Economic, environmental, and social sustainability of water-saving solutions for the rice sector in the Mediterranean basin

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Abstract

In the Mediterranean basin, rice has important economic and social implications, especially in areas where it is a staple food such as Egypt. On the other hand, the peculiar flooding conditions in which rice is traditionally grown lead to the use of huge volumes of water, as well as to the potential release of greenhouse gases and pesticides into the environment. The introduction of water-saving irrigation strategies could reduce water consumption and decrease the harmful environmental impacts while maintaining yield and rice quality. However, the environmental, economic and social sustainability of these strategies must be adequately evaluated.

To explore the overall sustainability of innovative water-saving irrigation strategies, several experimental farms were selected in the main rice producer countries of the Mediterranean basin (EG, IT, TR, ES, PT) in the context of the MEDWATERICE project (https://www.medwaterice.org/). In particular, the alternative irrigation strategies compared to the wet seeding and continuous flooding (considered as the 'reference' irrigation in all CSs), were: alternate wetting and drying (AWD); dry seeding and delayed flooding (DFL), water input reduction after day 100 from sowing (WIR), hybrid irrigation (HYBRID), multi-nozzle sprinkler irrigation (SPRINKLER), surface drip irrigation (DRIP), and subsurface drip irrigation (SDI).

A set of indicators for the quantitative assessment of the environmental and economic sustainability of the irrigation options were defined, which includes: Farm Profitability (Net Income); Labour Productivity; Productivity (Grain yield); Water Productivity; Relative Water Supply; Percolation to Groundwater; Energy Productivity; Nutrient (N, P, K) Use Efficiency; Greenhouse Gas Emission (CH_4 and N_2O); Environmental Potential Risk Indicator for Pesticides (EPRIP); Food Safety (Arsenic and Cadmium grain rice content). The social acceptability of the irrigation strategies was investigated through the Technology Acceptance Model (TAM) by involving rice growers of the pilot areas, barriers to the adoption of the irrigation strategies were assessed and ways to overcome them identified. The indicator set was applied to datasets collected in the experimental farms during the agricultural seasons 2019-2021, and results are being extrapolated to the irrigation district level to support water management decision makers and policy planners. The methodologies developed and the results achieved are illustrated and discussed in this paper.

Keywords: Water-saving irrigation strategies, Indicators, Sustainability, Rice, Social acceptability

1. Introduction

Rice cultivation is considered a source of environmental harm due to the flooding conditions in which rice traditionally grows. From 1961 to 2019, the rice area harvested globally increased from about 115 million ha to about 162 million ha, with significant conversions of natural to arable lands. Methane emissions of rice areas are estimated to have increased from 17,400 to 24,100 kilotons in the same period (FAOSTAT 2021). Yield production increased with the introduction of high yielding crop varieties, farm mechanization, and various types of chemical fertilizers and pesticides. Farmers, with respect to agronomic inputs, often adopt the attitude of 'more is better' to increase yield production, regardless of economic and environmental costs (Stuart et al., 2018; Huelgas et al., 2010).

On the other hand, rice cultivation has important economic and social implications in many areas of the word and also in the Mediterranean basin, in which it is cropped over an area of 1,300,000 hectares. The most important rice-producing countries in the Mediterranean area are Italy and Spain in Europe (72% of the EU production; 345,000 ha) and Egypt and Turkey among the extra-EU countries (almost totality of the production; 789,000 ha). In the Mediterranean area, the peculiar flooding conditions in which rice is traditionally cultivated lead to the use of huge volumes of water, as well as to the potential release of greenhouse gases and pesticides into the environment. For this reason, the introduction of water-saving irrigation strategies could reduce water consumption and decrease the harmful environmental impacts linked with rice cropping, while maintaining yield and rice grain quality. However, the environmental, economic, and social sustainability of these strategies must be adequately evaluated.

