Irrigation water resource in a rice-growing area: economic evaluation under different pricing conditions*

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Abstract. *Water Framework Directive (60/20000/EC), in order to assign an appropriate cost to irrigation water resource, urges member states to introduce the concept of full cost and to adopt economic instruments to improve the efficiency of its allocation. The option to apply a volumetric supply fee promoting the rationalization of the resource, could thus play a role in addressing emerging and future problems of water scarcity.*

The study aims to evaluate economic performances of farms and estimate water irrigation costs in a typical Lombard rice-cultivated area through a simple non-linear programming model. It returns the current structural features of farms, their productive inputs and performances. Secondly, different scenarios are considered, related both to a different water government, in terms of price, quantity and distribution method, and crop water requirements; in this way it is possible to analyze the observable consequences on supply and compare the output data of different scenarios.

Obtained results allow to identify critical points in water management and incentivize interventions for a better resource allocation, and their evaluation represents a useful instrument for supporting future policies on water resource.

Keywords: full cost, scenario analysis, pricing methods

Introduction

Water represents a fundamental element for all sectors of economic, social and environmental interest. Particularly in agriculture, it plays undoubtedly a key role as a fundamental productive input for the conduction of all the related activities, in arid and semi-arid regions and temperate ones, as well. In the former, water allows to obtain a sufficient crop production, while in the latter to maintain yields at high levels, reducing the risk of loss of the product[0][2][3]. However, in relation to several emerging issues, its importance is increasing, even in such areas where water availability for the primary sector has not traditionally been limiting. Also for irrigated agriculture, in fact, a quantitative reduction of the resource is occurring, due to global phenomena of climate change[4], to an increasing population and to a rapid urbanization, which are emphasizing the conflict of use of water among different sectors, as a result of an increasing demand on the part of each of them, and exacerbating the effects of decreased usability[5]. Water scarcity in agriculture is the becoming a significant issue and it has inevitably repercussions both on productive and economic performances of farms, modifying in long-term period their competitiveness and burdening on their possibility in continuing the activity. Along with water scarcity, and as a possible strategy to face with it, also the need of reducing the wastes of the resource has to be considered. Water as an economic asset with limited availability[6] is to be protected through promoting an efficient and equal use of it, which is possible only by the attribution of a fair price. The estimation of water irrigation costs is then a significant topic with an important role in supporting regulations about water and allows decision makers to make aware choices to face water shortages.

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The cost of the resource

Water Framework Directive (WFD) 60/2000/EC[7] emphasizes the allocation of a fair price for irrigation water and calls on member state to the introduction of the so-called "*full cost*" (figure 1), which, taking into account financial, opportunity and environmental costs, could represent the practical application of the "polluter-pays principle": it ensures that the end user pays a price high enough to recover all the costs arising from the use of water, and its adoption reduces wastes and non-virtuous behaviours caused by an underestimation of the resource.

Environmental costs not related to water	Environmental costs (external)	Economic costs
Environmental costs related to water		
Opportunity costs (scarcity)	Cost of the resource (external)	
Other direct costs	Financial costs (including environmental and opportunity costs already internalized)	
Administrative costs		
Capital operating and maintenance costs		

Figure 1. Structure of the full cost ([8], modified)

In agriculture applied fees are much lower than those hypothesized by regulatory and this could lead to an increase of irrigation costs; then, paradoxically, the farmer, as the end user of the resource, would be in the condition of having less water at a higher cost; therefore this situation would not be sustainable from the farmers' point of view. In order to achieve a sustainable use of the resource, different modalities for the delivery of water service can be adopted by the suppliers. Pricing and fees differ according to their efficiency in promoting a more rational use of irrigation water. A fixed fee set per irrigated or irrigable hectare (€/he) tends not to encourage such practices, but is relatively easier to adopt and may in some cases represent the most recommended solution[9]; volumetric fees, instead, determine a more aware use of water, but could have unit costs much lower than the actual cost of the resource. WFD suggests using preferentially a volumetric rate, as it would represent an economic instrument able both to reduce water consumption and cover all the costs of water service. It represents a more transparent and efficient[10] method of pricing, since it is based on water quantity actually supplied. As several studies have already demonstrated[11][9][12], a different tariff level, a different pricing and the increase of irrigation water cost influence farmers' choices, and lead to a significant reduction of water consumption, at the expense of withdrawals from wells and private water sources, as well as the need for management and/or productive changes; but these strategies, such as a reduced irrigated area, crop diversification towards less water-demanding crops, an increase in the efficiency of distribution and a different method of water application, can finally result in a significant decrease in farm income.

