Field Assessment of rice drip irrigation in the Lis Valley, Portugal – strengths and constraints

Manuel Nunes [1], José Manuel Gonçalves [1,*], Rui Eugénio [3], António Jordão [2], Susana Ferreira [1], Isabel Maria Duarte [1,4], Paula Amador [1,4], Henrique Damásio [3], Kiril Bahcevandziev [1,4]

[1] Instituto Politécnico de Coimbra, Escola Superior Agrária de Coimbra, 3045-601 Coimbra, Portugal; Portugal; jmmg@esac.pt; mnunes@esac.pt; susana.ferreira@esac.pt; iduarte@esac.pt; kiril@esac.pt
[2] Direção Regional de Agricultura e Pescas do Centro, Coimbra, Portugal; antonio.jordao@drapc.gov.pt
[3] Associação de Regantes e Beneficiários do Vale do Lis, Leiria, Portugal; eugenio-rui@sapo.pt; hdamasio71@gmail.com
[4] CERNAS-Research Centre for Natural Resources, Environment and Society, 3045-601 Coimbra, Portugal

* Correspondence: jmmg@esac.pt; Tel.: +351 239802261

Abstract: Increasing rice production through cultivation on land unsuitable for flooding, namely on sloping fields or on light textured soils, reconciling with water saving, is a major challenge necessary to meet the increasing rice demand in the world market. There are experiences in several regions of the globe that prove that drip irrigation can be viable due to water saving, use of unconventional water resources, irrigation automation and ease of cultural rotation. In this sense, sponsored by the MEDWATERICE project (www.medwaterice.org), an experimental field work of rice drip irrigation, was set in the Lis Valley, Portugal, on high land and light soil, outside the traditional paddies, to it assess feasibility and to identify the main production constraints. This paper presents the results of 2020 and 2021 regarding a test of drip irrigation system, in an experimental plot of a private farmer, on a traditional horticultural field. Three cultivars grown in Portuguese rice paddies were used, with a spacing between rows of 20 cm and 30 cm, with a plant density of 50 plants/m^2. Weeds were control with two herbicide treatments, complemented with manual weeding. The irrigation after sowing was by solid-set sprinkler, for 7 days, to favour the seed germination and plant emergence. The irrigation system comprises drip lines of 16.2 mm diameter, dripper spacing of 0.30 m, with 1.0 L/h with pressure of 1.0 bar, usually with an irrigation event per day. The monitoring system evaluated the water use, soil moisture, crop development and yield. The results revealed great variability in the crop development, where the maximum production reached 7 t/ha and the water productivity 0.64 kg/m^3, but with low average productions of the order of 2.5 - 4.2 t/ha, mainly due to high unproductivity in the maturation phase. Preliminary conclusions point to the need to test other varieties, specially adapted to aerobic conditions and with a deeper root system, to favour water and nutritional comfort, and a row crop spacing not exceed 20 cm. There are open agronomic issues, such as weed control, irrigation, and fertilization management to be sorted out, concluding that more knowledge is needed to optimize productivity and water and energy savings, especially on the response of the crop to soil moisture in the reproductive phase.

1. Introduction

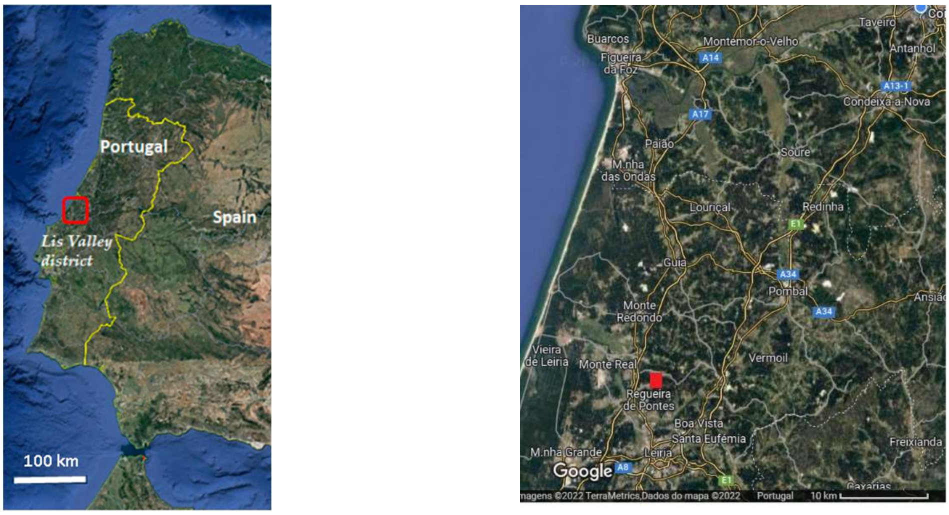
Rice (*Oryza sativa* L.) is the worldwide major staple crop, cultivated over 164 Mha [1], essential for ensuring global food security, given that over 90% of production is used directly for human consumption. Rice is cultivated in paddies and traditionally is irrigated by continuous flooding (CF), for environmental and microclimatic reasons. Consequently, rice is a very high-water demanding crop, making the water resources a limiting factor for sustainable production. On the other hand, the world demand for rice is increasing due to the population growth in the regions with higher consumption.