In the context of the MEDWATERICE project (https://www.medwaterice.org; 01/04/2019 - 31/03/2023), seven case studies (CSs) were implemented in experimental pilot farms of each country involved in the project (EG, IT, TR, ES, PT). Tested water-saving irrigation methods were tailored to local conditions using a participatory action research approach through the establishment of Stake-Holder Panels (SHPs). For each irrigation solution, innovative technologies and the most appropriate rice varieties and agronomic practices were implemented to minimize impacts on yield quantity and quality. Experimental activities were conducted in the pilot farms during at least two agricultural seasons in the period 2019-2021, to evaluate the economic, environmental and social sustainability of the water-saving techniques introduced. A literature review of the existing methodologies applied all over the world to assess economic, environmental and social aspects connected to rice production was carried out in Gharsallah et al. (2021). The review was the base for the selection/development of a set of economic and environmental indicators and a social analysis procedure then applied to the MEDWATERICE CSs. The current paper presents the methodologies adopted and the main results achieved so far.

2. Materials and methods

2.1. Indicator framework

Among the indicators found in the literature, the following economic and environmental indicators proposed by the Sustainable Rice Platform (SRP; https://www.sustainablerice.org/) were selected to be adopted in MEDWATERICE: Farm Profitability (Net Income); Labour Productivity; Productivity (Grain yield); Water Productivity (WP); Greenhouse Gas Emission (CH_4 and N_2O); N and P Use Efficiency (SRP Performance Indicators Version 2.0, 2019). A K Use Efficiency indicator was added, considering the same approach proposed by SRP (2019) for N and P Use Efficiency. To evaluate the effect of the irrigation strategies in terms of water saving, the indicator Relative Water Supply was included (Sanchez et al., 2015). Furthermore, to investigate the amount of energy consumed during the agronomic and irrigation operations, the Energy Productivity indicator was added to the indicator set (Rao et al., 2017). For the evaluation of the pesticides impact, the Environmental Potential Risk Indicator for Pesticide (EPRIP) described in Padovani et al. (2004) was selected and modified to account for rice specific growth conditions (Voccia et al., 2022). To evaluate the effect of irrigation strategies on the groundwater recharge, the indicator Percolation to Groundwater (PG) was built. Finally, an indicator describing the Food Safety risk (Cadmium and Arsenic content in rice grain) was developed. Social acceptability of the irrigation strategies proposed in the project was evaluated through a qualitative approach based on the Technology Acceptance Model (TAM) (Davis 1989). Selected indicators and approaches are shown in Figure 1.

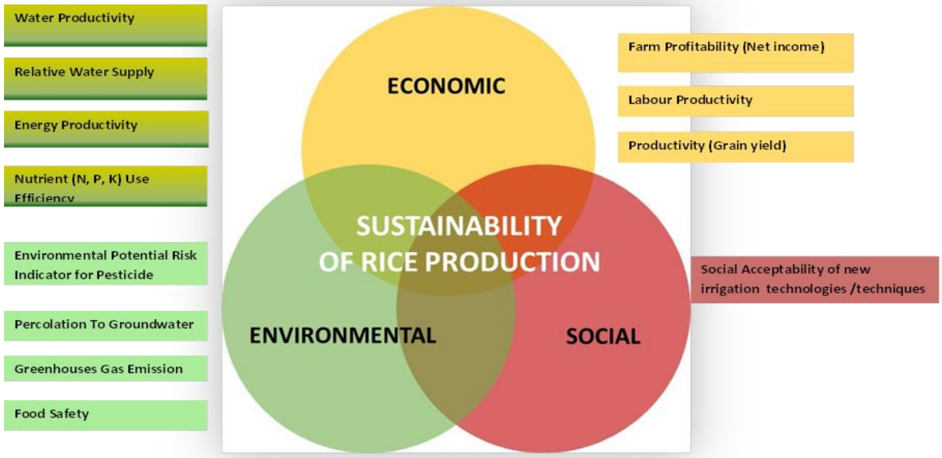

Figure 1: Indicators and approaches for the sustainability assessment of rice production under different irrigation strategies in MEDWATERICE

2.2. Data collection

All economic and environmental indicators were computed through data collected from the experimental fields in the MEDWATERICE pilot farms, and through questionnaires developed for on-farm data collection compiled by farmers hosting the experimentations with the support of the project researcher and technical staff. For each pilot farm, only fields cropped with rice were considered in the questionnaire, and a separate questionnaire was compiled for each rice irrigation strategy tested in the farm. In the questionnaire, all the processes involved in rice production from the land preparation till post-harvesting were taken into account. Social acceptability was evaluated using an additional questionnaire compiled through face-to-face interviews with a sample of rice growers in the study areas involved in MEDWATERICE.

