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Economic Performance of Traditional and Modern Rice Varieties under Different Water Management Systems

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Abstract: Italian rice production is progressively threatened by water scarcity. Some strategies have been developed to reduce water use. Nevertheless, reducing water irrigation amounts may lower paddy rice production. This publication compares the productivity and the economic performances of traditional and modern rice varieties in northern Italy using two different water management systems. The objective of this analysis is to enhance Italian rice cultivation at the economic, environmental and agronomic levels. Some positive variations of water productivity and economic water productivity were observed for the two varieties when using a lower amount of irrigation water. However, actual production costs and most water supply fees are the same for all the irrigation methods. Furthermore, the study of agronomic traits shows that during the recent years, there were no significant differences or increases of yield among varieties. Consequently, to be adopted by farmers, the irrigation costs coupled with improved rice accessions need to be optimized.

Keywords: rice cultivation; Italy; water saving; water productivity; economic water productivity

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1. Introduction

Worldwide, rice is one of the most important crops and it represents a staple food for over half of the world's population, with a global production of more than 700 million tons per year [1] and a harvested area reaching 165 million ha. In Europe, where *Japonica* rice is cultivated, Italy is the leading rice producer, with around 227,300 ha of rice-cultivated areas [2]. Additionally, a trend of continuous increase of the rice cultivation surface was observed during the last 30 years; also the area per farm has increased, moving from 20.9 ha of rice per farm in 1983 to 53 ha in 2012, with an increase of 3% to 5% per year [3]. Besides, rice cultivation is a high-water-consuming crop and irrigated rice is the most spread-out agrosystem. It represents 53% of worldwide rice-cultivated areas [4]. A volume of 2.5 to 5.0 m^3 is needed to produce 1 kg of rice, whereas only 0.4–0.7 m^3 of water is needed for 1 kg of sorghum [5]. However, a large amount of total water applied at the field-level is lost by evapotranspiration, seepage and percolation [6].

Moreover, rice cultivation is threatened by climate change which represents the major challenges that irrigated agriculture all over the world will have to face. It is foreseen that by 2025, 15–20 million ha of rice lands will suffer from water scarcity. As summarized by [7], hot-spots of water scarcity in rice-growing areas have been reported, and temperatures higher than the mean trend have been registered in many European countries. In Italy, the flow of the Po River, which provides water to an extensive network of artificial channels used for rice irrigation, decreased by 20%–25% in the last 30 years, passing from historical values of 1800 $m^3 \cdot s^{-1}$ to 1400–1500 $m^3 \cdot s^{-1}$ [8]. This trend caused a reduction of water availability during the dry summers of 2003 and 2012. Therefore, the effects of climate change necessitate an optimization of the water use in irrigated rice areas. To address these problems, new rice cultivation practices are being experimented with worldwide. These approaches, called water-saving technologies, can help to reduce the water irrigation amount associated with traditional rice farming, especially owing to the reduction of water losses at the field level [9,10], and optimize the use of available water. For instance, operations connected to land preparation can help in reducing or regulating irrigation water in rice-fields [4]. Specifically, field channels help in controlling the water volume flowing in and out of a rice field; a well-leveled field is necessary for good circulation of the water and good crop emergence, while additional shallow soil tillage before land preparation, as well as saturated soil culture, can decrease seepage and percolation flows [11]. Therefore, different cultivation methods have been tested to evaluate the effect on rice productivity and on irrigation. The alternate wetting and drying (AWD) method can reduce irrigation by 15%–30% without any impact on yield [12]. This method consists of applying irrigation a few days after the disappearance of water. Hence, the field is alternately flooded and non-flooded. The number of days of non-flooded soil between irrigations can vary from one to more than 10 days, depending on a number of factors such as soil type, weather and crop growth stage. This method requires varieties selected for cultivation in conditions of reduced irrigation. Asian countries developed a panel of accessions adapted to different methods of alternate or reduced irrigation. In aerobic rice cultivation, varieties are grown under dry land conditions like wheat or maize. This method can reduce irrigation by 30% to 50% [13]. Other advantages associated with reduced irrigation exist. It is known that under flooding conditions, there is a higher arsenic accumulation in rice grains compared to rice cultivated in conditions of alternate irrigation. This point is particularly important for areas with a Protected Geographical Indication such as the Verona area in Italy, where agricultural management practices are strongly prescribed. Furthermore, flooded rice produces a high level of greenhouses gases and the shift from permanent flooding to alternate irrigation can reduce CH_4 emissions. A single mid-season aeration can reduce the seasonal CH_4 emissions by 40%.