Moreover, some authors consider the use of incentives not encouraging good behaviours and the assignment of a political price to water service supply an inefficient management system, not stimulating a proper use[13], but efficient pricing, as well, may determine undesirable effects on farmers' decisions or environmental implications not immediately anticipated. In district of ancient irrigation, such as rice-cultivated areas in Northern Italy, environmental aspects also related to multiple use of the resource must be considered[14]: even though water distribution techniques are technically inefficient and characterized by huge losses due to filtration, the complex system and water network developed over the centuries, has allowed the creation of valuable paranatural aquatic environments. Even in these areas with high natural and environmental value the quantification of environmental costs is something difficult[15], leading to an uncertain estimation of full cost.

Finally, it must be considered that irrigation water value is strictly linked to that of agricultural production it contributes to. Consequently, a higher water cost inevitably reflects on water use efficiency and productivity[16][17][18], an increase of which could represent a further way to achieve an efficient use of water.

Modeling for irrigation water management

A valid support to policy makers and to decisional processes lies in the results of appropriate tools, such as mathematical programming models. They provide information not directly observable and allow simulations of different scenarios related to changes in agricultural policies, resource management or market development, and can guide decision makers towards the identification of the most suitable interventions to achieve economic and environmental targets of water policies.

Economic analysis of irrigation water are based on the formalization and implementation of both econometric and programming models, at different scales and levels (farm, local, regional). Among them the regional level is able to answer the requirements of WFD, which states that catchment area is the unit for the analysis and the integrated management of water resources.

The econometric approach, based on less informative inputs, has demonstrated on several occasions the possibility to estimate a function of operating costs of water distribution, in irrigation districts and consortia[19][20][21][22]; more often the economic analysis of irrigated agriculture is realized through the application of linear programming models (mono-objective, multicriteria, stochastic discrete) to evaluate the impacts derived from alternative conditions, both internal and external to the system: each simulation generates a new solution showing the effects of the changes themselves on crops, technological choices, use of productive inputs, economic performances of farms[19][20][21][22][23][24][25][26][27]. However, these models require the collection and procession of a large amount of economic and productive data and information; even though they are useful to understand the features of agricultural system by identifying relationships between the use of inputs and productive levels, their results strongly depend on the constraints imposed on the model.

In the same context the Positive Mathematical Programming (PMP)[28][29] is recently spreading. This new approach requires a limited amount of data used to perfectly calibrate the model for the reference period, according to three main phases: - specification of a linear programming model that uses all the information available, - reconstruction of a total variable cost[30], - formulation of a non-linear programming model to be used to perform simulations. Its application for water resource analyses is, however, currently underdeveloped. In this regard, it recalls the work of Blanco, Iglesias and Sumpsi[31] in which is considered the impact of pricing policies on two irrigation districts in Spain by specifying a cost function for each of them, and what Cortignani and Severini[32][33] have developed in relation to territorial analysis, also following the introduction of tariffs differentiated depending on the season.

These models can be used to face issues related to the variation in the cost of the water and its availability, but the possibility of analyze future scenarios is limited, since they do not allow to consider new and different production activities compared to the reference situation.

Aims and analysis methodology

The paper aims to identify and implement a mathematical programming model, in order to get to an economic evaluation of irrigation water resource in a rice-cultivated area in Lombardy, Northern Italy, characterized by peculiar uses of the resource itself and particularly suited for this analysis.

Data collection has been carried out through direct surveys at sample farms and using results of *ad hoc* experimentations conducted in an experimental farm in the same area (activities related to BIOGESTECA project).

The selection of rice-growing farms operating in the district started from their extraction from the regional database SIARL (*Sistema Informativo Agricolo della Regione Lombardia*), their classification on the basis of Utilized Agricultural Areas (UAA) of rice and the sampling within each class. To each farm a specific questionnaire requiring information about the crop year 2010-2011 was submitted and filled through direct surveys to farmers, for a total of 19 surveys carried out and a total rice-cultivated area of 808.5 hectares.

Data have then been elaborated to describe the features of the system and used for the identification and implementation of a model, returning current economical and productive conditions of farms. In order to evaluate the effects of new managerial and/or productive strategies on cultivated areas (possible reduction of the irrigated area, crop diversification, increase of the distribution efficiency and different method of water provision), it has also been used to make scenario analysis, related to a different pricing system.

Case study area: main features

The case study area is located in a typical rice-growing district in Lombardy, i.e. the so-called Lomellina (figure 2), and in particular around San Giorgio di Lomellina (PV).