3. Results and discussion

The most promising water-saving irrigation solutions explored in the CSs were: AWD in CS1 (Lomellina, Italy); DFL and SDI in CS2 (Baix Ter, Spain); WIR in CS3 (Guadalquivir marshes, Spain); AWD in CS4 (Lower Mondego Valley, Portugal); AWD and DRIP in CS5 (Lis Valley, Portugal); HYBRID, SPRINKLER, and DRIP in CS6 (Nile Delta, Egypt); AWD and DRIP in CS7 (Bafra Valley, Turkey). Results achieved for each water-saving technique were compared with the traditional continuous flooding (WFL) which was considered as the 'reference' irrigation strategy in all CSs. Average values of the indicators over the period 2019-21 are reported in this paper; all values are referred to 1 ha of rice surface. Only the calculation of Environmental Potential Risk Indicator for Pesticides (EPRIP) and the analysis of Social Acceptability are still in progress for all CSs except than CS1.

In the project, next steps will be: 1) to generalize results obtained in the experimental farms in order to make them representative for a 'typical farm' of the investigated rice areas; 2) to extrapolate water saving results demonstrated in the pilot farms at the irrigation district level to support water management decisions and policies. For both activities, final results will be available in the next months. Preliminary results in terms of water saving indicators at the irrigation district level for some CSs are reported in Gilardi et el (2022) for CS1, in Cufi et al. (2022) for CS2, in Alarcon et al. (2022a) for CS3, and in Alarcon et al. (2022b) for CS4 and CS7.

The main results achieved in the MEDWATERICE pilot farms are discussed in the following sections.

3.1. CS1 (Lomellina, Italy)

AWD: Alternate Wetting and Drying (AWD) was found to be a promising irrigation technique for rice cultivated in northern Italy, economically reliable, which allowed a reduction of water consumption without penalizing the rice yield or strongly influencing the rice grain quality (Cadmium and Arsenic content in rice grain). The main aspects emerged are the following:

- Farm Profitability of AWD was slightly higher than that of WFL, with an increase of about 22 euro/ha; rice yield was similar (11 t/ha).
- Labour Productivity of AWD was slightly lower than that of WFL (175 hour/ha in AWD *versus* 203 hour/ha in WFL). This was in particular due to the difference in hours spent for irrigation operations (22 hour/ha in WFL, 31 hour/ha in AWD) since AWD required more labour for the manual management of gates during the drying and wetting events. All the other agronomic operations conducted in the agricultural season were similar.
  Labour required to manually manage the inlet and outlet gates maintaining a constant ponding water level in the fields, increased under the AWD regime with respect to WFL, may be reduced through the adoption of automatic gates controlling the irrigation inflow on the base of the in-field ponding water level; a preliminary application in northern Italy is illustrated by Gangi et al. (2022).
- AWD showed a water saving of 20%, an increase in Water Productivity (WP) of 20%, a decrease in Relative Water Supply (RWS) of 21.5%, and a reduction in Percolation (PG) of 24% compared to WFL.
- AWD showed a similar Energy Productivity and Nutrient (N, P, K) Use Efficiency than WFL. Following the estimates done in the project, AWD allowed the reduction of CH_4 emissions by about 18% while increased N_2O emissions by about 39%.
- AWD decreased inorganic Arsenic content in rice grain and increased rice Cadmium content. Considering the EU Regulation 2015/1006, the maximum inorganic As content allowed in the non-parboiled milled rice is 0.20 mg/kg, in the parboiled and husked rice is 0.25 mg/kg, and in rice for baby-food is 0.10 mg/kg. Maximum admissible Cadmium content in rice is 0.15 mg/kg (Commission Regulation 2021/1323) while in rice for baby-food it is reduced to 0.04 mg/kg (Commission Regulation 2014/488). For CS1, inorganic Arsenic content was found to be below the legal limit for both irrigation strategies, while Cadmium content was even below the limit for baby food.
- Regarding the Environmental Potential Risk Indicator for Pesticides (EPRIP), AWD showed a similar EPRIP values than WFL. In particular, for the AWD the Predicted Environmental Concentration (PEC) showed the same probability to exceed Risk Point 3 (EXC_PROB_3%) than WFL. Details are illustrated in Voccia et al. (2022).
- Farmers of the Lomellina rice area declared their willingness to adopt AWD if requested since they were persuaded of the advantages for the environment; however, they declared they would need financial, technical, and, if possible, technological support (i.e. devices to guide the wetting and drying cycles). As a matter of fact, they must reintroduce water seeding, while now almost the whole territory has switched to wet seeding and delayed flooding.