Facing the increasing threat of water scarcity, it urges developing agronomic and irrigation practices to reduce water use, while maintaining or increasing land and water productivity [2,3]. In short, the efforts for sustainability of rice crop are of strategic importance in the context of food security. A great research investment has been made in the last decades, looking for alternatives to CF, which is a key element to water saving and safeguard environmental quality of rice agroecosystems [4].

Rice drip irrigation is a feasible solution in some contexts, 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 [5-7]. Based on worldwide published, an experimental research of rice drip irrigation was designed on the Lis Valley, to assess soil water, agronomic, and productivity issues. Such trial was innovative in this region, aiming to reduce consumption of rice irrigation water, and to extend rice cultivation outside of traditional paddy areas.

2. Materials and Methods

The experimental study was carried out in 2020 and 2021 in the Lis Valley, located in Coastal Center of Portugal (Figure 1a), with a Mediterranean climate, Csb of Köppen classification, with an annual average precipitation of 800 mm. It has temperate and mild summers, with virtually no rainfall, and rainy winters with mild temperatures. The local air daily temperatures during cropping season are presented in Figure 2.



(a) **(b)**

Figure 1. Location of the Lis Valley Irrigation District in Portugal (red square); (b) the experimental field (■) (source: Google Maps, https://maps.google.pt).

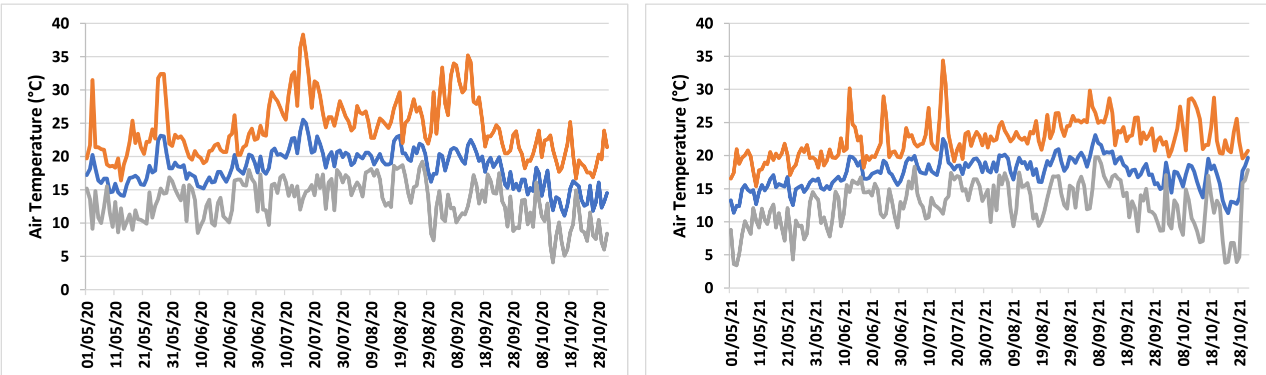


Figure 2. Daily air temperature, minimum, medium, and maximum, during 2020 and 2021 cropping seasons.

The experimental site mapped in Figure 1b, and its geographic coordinates and soil characteristics presented in Table 1. The trial plot belongs to a private farmer that usually grows horticultural crops.

The irrigation water was pumped from a well, located very close the experimental plot, with a submersible electric pump (Hidrobex, model Vetax-1000, 1 kW), with an automatic control. 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 100 kPa; the field installation had 16 drip lines with a length of 25 m, spaced of 0.60 m, working at a pressure of 100 kPa, with a total discharge of 1.33 m^3/h.

Table 1. Study site characteristics.