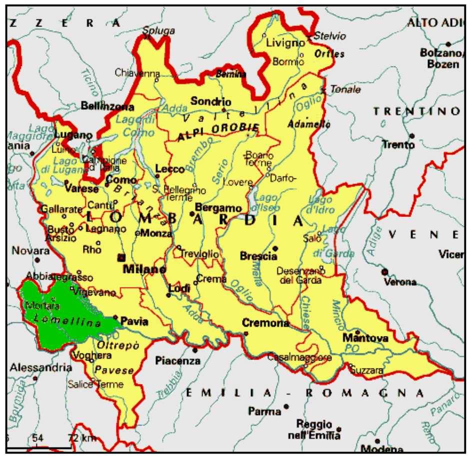

Figure 2. Case study area (www.infolomellina.net)

Agriculture in the district is mainly dedicated to rice, with a marginal portion for other arable crops, such as corn and soybean, and poplar. Consortium Est Sesia derives water from Cavour Canal, Arbogna River and leakages and provide it to farms, even though there are supplies from private sources. Distribution of water is mostly continuous and, for a less part, it refers to pre-established rotating shifts. To both cases corresponds the same product but different cultivation strategies, as shown in table 1.

Table 1. Different managerial typologies on rice-fields: general characteristics

<table>
<tr><th>Crop type code</th><th>Water dispensation</th><th colspan="2">Water management</th><th>Agronomic management</th><th>Farms (n.)</th><th>% UAA</th></tr>
<tr><td>CFW</td><td rowspan="2">Continuous</td><td rowspan="2">Continuous flooding. Water flows continuously for the whole duration of the crop cycle.
Submersions are interrupted by 3 or 4 dries in correspondence of certain phases of the cycle or treatments with herbicides or fertilizers.</td><td rowspan="2"></td><td>Water-seeding after the submersion of the field</td><td>10</td><td>50.63</td></tr>
<tr><td>CFS</td><td>Soil-seeding; the ground remains dry until the rice has reached the stage of 4^{th}-5^{th} leaf, then it is restored the normal regime of submersion</td><td>5</td><td>8.95</td></tr>
<tr><td>SCFW</td><td rowspan="4">Rotating shifts</td><td rowspan="4">Intermittent flooding. Water is available continuously only during predefined shifts.</td><td rowspan="2">Continuous flooding during the shift</td><td>Water-seeding after the submersion of the field</td><td>1</td><td>8.02</td></tr>
<tr><td>SCFS</td><td>Soil-seeding before the first irrigation</td><td>2</td><td>10.02</td></tr>
<tr><td>SIW</td><td rowspan="2">Flowing irrigation, trying to maintain water on the ground until the next shift</td><td>Water-seeding after the first irrigation</td><td>1</td><td>0.47</td></tr>
<tr><td>SIS</td><td>Soil-seeding before the first irrigation</td><td>6</td><td>21.91</td></tr>
</table>

According to experimentations conducted, crop production is linked to water and agronomic management, since differences among yields exist (table 2).

Table 2. Average yield for each crop type

Crop type	Yield (tons/he)
CFW	9.72 a
CFS	8.33 b
SCFW	9.72 a
SCFS	8.33 b
SIW	7.81 b
SIS	7.81 b

The estimation of water supplied indicates the traditional method as the most requiring for the resource, while differentiation of sowing techniques shows a lower overall water consumption for soil-seeding (table 3). At the same delivery typology, the determining factor increasing water consumption is the resource management typology during the growing season. Water quantity seems, then, to affect yields, suggesting that lower provision and availability causes a lower production.

Table 3. Seasonal water consumption and water flow for each crop type

Crop type	Water consumption (m^3/he)	Water flow (i_c) ($l * s^{-1} he^{-1}$)
CFW	22,711.6 ± 1,695.9	2.4
CFS	20,841.8 ± 114.3	2.4
SCFW	17,074.8 °	1.5
SCFS	13,073.4 ± 84	1.5
SIW	907.2 °	1.5
SIS	5,475.6 ± 6,344.2	1.5