However, the introduction of new cultivation methods requires an economic evaluation of production costs and net returns. It is known that Italian farms are affected by the fluctuation of rice prices. They varied from €186 to €489 per ton in the last 10 years, with many fluctuations between 2005 and 2015 [14]. At the same time, production costs follow a continuous increase (Figure 1).

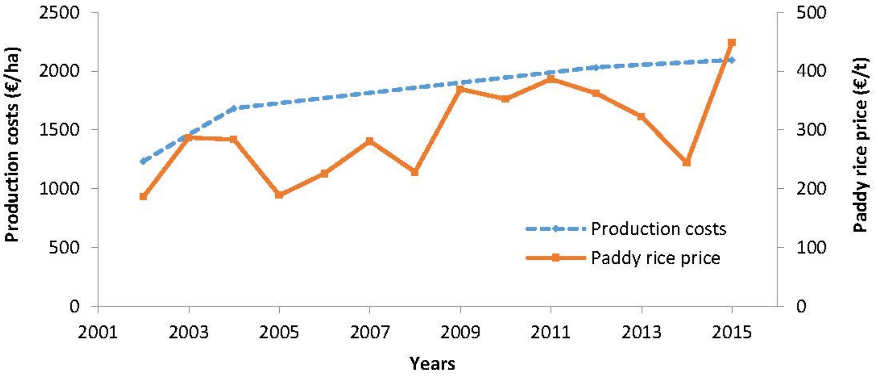


Figure 1. Trend of rice production costs [3] and paddy rice prices [13].

To find a more suitable solution for the Italian rice sector, it is necessary to evaluate the productivity and the economic efficiency of these strategies. The effectiveness of a production system can be assessed through the water productivity (WP), which is the ratio of the amount or value of product to the volume or value of water depleted or diverted. The study illustrated in [15] compared the WP of flooded, aerobic and AWD conditions and observed an increase in the index when water management alternatives were applied because of a higher reduction of water inputs with respect to the yield reduction. Similarly, the WP of aerobic rice, higher than that of flooded rice [9,10], suggests that this agrosystem can be considered as an adapted solution to water scarcity. However, water productivity does not provide any information about the economic effects of decreased water use. Consequently, it is important to also consider the economic water productivity (EWP) [16,17], which defines the production value per unit of water used.

The objective of this study is to explore the effect of different water management methods in paddy rice fields in northern Italy by evaluating their agronomic productivity and economic performances. Field experiments were carried out using traditional and modern varieties under irrigated and alternately irrigated conditions.

2. Materials and Methods

2.1. Experimental Sites

The field experiments were carried out in two rice research centers in the western Po Valley: The Rice Research Center (RRC) of Ente Nazionale Risi at Castello d'Agogna (Pavia province, Lombardy region) and the Rice Research Unit (RRU) in Vercelli (Piedmont region), which belong to the Council for Agricultural Research and Economics.

2.2. Experimental Design and Treatments

The RRC carried out the experiments during four growing seasons (2011 to 2014), using a split-plot design with water management as main plot factor and variety as sub-plot factor [18]. Each water management modality was allocated in two plots, of size 20 m × 80 m each as described below:

1. Standard condition of rice cultivation (referred as standard): broadcasted rice is sown into the water, the field is then continuously flooded;
2. Irrigated condition (irrigated): rice is sown into dry soil, and the field is submerged at the three to four leaf stage;
3. Alternately irrigated condition: rice is sown in rows into dry soil. Irrigation is then applied intermittently, when soil water potential reaches the limit of −30 kPa at 10 cm depth at RRC and −30 kPa at 30 cm depth at RRU.

