mm. It has temperate and mild summers, with virtually no rainfall, and rainy winters with mild temperatures [12]. The soils are mainly alluvial with high agricultural quality, some of which are poorly drained, with waterlogging and salinization risks, particularly on the downstream areas where rice is cultivated in paddies. The river water used for irrigation is diverted and conveyed mainly by gravity, from weirs, through a collective system [13].

The experimental design, at each site, consisted of two rice plots located in identical edaphoclimatic conditions, one irrigated by CF and the other by AWD. Three trial sites were selected: Bico-da-Barca (BB) and Quinta-do-Canal (QC) in the Lower-Mondego, and Nuno-Guilherme (NG) in the Lis Valley, mapped in Figure 1b, being their geographic coordinates and soil characteristics presented in Table 1.



(a) **(b)**

Figure 1. Geographic location of: (a) Mediterranean rice growing areas, and the study area in Central Costal Region of Portugal (arrow); (b) the experimental fields (■), on the Lower-Mondego and Lis Valleys (source: (a) [11]; (b) Google Maps, https://maps.google.pt).

Table 1. Study site characteristics.

Parameters		Experimental sites		
		BB	**QC**	**NG**
Location	Latitude	40°10′31′′ N	40°06′54′′N	39°52′17′′N
	Longitude	8°39′40′′ W	8°48′08′′ W	8°52′58′′ W
	Altitude (m)	5	2	8
Type of farm		State agricultural experimental station	Associative	Private
Area	Field plots (ha)	0.11	4.8	3.0
Texture (%)	Sand	30.0	6.4	7.1
	Silt	49.3	59.2	37.3
	Clay	20.7	34.4	55.6
Texture class		Silt loam	Silty clay loam	Clay loam
Soil	pH (H_2O)	5.9	7.6	7.2
	Soil Organic Carbon (%)	2.3	2.3	2.7
	Bulk Density (g cm^{-3})	1.28	1.28	1.25
Groundwater table level (bss, cm)		40-80	50-80	75-85
Soil Water Content (cm^3 cm^{-3})	Saturation	0.519	0.517	0.520
	Field Capacity	0.484	0.471	0.385
	Wilting Point	0.090	0.188	0.204

* Texture classification according to Gomes and Silva [14]; Soil characteristics are relative to the superficial depth of 60 cm; bss—below the soil surface. Experimental sites: BB, Bico-da-Barca; QC, Quinta-do-Canal; NG, Nuno-Guilherme (source: [13]).

A single Italian rice cultivar, Ariete (japonica type) was used in all the sites. Ariete is classified as semi-early, with a cycle of about 139-150 days. It was sown in mid-May, and harvested throughout October, and was fertilized with doses of about 70-90 kg N/ha. Crop development and irrigation practices, and corresponding dates, are presented on Table 2 (example of NG site in 2020 campaign).

Table 2. Crop development and irrigation practices and corresponding dates (E.g. NG site 2020 data).

Crop development and irrigation data	DAS*	Date
Initial soil flooding	-1	13 May
Wet sowing	0	14 May
Start tillering	34	18 June
Panicle differentiation	60	13 July
Start AWD	67	20 July
Flowering	90	12 August
Last irrigation event	128	19 September
Harvest	148	9 October

* DAS - Days after sowing

The experimental plots with the CF treatments were fully managed by the farmers. Traditional flooding practices were applied, which were used as reference to compare with the AWD. Identical agronomic practices were adopted in both treatments, namely the soil preparation, including the ploughing and harrowing, land levelling, fertilization, wet sowing, and crop protection treatments. Water from the river was supplied by gravity-fed systems, using open canals and buried pipes, which were manually controlled.

The methodology adopted in the AWD plots was based on the description by Bouman et al. [15], in the framework of the Mild version, with adjustments, according to the local experimental conditions [13]. In summary, the following steps were taken: i) An initial flooding for wet sowing, followed by an initial drying through a fast surface drainage event, to favor rice emergence, like the traditional practice; ii) Shallow ponding during the vegetative phase, considering the drying periods required for herbicide application, usually twice, like the traditional practice; iii) AWD technique applied after the vegetative phase, taken in account that: a) the target was a flood water depth not higher than 5-7 cm; b) the irrigation schedule considered was a minimum interval of 10 to 14 days between irrigation events; c) the water level should not fall to 15 cm below the soil surface, measured in a water tube; d) Particular attention was paid on the flowering period because at this phase plants are very sensitive to water stress; and iv) The last irrigation event took place about 20 days before the harvest.