3.2. CS2 (Baix-Ter, Spain)

DFL: Dry-seeding and Delayed Flooding (DFL) showed to be a valid technique to be adopted in Northern Spain. In particular, experimental activities conducted in the pilot farm showed that:

- DFL increased Farm Profitability by 45%. This was mainly related to the high yield obtained (8 t/ha *versus* 6.5 t/ha in WFL), as production costs were quite similar. The yield improvement in DFL can be explained by a more homogenous distribution of seeds, as the seeding operation was conducted through a seed-drill and this facilitated a better establishment of the plants before the tillering stage and consequently a more efficient competition of rice with the weeds.
- Labour Productivity of DFL was higher than for WFL. This was due to: i) the difference in yield production, and ii) the difference in hours spent to conduct agronomic and irrigation operations, since water seeding, pesticide treatments, and fertilizations required more time when conducted in flooded fields.
- No water saving was observed, WP increased by 6%, RWS decreased by 2%, and no PG reduction was found.
- DFL increased Energy Productivity and Nutrient (N, P, K) Use Efficiency. It reduced slightly CH_4 emissions (3%) while N2O emissions increased (23%).
- DFL showed quite a similar Cadmium grain content and a lower Arsenic grain content compared to WFL, and both were below the EU limits.

SDI: Sub-surface Drip Irrigation (SDI) showed to be a promising water-saving technique; however, in the specific CS, it demonstrated not to be economically profitable. Details are illustrated below:

- SDI experimented in the Cobert pilot farm showed to be not economically profitable. In particular, Farm Profitability was found to be about -2576 euro/ha; this was due to:
  - a low yield production obtained with SDI (3.5 t/ha), explained by: i) difficulties in designing and managing the SDI irrigation system (depth of driplines, spacing of drippers and driplines and emitter flowrates) in such a challenging conditions (sandy-loam texture and deep groundwater); ii) difficulties in controlling weeds in case of rice grown under aerobic conditions; and iii) need to select appropriate rice varieties for SDI: Onice variety produced 2.64 t/ha in 2019 and 2.65 t/ha in 2021, Furia variety produced 5.28 t/ha in 2020 and this demonstrated that a yield improvement could be achieved with a change in rice variety.
  - a total cost of the SDI irrigation system (irrigation materials, installation, sensors, yearly service for remote connection, user software), which was found to be 1424 euro/ha/year considering a lifespan of the SDI irrigation system of about 7 years.
  - the high cost of the electricity used (kW/ha) by the pumping system.
- Due to the low yield (3.5 t/ha), a low Labour Productivity value was obtained despite the lower amount of labour required to grow one ha of rice adopting SDI (24 hour/ha) compared to WFL (36 hour/ha).
- Compared to WFL, SDI showed a water saving of 30%, an increase of WP of 29%, a decrease of RWS of 22%, and a PG reduction of 85%.
- SDI decreased the Nutrient (N, P, K) Use Efficiency. CH_4 emissions were not considered, due to the aerobic field conditions, while N_2O emissions increased compared to WFL.
- When considering rice grain quality, rice Cadmium content was lower, while Arsenic content was higher compared to WFL.
- The experiment was repeated in 2021 in the Benzinera farm, characterized by a heavier soil, with the rice variety Bahia, obtaining a yield reduction of only 4.5% compared to WFL. Economic and environmental indicators will be calculated for this additional dataset in the next months.