Four varieties (Baldo, Selenio, Gladio and Loto) were allocated in subplots of size 2.5 m × 10 m within each main plot. In the following, they will be referred as traditional as they were released in Italy in 1977, 1987, 1998 and 1998, respectively.

The RRU carried out four experiments during two growing seasons (2012 and 2013), in two water management modalities (irrigated and alternately irrigated). Each modality was replicated only once per season. Within one season, the two fields were divided in small plots of size 1.33 m^2 (1.9 m × 0.7 m) to evaluate a diversity panel of 284 varieties released from 1904 to 2012 (90 of which were Italian, including the four traditional varieties grown at RRC). All trials used a completely randomized design with three plots per variety.

2.3. Water Balance Monitoring

At the RRC experimental site, elements of water balance were continuously monitored by an integrated multi-sensor system [19,20]. The values obtained for the standard, irrigated and alternately irrigated conditions were respectively 2270 mm, 1760 mm, and 680 mm [18]. At the RRU site however, detailed measurements of circulating water volumes were lacking, thus we will use the values measured at the RRC site.

2.4. Phenotyping

At RRC, grain yield (tons ha^{-1}) was estimated on the basis of 14% moisture content. It was the only trait used for this site. At RRU, several traits were measured including yield, yield components (panicle number and 50-panicle weight), and other traits (height, earliness) and less correlated traits (grain format).

3. Water Productivity and Economic Water Productivity

Water productivity is the amount of grain produced for each volume of water used, which can be taken as evapotranspiration, irrigation, or irrigation and rainfall. For the purpose of this study, rainfall and irrigation are considered as the only water volume. Thereby, *WP* is defined as:

$$WP = \frac{Y}{TWU} \tag{1}$$

WP is expressed in kg m^{-3}, Y is the yield (tons ha^{-1}), and *TWU* is the total water used (mm).

A high reduction of available water may affect crop productivity and reduce yield, with important consequences on farmers' incomes [16]. Thus it is important to evaluate the economic impact of a reduction of irrigation water relative to the economic water productivity, *EWP* (€ m^{-3}) [21] defined as

$$EWP = \frac{HV}{TWU} \tag{2}$$

where *HV* (€/ha) is the harvest value. A five-year mean [22] was used to evaluate rice prices in order to reduce the impact of price volatility that characterizes the rice sector (Figure 1).

To go further on the economic analysis, it is possible to evaluate the Economic Water Productivity Ratio (*EWPR*) [23–25] where *IWC* (€) is the irrigation water costs

$$EWPR = \frac{HV}{IWC} \tag{3}$$

4. Results

4.1. Agronomic Performances of Traditional and Modern Varieties Using Three Water Management Methods

First, Table 1 shows the results for yield, yield components and water productivity (WP) per site, varietal group and water management condition. In both sites, rice production was significantly reduced when using the alternately irrigated method. Yield differences between modern and traditional varieties were not significant for any condition. However, the groups differed in terms of height and yield components, especially when comparing the two largest groups (63 and 23 varieties). Thus, modern varieties were, on average, smaller and produced more panicles. The amount of water used in the alternately irrigated condition was more than two times lower than the amount used in the irrigated condition. Therefore, a higher productivity was observed in the alternately irrigated condition.

Table 1. Yield components and water productivity (WP) under three water management methods and three groups of Italian varieties in in the western Po Valley (Italy).