The hydraulic monitoring system installed had two components: water tubes with automatic sensors, and water accounting devices with continuous record. The water tubes, consisting of PVC pipes, were placed on soil at 25 cm depth. These tubes, with 40 cm long and 10 cm in diameter, have holes with 1cm in diameter through which the soil water flows into its lumen, allowing the observation of the field water level (FWL) and the measurement with a piezometric head. The water tubes were equipped with automatic water level sensors, which data was complemented with the measurement of the atmospheric pressure though a barometer located nearby. Regularly, at least once a month, the loggers data were downloaded to a PC for further data analysis. During the crop season, manual FWL measurements were carried out in the water tubes with ruler, and the data was used for testing and calibrating the sensors.

The comparison of CF with the AWD practices was based on the water level recorded on water tubes, elucidating about the water level above the soil surface in the flooding irrigation plots, during the entire crop season. The meteorological observations were carried out with automatic weather stations, installed near the experimental sites, with a set of sensors for air temperature and humidity, solar radiation, and wind speed, a Class A pan evaporimeter, and remote communication tool via GSM to the several data users (Table 4). Daily reference evapotranspiration was calculated by Penman-Monteith method, based on Allen et al. procedure [16]. The daily crop evapotranspiration (ETc) was calculated through the crop coefficients of 1.25 for flooding condition, and 1.10 for dry periods.

These measurements allowed obtaining daily data from the system, necessary for the daily water balance method that enabled to calculate the deep percolation (DP), by applying the equation (1),

$$DP = P + I - ETc - SD - \Delta SW, \quad (1)$$

which requires the values of precipitation (P), irrigation (I), surface drainage (SD) and storage difference of surface or subsurface soil water (ΔSW) [3].

The crop yield parameters were determined at harvest, collecting the aerial part of the total rice plants in diverse unit areas of 0.5 m^2, with about 5-unit areas per hectare. The biomass harvest was latter processed in the laboratory, determining the dry matter of grain with 14% of humidity and straw and the weight of 1000 grains.

Based on the irrigation water applied (I, $m^3\ ha^{-1}$), precipitation (P, $m^3\ ha^{-1}$) and yield (Y, $kg\ ha^{-1}$), the water productivity (WP, $kg\ m^{-3}$) was calculated through the equation (2),

$$WP = Y / (P + I). \quad (2)$$

3. Results

3.1. Soil flooding changes and crop development

The characterization of the traditional CF practice, illustrated in Figure 2 with data from the NG site in the 2021 season, evidenced the contrast with the dry periods in the AWD treatment. The AWD technique was applied, making up to three wet-dry cycles, until the final period of 30 days before the harvest. These cycles corresponded to a period three weeks, with irrigation depths between 72 and 210 mm, and 4 to 6 days with dry soil, per cycle.

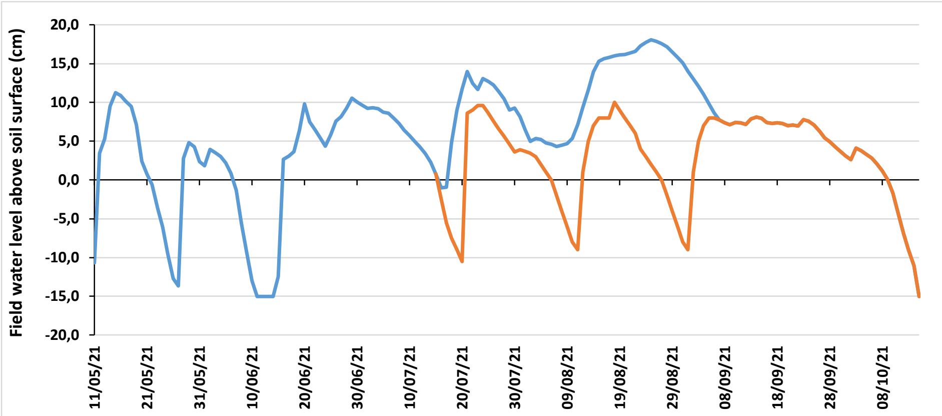


Figure 2. Water level above and below the soil surface (cm) of CF (blue line) and AWD (orange line) irrigation during 2021 rice crop season in NG site, Lis Valley.