Location (geographic coordinates)	Latitude	40°49′08′′ N
	Longitude	8°49′24′′ W
	Altitude (m)	220
Type of farm		Private
Plot Area	12 m width x 25 m length	240 m^2
Texture top 60 cm soil (%)	Sand	86.3
	Silt	8.0
	Clay	5.7
Texture class		Loamy Sand
Soil	pH (H_2O)	5.3
	Soil Organic Carbon (%)	1.5
	Bulk Density (g cm^{-3})	1.50
Groundwater table level (below the soil surface, m)		3-4
Soil Water Content (cm^3 cm^{-3})	Saturation	0.40
	Field Capacity	0.18
	Wilting Point	0.08

*Texture classification according to Gomes and Silva [8].

Three japonica type of Portuguese rice cultivars were used: "Ariete", "Teti", and" Crono", to compare their performance to the drip irrigation. The spacing of rice rows was 20 cm and 30 cm, in the trials of 2020 and 2021 seasons, respectively. In both years, the average plant spacing within rows of 10 cm and 6.7 cm, respectively, performing about 50 plants/m^2. The soil preparation included the usual practice of ploughing and harrowing. The dry sowing was manual. Due to the dry and hot weather that was felt in the days after sowing, in both years, soil was irrigated by sprinkler solid-set, 30 minutes per day, for 7 days, with a depth of 5 mm/day, to favor the seed germination and plant emergence. The drip system started one week after sowing, in general with daily irrigation events, being the irrigation time regulated with automatic controller. The irrigation depth was determined according to the crop development and evapotranspiration intensity.

Weed were controlled with by two herbicide applications the active substance Bentazona, complemented with manual weeding. For *Pyricularia oryzae* control a mixture of difenoconazole and azoxystrobin were foliarly sprayed twice, 78 and 93 DAS.

The monitoring system evaluated the water use, soil moisture, crop development, yield quantity and quality. Crop yield was assessed through the sampling of aerial part at harvest time. 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 randomly selected. The biomass harvest was latter processed in the laboratory, determining the dry matter of aerial biomass straw and grain with 14% of humidity and the weight of 1000 grains.

These measurements allowed obtaining irrigation system daily data. The deep percolation (DP) was calculated through the daily water balance method, 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) [43]. The local field conditions implied that SD was null (no surface drainage runoff) and that ΔSW was negligible (soil moisture at root zone almost constant during irrigation season).

Based on the seasonal irrigation water applied (I, m^3 ha^{-1}), precipitation (P, m^3 ha^{-1}) and crop 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

The crop development phases, the fertilization, and the irrigation depths applied on drip experiment carried out in 2020 and 2021 are presented in the Tables 2 and 4, respectively. A crop view, at harvest, is presented in Figures 3 and 4 for 2020 and 2021 campaigns, also showing the drip laterals. The yield, water productivity and grain quality are presented in Table 3 for 2020, and Table 5 for 2021.

In the 2020 campaign, there was a great variability in the development and productivity of the crop, within the test plots, especially evident in the maturation phase. This visual observation is evidenced by the great difference between the average values and the respective maximum values, with maximum and average production ratios of 1.7, 1.9 and 3.2, for the Ariete, Teti and Crono varieties, respectively (Table 3).

Figure 3. Drip irrigation experiment in 2020, at harvest, showing the drip lines (orange arrows).

Table 2. Crop development phases, fertigation, and irrigation depths of 2020 drip experiment.

Phases	Vegetative	Panicle D[1].	Flowering	Milky	Maturation	Final	Total
Start date	20 May	28 Jul.	19 Aug.	30 Aug.	18 Sep.	2 Oct.	18 Oct.
Start DAS[2]	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[3] (mm/d)	6.1	10.3	14.5	14.0	5.0	0	
I[4] (mm)	415	216	160	238	85	0	1114
ETc[5]	320.7	89.0	51.5	72.2	36.1	32.0	602
P[6]	10.4	1.4	17.0	0.4	49.4	12.8	91
DP[7]	104.7	128.4	125.5	166.2	98.3	0	623

[1] Panicle D. - Panicle Differentiation; [2]DAS - Days After Sowing, at 20th May; [3]DI - Daily Irrigation depth, average value, mm/day; [4]I - Phase Irrigation depth, mm; [5]ETc - crop evapotranspiration (mm); [6]P - precipitation (mm); [7]DP - deep percolation.

Table 3. Yield, water productivity and grain quality of 2020 season trial.