Site	Varietal Group	Water Management	Total Height (cm)	Panicles Number/m	50-Panicles Weight (g)	Yield (t ha^{-1})	WP (kg·m^{-3})
RRC	4 Traditional Varieties [1]	Standard	-	-	-	9.7 ± 0.3	0.43
		Irrigated	-	-	-	9.3 ± 0.4	0.53
		Alternately irrigated	-	-	-	7.6 ± 0.4	1.12
RRU	4 Traditional Varieties [1]	Irrigated	81.6 ± 4.6	92.9 ± 11.3	169.9 ± 17.6	11.8 ± 1.3	0.65
		Alternately irrigated	69.5 ± 4.6	87.4 ± 11.5	128.7 ± 17.9	8.0 ± 1.4	1.27
	63 other Traditional Varieties [2]	Irrigated	94.3 ± 1.2	85.3 ± 2.9	183.4 ± 4.5	11.7 ± 0.3	0.63
		Alternately irrigated	84.2 ± 1.2	80.3 ± 2.9	137.8 ± 4.5	8.1 ± 0.3	1.29
	23 Modern Varieties [3]	Irrigated	80.3 ± 1.9	91.2 ± 4.8	160.8 ± 7.4	11.1 ± 0.6	0.66
		Alternately irrigated	70.0 ± 1.9	92.5 ± 4.8	126.7 ± 7.5	8.8 ± 0.6	1.18

[1] Baldo, Gladio, Selenio, Loto; [2] Sixty-three varieties released from 1904 to 1998; [3] Twenty-three varieties released from 1999 to 2012.

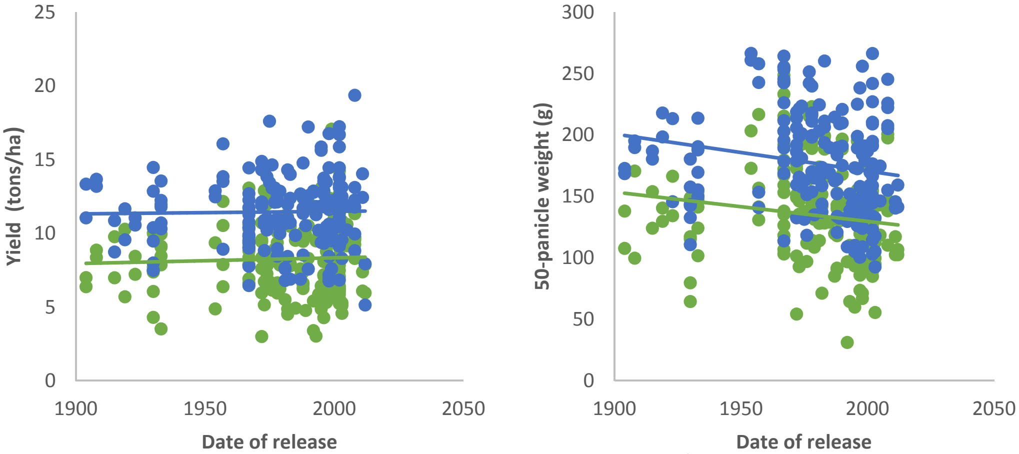
4.2. Evolution Trends of Italian Varieties Cultivated in Irrigated and Alternately Irrigated Conditions

Table 2 investigates further the evolution trend of Italian varieties over time. It shows a linear trend for all yield components. The most important information is that the trend seems to not differ between water management methods (slope of the same magnitude). However, the linear trend represented only a fraction of the phenotypic variation among varieties. Phenotypic variation between varieties as a whole was high, including for yield and in both water management methods (Figure 2).

Table 2. Evolution trend of Italian varieties over time evaluated at the Rice Research Unit in Vercelli (Piedmont region, Italy). Mean yield and mean yield components of 90 varieties are regressed on the respective date of release.