The additional number of days with dry soil, comparing CF with AWD after the vegetative phase (average values of 2020 and 2021 seasons) was 5, 8 and 21 days, for QC, BB and NG, respectively (Table 3). Referring all cropping seasons, the total number of days with dry soil on cropping cycle was 38%, 54% and 29%, for QC, BB and NG, respectively.

Table 3. Number of days with wet and dry soil, in the experimental rice fields irrigated with CF with AWD (average and standard deviation values of 2020 and 2021 season).

Experimental site	Soil condition	Crop season (days)		After vegetative phase (days)	
		CF	AWD	CF	AWD
QC	Wet	96 ± 8	92 ± 14	50 ± 10	45 ± 16
	Dry	52 ± 6	57 ± 12	24 ± 9	29 ± 15
	Total	149 ± 2	149 ± 2	74 ± 1	74 ± 1
BB	Wet	72 ± 12	74 ± 6	32 ± 8	24 ± 4
	Dry	68 ± 16	77 ± 2	44 ± 4	52 ± 6
	Total	139 ± 4	139 ± 4	76 ± 3	76 ± 3
NG	Wet	126 ± 8	106 ± 16	76 ± 8	56 ± 16
	Dry	22.5 ± 1	44 ± 8	8 ± 1	28 ± 8
	Total	148 ± 8	148 ± 8	84 ± 8	84 ± 8

CF — Continuous flooding; AWD — Alternate Wetting and Drying; Experimental sites: BB, Bico-da-Barca; QC, Quinta-do-Canal; NG, Nuno-Guilherme.

The average irrigation water use (average values of 2020 and 2021 seasons) of CF was 1483 mm, 1865 mm and 1327 mm, for QC, BB and NG, respectively (Table 4). The correspondent deep percolation ratio for CF was 40%, 72% and 48%, which explain the high irrigation use of BB plot. The AWD relative water savings (compared with CF) was of 10%, 21% and 10%, for QC, BB and NG, respectively. The values for QC and NG could be considered a feasible target for most paddies, such as their soil representativeness. The AWD relative reductions in cultural evapotranspiration was 0.8%, 1.7% and 1.9%, and its reductions in deep percolation of 13.6%, 21.5% and 7.5%, for QC, BB and NG, respectively.

Table 4. Water use parameters in the experimental rice fields irrigated with CF with AWD, during the crop season, and after the vegetative phase (average and standard deviation values of 2020 and 2021 seasons).

Experimental site	Water use (mm)	Entire cropping season		After vegetative phase	
		CF	AWD	CF	AWD
QC	ETc	667.2 ± 29.0	661.6 ± 23.4	289.8 ± 9.1	284.2 ± 3.5
	I	1483 ± 104.5	1327 ± 61.0	634.3 ± 17.2	459.8 ± 34.6
	P	157.8 ± 27.4	157.8 ± 27.4	78.8 ± 1.2	78.85 ± 1.2
	DP	600.2 ± 61.8	518.4 ± 98.6	302.8 ± 41.4	223.6 ± 71.0
	SD	408.2 ± 108.2	345.4 ± 115.4	167.0 ± 44.6	77.5 ± 39.5
BB	ETc	594.2 ± 6.2	584.2 ± 16.1	279.0 ± 2.9	269.7 ± 6.3
	I	1865 ± 140.5	1473 ± 48.6	740.6 ± 1.5	467.8 ± 69.7
	P	131.6 ± 32.0	131.6 ± 32.0	84.0 ± 3.8	84.0 ± 3.8
	DP[1]	1342 ± 78.8	1027 ± 47.5	642.5 ± 8.9	436.7 ± 57.4
NG	ETc	677.9 ± 3.2	664.8 ± 8.5	358.8 ± 11.4	345.7 ± 16.7
	I	1327 ± 35.0	1194 ± 25.5	677.8 ± 38.6	545.6 ± 28.6
	P	102.2 ± 20.4	102.2 ± 20.4	74.0 ± 5.6	74.0 ± 5.6
	DP	638.1 ± 50.3	590.4 ± 84.2	374.0 ± 43.8	327.2 ± 78.6
	SD	135.0 ± 19.8	112.8 ± 5.45	41.0 ± 4.5	18.8 ± 18.8