3.3. CS3 (Guadalquivir marshes, Spain)

WIR: Water Input Reduction (WIR) after day 100 from the sowing date showed to reduce water consumption, without penalizing significantly yield production, and without reducing rice grain quality. In particular, it can be reported that:

- Farm Profitability was about 1347 euro/ha, with a yield production about 8 t/ha.
- Labour Productivity of WIR was slightly lower than WFL. This difference was in particular due to the difference in yield production (about 1 t/ha), as labour input required to conduct agronomic and irrigation operations was similar for the two strategies.
- Water saving was found to be about 31% with respect to WFL, WP increased by 29% and RWS decreased by 28%.
- Energy Productivity was slightly lower than WFL, mainly due to the reduction of yield production, as the amount of carburant consumed to conduct agronomic operations was similar (92 l/ha). Nutrient (N, P, K) Use Efficiency was slightly lower than for WFL, CH4 emissions were slightly reduced compared to WFL (WFL had a few more days of flooding compared to WIR), N2O emissions were similar to WFL since very similar irrigation and fertilizer management strategies were adopted for the two irrigation solutions (i.e. flooding irrigation regime, with one single field drainage, and similar nitrogen treatments).
- Cadmium and total Arsenic contents in the rice grain remained unchanged.

3.4. CS4 (Lower Mondego Valley, Portugal)

AWD: Alternate Wetting and Drying (AWD) showed indicators quite in line with WFL, no significant water saving was achieved and no effect on yield production was observed. Main results are:

- Farm Profitability of AWD was about 2846 euro/ha, no significant reduction in yield production was found for AWD compared to WFL (about 9 t/ha).
- Labour Productivity was lower for AWD (271 kg/hour for WFL *versus* 244 kg/hour for AWD). This was in particular due to the increase of labour required by AWD for the irrigation management.
- Water consumption was slightly lower than for WFL (about 2%). No significant changes were observed in WP and RWS, while PG was reduced by about 8%.
- Energy Productivity was similar to WFL, since the amount of fuel consumed to conduct agronomic operations was similar (135 l/ha) for both irrigation strategies (AWD and WFL). Nutrient (N, P, K) Use Efficiency was slightly lower for AWD than for WFL. No significant changes in CH_4 and N_2O emissions were observed.
- Cadmium and total Arsenic content in rice grain remained similar to WFL, under the EU limits.

3.5. CS5 (Lis Valley, Portugal)

AWD: Alternate Wetting and Drying (AWD) showed to be a promising irrigation technique for the Lis Valley, reducing water use with a slight yield production loss. The main observed results are:

- Farm Profitability was about 1755 euro/ha, yield production was reduced by about 9%.
- Labour Productivity was lower than for WFL (199 kg/hour for WFL *versus* 149 kg/hour for AWD). This was in particular due to the difference in yield production, as well as in labour input, as AWD required more labour for the irrigation management compared to WFL.
- Water saving was found to be about 10% with respect to WFL. No significant change was observed for WP, while RWS decreased by 11%, and PG by about 29%.

- Energy Productivity was lower than for WFL, due to the reduction of yield production, since the amount of fuel consumed for agronomic operations was similar (140 l/ha) in both irrigation strategies (AWD, WFL). Nutrient (N, P, K) Use Efficiency was slightly lower than for WFL, CH_4 emissions decreased by about 23% and N_2O emissions were slightly higher than for WFL.
- No changes were found in Cadmium and Arsenic content in rice grain.

3.6. CS6 (the Nile Delta, Egypt)

HYBRID: Multi-outlet Hybrid irrigation was found to be a very promising water-saving technique, with a high economic reliability. In particular, when considering the Hybrid variety, it was highlighted that:

- Farm Profitability was about 2153 euro/ha, increased by 30% when compared to WFL. Yield production was incremented by 17% achieving 12.5 t/ha. The cost of the multi-outlet hybrid irrigation system was about 325 euro/ha, considering a lifetime of 15 years. Therefore, the initial investment (325 euro/ha) could be covered in the first year.
- Labour Productivity was highly increased when compared to WFL. This was in particular due to the increase in yield production, and to the decrease in labour input of 22%, as HYBRID required less labour hours to conduct agronomic and irrigation operations.
- Water saving was found to be about 25% with respect to WFL. WP increased by 54%, RWS decreased by 25%, and a relevant PG reduction was achieved.
- Energy Productivity was found to be higher than WFL, as the consumed energy was reduced by 35% and the production was increased. Nutrient (N, P, K) Use Efficiency was incremented with respect to WFL. No changes were observed in CH_4 and N_2O emissions.
- Cadmium and Arsenic rice content were slightly decreased with respect to WFL.