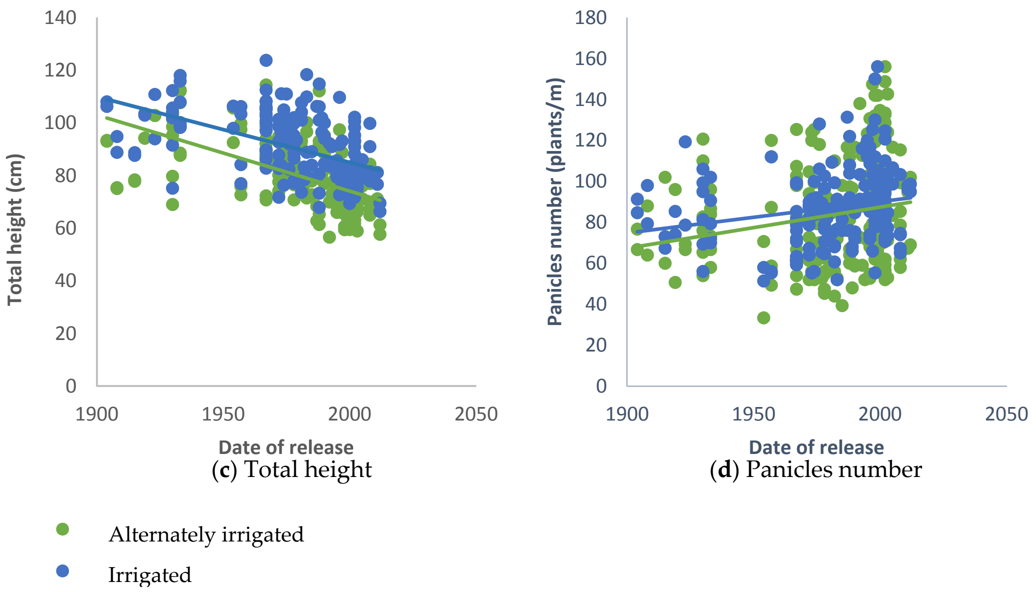
Trait	Water Management Method	Regression Slope [1]	Unit
Total height	Irrigated	−0.274 *** ± 0.030	cm/year
	Alternately irrigated	−0.289 *** ± 0.031	
Panicles number	Irrigated	0.224 ** ± 0.066	panicles/year
	Alternately irrigated	0.200 ** ± 0.067	
50-panicles weight	Irrigated	−0.383 ** ± 0.114	g/year
	Alternately irrigated	−0.239 ** ± 0.115	
Yield	Irrigated	0.005 ^{NS} ± 0.007	tons/year
	Alternately irrigated	0.004 ^{NS} ± 0.007	

[1] F test (*: significant at p = 0.05, **: significant at p = 0.01, ***: significant at p = 0.001, NS: not significant) and confidence interval.



(**a**) Yield (**b**) 50 panicles weight

Figure 2. *Cont.*



(**c**) Total height (**d**) Panicles number

Figure 2. Distribution of varietal means (90 varieties) along the date of release for irrigated (**blue**) and alternately irrigated (**green**) conditions for (**a**) Yield, (**b**) 50 panicles weight, (**c**) Total height, (**d**) Panicles number.

4.3. Sources of Phenotypic Variation among Italian Varieties

The analysis of variance (Table 3) quantifies the amount of variance associated with varieties, water management methods, as well as their interaction. The model was based on varietal means within each trial (season × water management combination) and explained 45% to 95% of the total variation. Tests were constructed using the season effect as the residual. The total height and 50-panicle weight were known with high precision (high R^2 and low CV). Both main factors were very highly significant for all traits, except the number of panicles. Any interaction was detected, meaning that the varieties' ranking did not change from one water management method to another.

Table 3. Sources of phenotypic [1] variation for yield and yield components of 90 Italian varieties evaluated at the Rice Research Unit (Vercelli, Piedmont region, Italy).

		Total Height	**Panicles Number**	**50-Panicles Weight**	**Yield**
	R^2	0.95	0.45	0.85	0.70
	CV	4.86	28.4	15.4	22.7
Source of variation					
Variety		***	*	***	***
Water management		***	NS	***	***
Variety × water management		NS	NS	NS	NS

[1] Significance level of F test: *: significant at $p = 0.05$, ***: significant at $p = 0.001$, NS: not significant.

4.4. Economic Analysis of the Agrosystems

Table 4 shows the economic analysis of gain and production costs for each condition and each type of variety. We noticed that for the alternately irrigated condition, production cost (PC) and irrigation water cost (IWC) were higher for the alternately irrigated condition, due to the additional hours of work and herbicides linked to the alternately irrigated management. The harvest value and net incomes were higher for the irrigated conditions. The EWP was higher for the alternately irrigated condition whereas the EWPR was lower for the irrigated conditions.