ETc — Crop Evapotranspiration(mm); DP — Deep percolation (mm); P — Precipitation (mm); I — Irrigation (mm); SD — Surface Drainage (mm); CF — Continuous flooding; AWD — Alternate Wetting and Drying; Experimental sites: BB, Bico-da-Barca; QC, Quinta-do-Canal; NG, Nuno-Guilherme. [1] Includes a small fraction of surface drainage

The average rice yield (unhusked grain with 14% of moisture) was higher in the plots irrigated by CF than in those with AWD. The relative yield decrease of AWD was 5.2%, 7.3% and 2.7%, for QC, BB and NG, respectively. The relative WP increase of AWD was 5.9%, 12.5% and 6.6%, for QC, BB and NG, respectively. However, yield varied significantly between the sites, due to the effects of local edaphoclimatic conditions (Table 5).

Table 5. Rice and water productivity of CF and AWD plots (average and standard deviation values of 2020 and 2021 seasons).

Experimental site	Method	Y (t/ha)	WP (kg/m³)	G (g)	RS (t/ha)
QC	CF	8.542 ± 1.041	0.541 ± 0.062	27.0 ± 1.95	5.595 ± 0.11
	AWD	8.101 ± 1.151	0.573 ± 0.094	26.4 ± 2.50	5.910 ± 0.29
BB	CF	6.613 ± 1.489	0.353 ± 0.117	27.7 ± 3.30	4.560 ± 0.11
	AWD	6.128 ± 1.996	0.397 ± 0.137	28.3 ± 2.70	4.735 ± 0.55
NG	CF	6.149 ± 0.156	0.401 ± 0.035	28.1 ± 3.95	4.145 ± 0.02
	AWD	5.986 ± 0.327	0.428 ± 0.024	27.5 ± 3.35	3.825 ± 0.18

Y – Yield (t unhusked rice grain, 14% of humidity/ha); WP—Water Productivity (Y(kg/ha) / (I+P, m^3/ha) (kg/m^3); G—Weight of 1000 grãos, with 14% of humidity (g); RS—Rice Straw (dry matter, t/ha); CF—Continuous flooding; AWD—Alternate Wetting and Drying; Experimental sites: BB, Bico-da-Barca; QC, Quinta-do-Canal; NG, Nuno-Guilherme.

The water savings and the impacts on production due to AWD, recorded in this study are, in general, in agreement with the values indicated in the literature [17,18]. Therefore, this experiment confirmed the importance of AWD for water saving in rice irrigation, especially from the reproductive phase onwards, which occurs after mid of July. This water saving allows the Water Users Associations to mitigate the water scarcity in this period at district level, which corresponds to the maximum demand of most irrigation crops, such as corn, widely grown in Portugal. However, the successful application of AWD requires several changes on the rice production system, namely on precise land levelling (PLL), weeds control and fertilization scheme. PLL is a crucial complementary aspect to the success of AWD, so that the water depth on the soil is uniform throughout the entire plot. This is a condition for adopting a thinner water layer which, therefore, allows for a reduction in water use [19]. To this end, a regular and rigorous practice of level maintenance and monitoring should be encouraged.

Irrigation management in the alternating flooding period can be carried out in several ways. Gonçalves et al. [13] presented the main issues related to the application of AWD to rice irrigation to Center of Portugal. The AWD negative impacts on yield raises the question of the farmer's economic income, making this technique unattractive, especially when the water supply is sufficient for CF. This issue claims for a political strategy to promote rice production sustainability because the governmental support to change the rice irrigation system should guarantee the farmer's income.

4. Conclusions

This study confirmed the interest of the AWD irrigation of rice paddies in the Center of Portugal, a technique to be applied after the vegetative phase of the crop. AWD should be applied after the reproductive phase, through 2 to 4 drying cycles, with a dry period of 4-5 days in each cycle, allowing water savings in relation to the traditional continuous flooding of about 10%, an additional 10-20 days with dry soil, without significantly compromising rice production with a decrease in production about 5%. It was also concluded that the process of application and extension of AWD must be guided by a progressive adaptation of irrigation techniques, to obtain consolidated knowledge and adapted to local conditions, to limit the risks of loss of income and to build up the confidence in farmers for technological change.

The practice of waterlogging in the early stages of the crop is highly conditioned by particularly sensitive agronomic criteria (thermal control, weeds, wind, and phytosanitary treatments). Therefore, changes of the conventional procedure are not recommended until the beginning of the reproductive stage. Furthermore, the need to carry out frequent and planned irrigation events during the AWD period, demands for more accurate inflow control devices, making place for its automation, leading towards to rice modernization through smart flooding irrigation systems.