° only one data available

The model implemented

For an economic evaluation of irrigation water in the district a simple non-linear programming model has been developed.
Decisional variable set in simulations is the rice-growing area ($xcrop_{f,c}$) in each farm (*f* index) subject to irrigation according to the different ways of water supply and agronomic management (*c* index).
The objective function Z aims to maximize farm gross margins, as difference between revenues and costs, related both to cost of water supply and cost of water management[34] (table 4).
The *k-1*–degree equation related to water managing costs appearing in the model gives it the characteristic of non-linearity, justifying the use of the specific algorithm.
In particular Z takes the following form:

$$Z = \sum f,c \ \ ($$

$$(r * xcrop_{f,c} - 0.08 * (r * xcrop_{f,c} - 5{,}000))$$

$$+ (p * y_{f,c} * xcrop_{f,c})$$

$$-100/95 * ($$

$$((xcrop_{f,c} * (w + wc * i_c * 3.6 * dur_{f,c}))$$

$$+ (m_f * ((n * xcrop_{f,c} * hhat_{f,c})^{(k-1)}) * xcrop_{f,c} * hhat_{f,c}))$$

$$+ (xcrop_{f,c} * ((pwr_f/69) * (hhat_{f,c} * (9.4 * fp + 0.04 * op) + 7.65 * int_{f,c}))$$

$$+ (2 * l * xcrop_{f,c} * inttot_f)$$

$$+ (Vo_f * (((1 - Td))/ n))$$

$$+ (o * Vo_f))$$

Table 4. Elements of the implemented model

Total revenues	CAP subsidies	$(r * xcrop_{f,c} - 0.08 * (r * xcrop_{f,c} - 5{,}000))$ r contribution of 850 €/he, with allowance of 8% for the portion in excess of 5,000 €
	Sale of paddy-rice	$(p * y_{f,c} * xcrop_{f,c})$ *p* selling price (333.38 €/ton) (*Camera di commercio di Pavia, 2011*) $y_{f,c}$ crop yield (tons/he)
Total costs related to irrigation	**Water supply cost (€/year)**	
	Water supply cost	$xcrop_{f,c} * (w + wc * i_c * 3.6 * dur_{f,c})$ w current water supply fee (278.62 €/he) wc (€/mc) volumetric supply fee i_c ($l * s^{-1} * he^{-1}$) water flow supplied $dur_{f,c}$ duration of the irrigations
	Water management costs (€/year)	
	Maintenance and repair of technical means used for irrigation	$m_f * ((n * xcrop_{f,c} * hhat_{f,c})^{(k-1)}) * xcrop_{f,c} * hhat_{f,c}$ where $m_f = FR * Vo_f / D_f^{\,k}$ FR repair and maintenance factor (80%), V_o value of a new machine (70,000 €), n economic life of the machine (12 yrs), D_f physical life of the machine (12,000 hrs), k (-) exponent coefficient for repair and maintenance, equal to 1.9, $hhat_{f,c}$ working capacity of the pump used for irrigation (hrs/ha)
	Costs for consumables (fuel and oil)	$xcrop_{f,c} * (pwr_f/69) * (hhat_{f,c} * (9.4 * fp + 0.04 * op) + 7.65 * int_{f,c})$ pwr_f power of the tractor machine used for irrigation (kW), $hhat_{f,c}$ working capacity of the pump used for irrigation (hrs/ha), fp fuel price (0.8 €/kg), op oil price (3.5 €/kg) $int_{f,c}$ number of irrigation interventions during season for each crop type
	Labour costs	$2 * l * xcrop_{f,c} * inttot_f$ l hourly labor cost (€/h), set equal to 15 €/h $inttot_f$ total number of irrigation interventions during season
	Share of deterioration of the machine used for irrigation	$Vo_f * (((1 - Td))/n)$ V_o value of a new machine (70,000 €), Td depreciation rate (-), equal to 0.125, n economic life of the machine (12 yrs),
	Various expenses (shelter and surveillance for machinery, taxes, insurance)	$o * Vo_f$ V_o value of a new machine (70,000 €), o coefficient of various expenses (-), equal to 0.025

Z is subjected to two main farm-level and consortium-level constraints regarding land and water. Land balance ensures that no more land than the total available in each farm is cultivated (1.) and that cultivated areas still maintain the same water dispensation, continuous (2.a) or not (2.b):

$$\sum_c xcrop_{f,c} \leq land_{f,c} \tag{1.}$$

$$\mathrm{xcrop_{f,CFW}} + \mathrm{xcrop_{f,CFS}} \leq \mathrm{a_{f,CFW}} + \mathrm{a_{f,CFS}} \tag{2.a}$$

$$\mathrm{xcrop_{f,SCFW}} + \mathrm{xcrop_{f,SCFS}} + \mathrm{xcrop_{f,SIW}}\ \mathrm{xcrop_{f,SIS}} \leq \mathrm{a_{f,SCFW}} + \mathrm{a_{f,SCFS}} + \mathrm{a_{f,SIW}} + \mathrm{a_{f,SIS}} \tag{2.b}$$