Table 4. Economic balances of the varietal groups cultivated in three water management methods.

Site	Varietal Group	Water Management Condition	HV (€/ha)	PC (€/ha)	IWC (€/ha)	NI (€/ha)	EWP (€/m^{-3})	EWPR (-)
RRC	4 traditional varieties [1]	Standard	2 920	2 059	253	861	0.130	11.5
		Irrigated	2 799	2 064	293	735	0.160	9.6
		Alternately irrigated	2 288	2 114	343	174	0.340	6.7
RRU	4 traditional varieties [1]	Irrigated	3 251	2 064	293	1187	0.180	11.1
		Alternately irrigated	2 348	2 114	343	234	0.350	6.8
	63 other traditional varieties [2]	Irrigated	3 335	2 064	293	1271	0.197	11.8
		Alternately irrigated	2 645	2 114	343	531	0.357	7.08
	23 modern varieties [3]	Irrigated	3 483	2 064	293	1419	0.189	11.4
		Alternately irrigated	2 429	2 114	343	315	0.389	7.7

HV: harvested value; PC: production cost which includes IWC; IWC: irrigation water cost; NI: net income. [1] Baldo, Gladio, Selenio, Loto; [2] Sixty-three varieties released from 1904 to 1998; [3] Twenty-three varieties released from 1999 to 2012.

The economic analysis in Table 5 shows that the five most productive varieties in the alternately irrigated condition obtained a higher harvest value than all the varieties cultivated in the irrigated condition. Therefore, NI and EWP were also higher for these five varieties, and the EWPR was nearly the same for both conditions as the higher harvest value compensated the IWC value of the alternately irrigated condition.

Table 5. Economic balances of the 90 Italian varieties in irrigated conditions and the five most productive varieties in the alternately irrigated condition evaluated at the Rice Research Unit (Vercelli, Piedmont region, Italy).

Site	Varietal Group	Water Management Condition	HV (€/ha)	PC (€/ha)	IWC (€/ha)	NI (€/ha)	EWP (€/m^{-3})	EWPR (-)
RRU	90 Italians varieties	Irrigated	3409	2064	293	1345	0.193	11.63
	5 most productive Varieties in Alternately irrigated condition	Alternately irrigated	3980	2114	343	1866	0.600	11.6

5. Discussion

This study shows that moving from irrigated to alternately irrigated conditions increases the total production costs. We can also see that the varieties actually cultivated are not adapted to a situation of water scarcity.

First of all, the yield between the modern and traditional varietal groups did not differ significantly but the variation was higher within each group.

It varied only between the water management methods with a higher production for the irrigated conditions. However, a significant reduction of irrigation water was observed for the alternately irrigated condition, inducing higher water productivity. This is in accordance with the data of [26], which reported water savings of 23% under AWD with a yield reduction of only 6%. In another study, [27] showed that AWD induced a reduction of water input of 50%, with a consequent increase in the WP. In many Asian countries, agronomic practices for growing rice provide puddling before sowing with the objective of the disruption of its structure. These operations lead to greater compaction of the soil which results in a reduction of water losses by percolation, and therefore it leads to an increase in the efficiency of irrigation and WP. The situation is different in southern Europe, where puddling is not applied.

Calculation of the EWP shows that the alternately irrigated condition is the economically more efficient method because the water volume is sufficiently low to permit a cost-effective production. The calculation of EWPR shows a higher value for the irrigated conditions, suggesting that the production increase is high enough to cover the IWC. These results agree with the values of NI obtained.