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References

1. MEDWATERICE Homepage, http://www.medwaterice.org/, last accessed 2022/03/23.
2. GPP - Gabinete de Planeamento, Políticas e Administração Geral. Available online: https://www.gpp.pt/ (accessed on 20 March 2022).
3. Pereira, L.A. Management of rice irrigation. PhD Thesis, ISA, Technical University of Lisbon, Lisbon, 1989 (in Portuguese).
4. Tuong, T.P., Bouman, B.A.M. Rice production in water-scarce environments. In Kijne, J.W., Barker, R. Molden, D. (eds.) Water Productivity: Limits and Opportunities for Improvement. CABI Pub., Oxon, pp. 53-67 (2003).
5. Richards, M., Sander, B.O. Alternate wetting and drying in irrigated rice. Implementation guidance for policymakers and investors. Info Note, CGIAR, CCAFA, IRRI, 2014.
6. Carrijo, D.R., Lundy, M.E., Linquist, B.A. Rice yields and water use under alternate wetting and drying irrigation: A meta-analysis. Field Crops Research 2017, 203, 173–180; doi: 10.1016/j.fcr.2016.12.002.
7. Runkle, B.R.K., Suvoscarev, K., Reba, M.L., Reavis, C.W., Smith, S.F., Chiu, Y.L., Fong, B. Methane emission reductions from the alternate wetting and drying of rice fields detected using the eddy covariance method. Environ. Sci. Technol. 2019, 53, 671-681.
8. Linquist, B., Anders, M.M., Adviento-Borbe, M.A.A., Chaney, R.., Da Roda, E.F.F., Van Kessel, C. Reducing greenhouse gas emissions, water use, and grain arsenic levels in rice systems. Glob. Change Biol. 2014, 21, 407-417.
9. Tanner, K.C., Windham-Myers, M., Marvin-DiPasquale, M., Fleck, J.A., Linquist, B.A. Alternate Wetting and Drying Decreases Methylmercury in Flooded Rice (Oryza sativa) Systems. Soil Sci. Soc. Am. J. 2018; doi:10.2136/sssaj2017.05.0158.
10. Mote, K., V Praveen Rao, V.P., Anitha, V. Alternate wetting and drying irrigation technology in rice. Indian Farming 2020, 70(04), 06–09.

11. USDA – US Department of Agriculture – Foreign Agricultural Service. Available online: https://ipad.fas.usda.gov/cropexplorer/ (accessed on 20 March 2022).
12. IPMA. IPMA Home Page. Available online: www.ipma.pt (accessed on 10 November 2018).
13. Gonçalves, J.M., Nunes, M., Ferreira, S., Jordão, A., Paixão, J., Eugénio, R., Russo, A., Damásio, H., Duarte, I.M., Bahcevandziev, K. 2022. Alternate Wetting and Drying in the Center of Portugal: Effects on Water and Rice Productivity and Contribution to Development. Sensors, 22, 3632.
14. Gomes, M.P.; Antunes-da-Silva, A. A new triangle diagram for basic soil texture classification. Estudos Agronómicos 1962, 3 (1), 1-9, Lisbon (in Portuguese).
15. Bouman, B.A.M., Humphreys, E., Tuong. T.P., Barker. R., 2007. Rice and water. Adv. Agron. 92, P.187-237.
16. Allen, R.G., Pereira, L.S., Raes, D., Smith, M. Crop Evapotranspiration. In Guidelines for Computing Crop Water Requirements; FAO Irrigation and drainage paper 56; FAO: Rome, Italy, 1998; 300p.
17. Datta, A., Ullah, H., Ferdous, Z. Water management in rice. In: Chauhan, B.S. (eds.) Rice Production Worldwide, pp. 255-277. Springer Int. Pub. AG (2017).
18. Jalindar, M.K., Rao, V.P., Ramulu, V., Kumar, K.A., Devi, M.U. Effectiveness of field water tube for standardization of alternate wetting and drying (AWD) method of water management in lowland rice (Oryza Sativa L.). Irrig. and Drain. 2019, 68: 679-689.
19. Evangelista, G.K.M. Land Gradient Effects on Water Productivity in Rice Production; Crop Science, University of Philippines: Los Banos, Philippines. 2019.