Rice cultivar	Ymed[1] (t/ha)	Ymax[2] (t/ha)	WPmed[3] (kg/m^3)	WPmax[4] (kg/m^3)	WG[5] (g)	SY[6] (t/ha)	As (mg/kg)	Cd (mg/kg)
Ariete	4.218±1.646	7.138±2.544	0.379	0.641	25.5±0.9	10.96±2.845	< 0.10	0.025
Teti	3.306±1.850	6.341±2.401	0.297	0.569	23.7±1.0	8.483±3.363	< 0.10	0.054
Crono	2.545±2.408	8.129±2.432	0.228	0.730	22.3±4.6	8.290±6.147	< 0.10	0.070

[1]Ymed - Medium plot rice unhusked grain yield at 14% humidity (t/ha); [2]Ymax - Maximum plot rice unhusked grain yield at 14% humidity (t/ha); [3]WP - Water Productivity=grain yield at 14% humidity (kg/ha) / (irrigation + precipitation) (m^3/ha); [4]WG - Medium Weight of 1000 grains at 14% humidity (g); [5]SY - Medium straw yield, dry matter (t/ha).

In the 2021 campaign, the positioning of the drip laterals, in relation to the culture lines was changed compared to the previous year. The 2021 results revealed great uniformity in the development and productivity of the crop within each plot, with a lower amount of irrigation water applied. However, because of the longer spacing, 30 cm, and the specific weather conditions this year, the production values were significantly lower than those expected under normal conditions for these varieties.

Figure 4. Drip irrigation experiment in 2021, at vegetative phase.

Table 4. Crop development phases, fertigation, and irrigation depths of 2021 drip experiment.

Phases	Vegetative	Panicle D[1].	Flowering	Milky	Maturation	Final	Total
Start date	26 May	2 Aug.	22 Aug.	3 Sep.	23 Sep.	10 Oct.	20 Oct.
Start DAS[2]	0	68	88	100	120	137	147
N (kg/ha)	175*	43					218
K_2O (kg/ha)	39*	20	27	15			101
P_2O_5 (kg/ha)	25*		25				50
DI[3] (mm/d)	4.9	7.0	6.7	5.9	4.0	0	
I[4] (mm)	331	140	80	118	68	0	737
ETc[5]	284.6	84.2	47.4	66.9	43.3	25.4	552
P[6]	36.6	3.4	0.2	30.4	43.0	3.2	117
DP[7]	109.2	59.2	32.8	81.5	67.7	2.0	352

[1] Panicle D. - Panicle Differentiation; [2]DAS - Days After Sowing, at 26th May; [3]DI - Daily Irrigation depth, average value, mm/day; [4]I - Phase Irrigation depth, mm; [5]ETc - crop evapotranspiration (mm); [6]P - precipitation (mm); [7]DP - deep percolation; * - includes the basal fertiliser.

Table 5. Yield and water productivity of 2021 season trial.

Rice cultivar	Ymed[1] (t/ha)	Ymax[2] (t/ha)	WPmed[3] (kg/m^3)	WPmax[4] (kg/m^3)	WG[5] (g)	SY[6] (t/ha)
Ariete	2.734±1.050	3.904±0.228	0.320	0.457	14.2±2.9	6.923±0.389
Teti	3.287±0.381	3.577±0.180	0.385	0.419	18.9±1.4	6.144±0.315
Crono	2.345±0.530	2.905±0.390	0.275	0.340	17.1±1.6	7.724±0.518

[1]Ymed - Medium plot unhusked rice grain yield at 14% humidity (t/ha); [2]Ymax - Maximum plot unhusked rice grain yield at 14% humidity (t/ha); [3]WP - Water Productivity=grain yield at 14% humidity (kg/ha) / (irrigation + precipitation) (m^3/ha); [4]WG - Medium Weight of 1000 grains at 14% humidity (g); [5]SY - Medium straw yield, dry matter (t/ha).

4. Discussion

The trial experiment was installed in a field with light soil, with a loamy sand texture; thus, allowing to test the edaphic conditions opposite to those of the traditional type of soil, where paddies allow the best development conditions for rice. In 2020, a line spacing of 20 cm was used, as this is the most referenced value for most soils. In turn, the drip laterals were spaced 60 cm apart. Consequently, some plant rows were very close to the drippers, while others were at greater distance, implying, therefore, conditions for differences in wetting and nutrition among lines. This aspect was identified as the main cause for the non-uniformity in the development and productivity of the crop. In 2021, in the search for a solution to that problem, a line spacing of 30 cm was adopted, thus ensuring the same distance between rice rows and drip laterals. In fact, this modification allowed a great uniformity in the plant development, but with a reduction in the productivity per unit of area. In conclusion, the main significant contributions of this experiment point to the low average productivity of rice and the high variability in the use of irrigation water. These issues will then be discussed, seeking to find the proper explanations and possible practical solutions.