We noticed differences in PC and IWC due to weeding interventions and the number of irrigation cycles associated with each management method. For the standard and irrigated conditions, the differences in field management are very low, as they differ only in the moment of the first field irrigation. Nevertheless, water supply fee set by the Water Use Association (WUA) of the study area depends on the irrigated area and not on the water volume; the water supply costs are thus the same for all methods, despite a large difference in the irrigation water volume used. In Italy, the watering contribution cost is independent from the water amount applied. It should be evaluated considering the size of the areas that have to be irrigated or the volume of water used, as each irrigation method requires a different volume of water, but this contribution depends on the water policies of each country. In the Ebro delta in Spain, the irrigation contribution is dependent on the quantity of water used [28]. In this case, the reduction of irrigation water can also reduce the cost of rice production. In the case of northern Italy, the cost of the watering contribution should be adapted to each water management method.

In Italy, some farmers already practice rice cultivation under alternate irrigation, e.g., in Pavia [29] where other high-water-demanding crops are cultivated, such as maize, farmers alternate rice field irrigation. Water scarcity would also impact other sectors. Indeed, a part of the water managed by the Water Use Association (WUA) is used to supply hydroelectric stations and another part is used to produce potable water for the district towns. However, the actual yield level of varieties used in alternate irrigation does not reach the levels obtained in continuous irrigation conditions. To encourage farmers to use alternate irrigation, it is necessary to have adapted varieties, with yields equal to or higher than those of the traditional method. However, the two-season experiment carried out by the Rice Research Unit in Vercelli, based on a large diversity panel including 90 Italian varieties, did not allow us to highlight the specific adaptation to reduced irrigation. Furthermore, little is known about rice cultivation under alternate irrigation in Europe. Even with the increasing problem of climate change, water scarcity is not actually the main research subject and research activities are concentrated on other topics, such as rice diseases, e.g., infections by fungi [30], or grain quality [31]. In the panel of accessions studied here, the differences between varieties are significant. It was not possible to denote differences for yield when considering the mean production of the two main groups of varieties in each condition. However, some varieties can tolerate a situation of water scarcity. This was confirmed by the economic analysis of the most productive varieties in the alternately irrigated condition. Thus, these varieties can be exploited to produce a reasonable quantity of rice. This positive variability can also be exploited for rice breeding for adaptation to water scarcity.

6. Conclusions

The applicability of the different systems depends on many factors such as the availability of water, production costs, IWC and the varieties used. The genetic variability of these varieties has to be studied to breed for other adapted rice varieties that can produce the same quantity or more.

However, other factors may affect the the applicability of those systems. The irrigated system may lead to a competition of water availability with other crops such as maize during the irrigation period in June. Additionally, it would lead to a decrease in the recharge of the phreatic aquifer and therefore to the lowering of groundwater levels. As the availability of water depends on the groundwater depth, a conversion of flooded rice to alternate irrigated rice would result in lowering water savings. On the other hand, flooded rice cultivation can provide important ecosystem services such as the preservation of wetland habitats for a range of aquatic and semi-aquatic wildlife, or of the local traditional landscapes. Consequently, the applicability of these methods at a larger scale depends on the district of rice cultivation, and may be more profitable where rice is the monoculture.

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Author Contributions: Manel Ben Hassen performed technical experiments and phenotypic analyses, analyzed the data and wrote the manuscript; Manel Ben Hassen, Federica Monaco and Guido Sali conceived the study and developed the methodological approach; Federica Monaco and Guido Sali contributed to the writing; Giampiero Valè conceived the phenotypic evaluation part of the study at the Rice Research Unit and contributed to the writing; Arianna Facchi, Marco Romani and their respective staffs conceived and performed field experiments at the Rice Research Center. Arianna Facchi, Marco Romani contributed to the writing. All the authors read and accepted the final version.

Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

The following abbreviations are used in this manuscript:

RRC	Rice research center
RRU	Rice research unit
WP	water productivity, kg·m^{-3}
EWP	economic water productivity, €·m^{-3}
Y	Yield, t.ha^{-1}
TWU	Total water use, mm
CV	Coefficient of variation
HV	Harvest Value, €·t^{-1}
PC	Production cost
IWC	Irrigation water cost, €·ha^{-1}
EWPR	Economic water productivity ratio, dimensionless
WUA	Water use association

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