SPRINKLER: Multi-nozzle Sprinkler irrigation demonstrated to be an appropriate water-saving irrigation technique, economically profitable, that could be adopted as an alternative to the traditional continuous flooding in the rice area of the Nile Delta. It was highlighted that:

- Farm Profitability achieved was 1421 euro/ha. Yield production was incremented by 5% with respect to WFL, achieving 11.3 t/ha. Cost of the multi-nozzle sprinkler irrigation system was about 725 euro/ha and the considered lifetime was estimated to be 8.5 years. Therefore, it can be concluded that the initial investment could be covered in the first year.
- Labour Productivity was incremented due to the increase in yield production and to the reduction of labour input by 18%, since SPRINKLER required less labour hours for agronomic and irrigation operations.
- Water consumption was reduced by 31% with respect to WFL, WP increased by 51%, and RWS decreased by 29%, while an important PG reduction was achieved.
- Energy Productivity decreased due to the increase of the energy input required for pump functioning in the sprinkler irrigation system. Nutrient (N, P, K) use Efficiency and N_2O emissions increased, and CH_4 emissions were not considered due to the aerobic condition.
- Cadmium and Arsenic contents in rice grain were slightly increased, with a few samples above the EU legal limit for As concentration.

DRIP: Surface Drip irrigation showed to be an innovative water-saving irrigation technique that could be adopted in rice cultivated areas of the Nile Delta, guaranteeing a high water saving without penalizing yield production. The main results obtained are:

- Farm Profitability was found to be 1158 euro/ha. Yield production was incremented by 5% and it attained 11.3 t/ha. The total cost of the surface drip irrigation system was about 1000 euro/ha.

Therefore, it can be deduced that the initial investment could be economically covered in the first few years of rice production, taking into consideration that the system lifetime was estimated to be about 7.5 years.

- Labour Productivity increased when compared to WFL, due to the labour input reduction (about 18%), as DRIP irrigation required less labour hours for agronomic and irrigation operations.
- Water consumption highly decreased (about 43%) with respect to WFL, WP highly increased (84%), RWS was reduced by 37%, and PG decreased of about 90% when compared to WFL.
- Energy Productivity decreased, as the consumed energy was incremented by 57% with respect to WFL, due to the energy input required for the pumping system. Nutrient (N, P, K) Use Efficiency and N_2O emissions increased with respect to WFL, and CH_4 emissions were not considered due to the aerobic conditions of rice.
- Cadmium content in the rice grain was similar to WFL, while Arsenic rice content decreased, with values below the EU legal limit.

3.7. CS7 (Bafra Valley, Turkey)

AWD: Alternate Wetting and Drying (AWD) showed to be a promising irrigation technique reducing water consumption without important yield production losses, and improving the impact of rice production on the environment. The Alternate Wetting and Drying (AWD) strategy was tested in the Bafra Valley adopting three severity degrees AWD (-5cm), AWD (-10cm) AWD (-15cm); details are reported in Enginsu et al. (2022). Indicators were calculated for the three cases, but average values are reported in this paper. The main results are:

- Farm Profitability was found to be 2100 euro/ha (1825-2361 euro/ha for the three AWD severity options). Yield production was reduced by 12% (7-16%), achieving about 7 t/ha (6.7-7.4 t/ha).
- Labour Productivity was slightly lower than for WFL due to the slight reduction of yield production. Labour input for AWD was found to be similar than that for WFL.
- Water saving was about 26% (19-32%) when compared to the traditional flooding, WP increased by 19% (17-21%), and RWS decreased by 24% (17-31%).
- Energy Productivity was higher than for WFL, due to the lower use of electricity for water pumps taking water from the irrigation channel used in AWD. Nutrient (N, P, K) Use Efficiency was slightly decreased, total CH_4 emissions were rather reduced, while N2O emissions incremented.
- Cadmium content in the rice grain was comparable to WFL, while Arsenic content significantly declined; however, concentrations were widely below the EU legal limits.