The seasonal irrigation depths in 2020, of 1114 mm, which were much higher than the crop evapotranspiration (601 mm), might be explained by the following problems recorded during vegetative and reproductive phases:

i) The crop showed water stress signs in the leaves, particularly in the plants located in the rows far from the dripper line; to circumvent this problem, an over irrigation practice was adopted, to favor the lateral wetting, that only had a partial success.
ii) The over irrigation on a very permeable soil, led to an excessive deep percolation (total of 623 mm), resulting in significant leaching of fertilizer close to the drip line, justifying the symptoms of chlorosis on the plant leaves. Regarding the drip irrigation test, the 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, mainly incident in the field patches with lighter soil.

In turn, the 2020 experiment showed that the maximum yield of several rice samples was much higher than the average, makes glimpse a potential good performance. These results explained the change of rice row spacing in the 2021 season, with a distance between row crops of 30 cm, and a uniform distance of drip lines to the row crops of 15 cm, to improve crop uniformity.

The 2021 trial allowed an IWU seasonal irrigation depth of 737 mm, a value much lower than the one applied in 2020 (1114 mm) and the one used in traditional rice fields (about 1200-1400 mm). This value corresponds to an ETc/IWU=551.8mm/737mm ratio of 0.75. It should be noted that in the 2021 agricultural season temperatures were slightly lower than in 2020, with averages of 18.9°C and 17.9°C in 2020 and 2021, respectively (Figure 2), with an ETc also lower (of 602mm to 552mm), a condition that may also have contributed to reduced productivity.

Regarding the distance between lines, these results do not recommend values beyond 20 cm, and the position of the drippers must be adjusted to favour the best uniformity of the wetted area of the soil.

One issue that needs to be evaluated is the response of new varieties to aerobic soil conditions created with drip irrigation. In fact, the tested varieties are especially suitable for flooding conditions. This issue should be explored in future trials to test varieties with special aptitude for these conditions.

5. Conclusions

This trial was the first experiment of aerobic drip irrigated rice applied in the Lis Valley Region. This technology has the potential to allow rice cultivation to be extended to highlands with less heavy textured soils than the traditional paddies, allowing for an increase in rice supply to the market.

An important step in this study is to test varieties specially adapted to aerobic conditions and with a deeper root system, to favour water and nutritional comfort. There are open agronomic issues, such as weed control, irrigation, and fertilization management, concluding that more knowledge is needed about the crop response to soil moisture in the reproductive phase, to optimize productivity and water and energy savings. It was concluded that the crop spacing should not exceed 20 cm.

As a result of the lack of knowledge that still exists, more studies are needed under Portuguese conditions to assess the feasibility of this rice irrigation system, before moving on to rural extension and dissemination by farmers.

Funding:

Project MEDWATERICE: Towards a sustainable water use in Mediterranean rice-based agro-ecosystems.
The project is financed in the context of the PRIMA Programme (PRIMA-Section-2018; Topic: 1.1.3: Irrigation technologies and practices) (MEDWATERICE-PRIMA-0005-2018, www.medwaterice.org).

References

1. AQUASTAT—FAO's Global Information System on Water and Agriculture. Water Use. Available online: www.fao.org/nr/water/aquastat/water_use/index.stm (accessed on 20 March 2022).
2. 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).
3. Bouman, B.A.M., Humphreys, E., Tuong, T.P., Barker, R. Rice and water. Adv. Agron. 92:187-237 (2007).
4. 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).
5. Parthasarathi, T., Mohandass, S., Senthivel, S., Vered, E. Effect of drip irrigation systems on yield of aerobic rice. Environment & Ecology 31 (4A): 1826-1929 (2013).
6. Arbat, G., Cufí, S., Duran-Ros, M., Pinsach, J., Puig-Bargués, J., Pujol, J., Ramírez de Cartagena, F. Modeling Approaches for Determining Dripline Depth and Irrigation Frequency of Subsurface Drip Irrigated Rice on Different Soil Textures. Water 2020, 12, 1724 (2020).
7. McClung, A.M., Rohila, J.S., Henry, C.G., Lorence, A. Response of U.S. Rice Cultivars Grown under Non-Flooded Irrigation Management. Agronomy 2020, 10, 55 (2020).
8. 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).