DRIP: Surface Drip irrigation showed to be a promising water-saving irrigation technique in the Bafra Valley area. It was experimented under two management strategies (DRIP-1.75 and Drip 2.0); details are reported in Enginsu et al. (2022). Both trials gave similar results, average values were considered in this paper.

- Farm Profitability reached approximately 1700 euro/ha (1676-1731 euro/ha). Yield production slightly decreased to about 7.5 t/ha (7.4-7.6 t/ha). The cost of the surface drip irrigation materials was about 1394 euro/ha; the initial investment could be economically covered in the first few years of rice production, taking into consideration that the system lifetime was estimated to be about 3 years.
- Labour Productivity was highly incremented, due to the huge reduction of labor input (about 83%) spent in agronomic and irrigation operations.
- Water saving was about 75% when compared to the traditional flooding, WP highly increased by 270% (248-287%) and RWS decreased of 73% (71-75%).

- Energy Productivity was higher than that for WFL, due to the lower electricity consumed in DRIP to pump water from the irrigation channel. Nutrient (N, P, K) Use Efficiency was slightly lower than for WFL, total CH4 emissions were not considered due to the aerobic field conditions, and N_2O emissions resulted to be highly incremented.
- Cadmium content in the rice grain slightly increased and Arsenic content was found to be lower than for WFL, although values were always widely below the EU legal limit.

4. Conclusions

Water management practices alternative to continuous flooding are highly required to enhance water use efficiency and safeguard environmental quality in rice agro-ecosystems. In the MEDWATERICE project, a novel and multidisciplinary approach to evaluate the overall sustainability (economic, environmental, and social) of water-saving irrigation techniques/technologies alternative to the traditional continuous flooding is proposed and applied to a set of alternative irrigation strategies experimented in pilot farms of project participating countries. The results achieved highlight its effectiveness in summarizing the main economic, environmental and social aspects that emerged from the application of the innovative techniques/technologies in the different geographical contexts.

As regards the specific results achieved in the MEDWATERICE pilot farms, it can be noted that, although general trends can be observed for the indicator values when used to analyse the same irrigation strategy compared to WFL in different geographical areas, absolute values are strongly dependent on the individual Case Study. This is undoubtedly due to the specific environmental conditions, to the rice variety used, to the design, realization and management of irrigation systems at the field and farm level, and to the agronomic and irrigation practices adopted locally.

In general, it emerged that Alternate Wetting and Drying (AWD), Dry-seeding and Delayed Flooding (DFL), Water Input Reduction from day 100 after sowing (WIR), and HYBRID irrigation can be seen as interesting alternatives to the traditional flooding method, ready to be spread among farmers, which could substitute the traditional technique in all the Mediterranean rice area allowing a slight to moderate water saving and a reduction of environmental impacts without radically modifying the irrigation systems. Surface drip (DRIP), subsurface drip irrigation (SDI) and SPRINKLER are promising irrigation solutions to be adopted in geographical context where water resources are limited, which would allow to extend the rice cultivation areas and consequently satisfy the growing product demand; however, it must be taken into account that the high water savings achievable with these techniques is often paid through high investments for the irrigation systems (irrigation equipment, installation, periodic maintenance, sensors to support the irrigation management if any, etc.) and energy costs. Thus, to achieve yield productions able to cover the high investment and energy costs, particular attention must be paid to: i) the choice of appropriate rice varieties adapted to aerobic conditions; ii) the choice of a proper irrigation system design (laterals and emitters spacing, flow rates, etc.) and management (irrigation schedule and duration), taking into consideration site-specific soil hydraulic properties, crop water requirements, and irrigation water quality (salinity, etc.); iii) the consideration of solar-powered pumping systems to reduce energy inputs; and iv) the use of the irrigation system for other profitable crops after the end of the rice season.

The specificities of each technique and the best practices to be adopted for its implementation in the different geographical contexts to minimize economic and environmental drawbacks are described in guidelines and fact-sheets produced during the project and uploaded to the project website (https://www.medwaterice.org/downloads/).

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