Water balance ensures that water flow resulting from the model is not higher than those currently provided by the consortium (i_c) estimated by the experimentations and differing for each water dispensation (see table 3):

$$\sum_c \mathrm{i_c} * \mathrm{xcrop_{f,c}} \leq \sum_c \mathrm{i_c} * \mathrm{a_{f,c}}$$

Scenario analysis

A scenario analysis has been then performed.
The first condition (scenario #0) applies the maximization to available data. In a further scenario (scenario #1), a volumetric fee replaces the current one, that is a fixed fee per hectare, *ceteris paribus*. This phase has required a preliminary step to determine the volumetric fee level (in €/m^3) to be then applied to the objective function above. A further equation has been defined to find the limit of the fee for which there is a change in water management. This approach started from setting the equivalence between known and unknown values of cultivated areas, leading to the introduction of a further variable *tv* replacing the previous parameter *wc* (3.); more suitable constraints have then been defined (from 4. to 10.)

$$\sum_c(-xcrop_{f,c} * (w + tv * i_c * 3.6 * dur_{f,c})) = \sum_{f,c}((r * xcrop_{f,c} - 0.08 * (r * xcrop_{f,c} - 5{,}000) + (p * y_{f,c} * xcrop_{f,c}) - 100/95 * (\left(\left(xcrop_{f,c} * \left(w + wc * i_c * 3.6 * dur_{f,c}\right)\right) + (m_f * ((n * xcrop_{f,c} * hhat_{f,c})^{(k-1)}\right) * xcrop_{f,c} * hhat_{f,c})) + (xcrop_{f,c} * (pwr_f/69) * (hhat_{f,c} * (9.4 * fp + 0.04 * op) + 7.65 * int_{f,c})) + (2 * l * xcrop_{f,c} * inttot_f) + (Vo_f * ((1 - td)/n)) + ((o * Vo_f)) \tag{3.}$$

$$\sum_c xcrop_{f,c} \leq land_{f,c} \tag{4.}$$

$$xcrop_{f,CFW} = a_{f,CFW} \tag{5.}$$

$$xcrop_{f,CFS} = a_{f,CFS} \tag{6.}$$

$$xcrop_{f,SCFW} = a_{f,S\,CFW} \tag{7.}$$

$$xcrop_{f,SCFS} = a_{f,SCFS} \tag{8.}$$

$$xcrop_{f,SWS} = a_{f,SWS} \tag{9.}$$

$$xcrop_{f,SIS} = a_{f,SIS} \tag{10.}$$

Finally, referred to all conditions analyzed, economic and productive parameters have been recalculated (respectively scenarios #0.1 and #1.1). In particular:
- *Total costs and revenues*, as described in table 4;
- *Water cost*, or the price of irrigation water (PU, in €/m^3), as the ratio between costs and water available to farm:

$$PU\ [€/m^3] = \text{costs / irrigation water}$$

-*Water productivity (WP)*. It is defined as the ratio between total yield (in tons) and its water consumption (m^3) during season due to evapotranspiration[37][38], but we have calculated it as yield compared to total amount of water used during watering season, not considering line losses, namely the amount potentially distributed each year according to the available resource:

$$WP\ [g/kg] = \text{total yield / water consumption} * 1000$$

In addition, it has also been considered the *economic crop water productivity (EWP)* based on the market value of the crop[35][36][37][38]:

$$EWP\ [€/kg] = \text{crop economic value / available water} * 1000$$

Results and comments

The model has been solved through the software GAMS[39][40] (General Algebric Modeling System), and has allowed the generation and display of a large amount of data output.
The model has returned information about current structural features of farms, their productive inputs and productive and economic performances of each of them and for every type of culture, allowing the comparison between farm and cultural types, homogeneous or not.

It is important to note that to SIW corresponds a very anomalous water consumption (see table 3) that would affect subsequent results and conclusions. Starting from this consideration and taking into account that it derives from only one observation and covers a very little portion of the total cultivated area (3.5 he), this category is no more considered in the following and results concern with a selection of crop typologies.

Optimal allocation of cultivated areas

Optimal allocation of cultivated areas in comparison with current conditions are shown in table 5, where *S1_ALL* represents the best solution if the anomalous value would be considered, while *S1_SELECTION* if it would not. The maximization of overall margin leads in any case to managerial and agronomic choices mostly far from what really applied.
Fixed fee per hectare doesn't seem to encourage water saving, since areas with continuous supply are suggested to be cultivated according to water seeding, that is more water requiring than soil-seeding, and those provided periodically shift to the most requiring method within the category (SCFW). In this case are brought down water management costs, rather than water supply ones. On the contrary, the adoption of a different pricing has more evident effects both on typology of water management and agronomic strategies: in relation to periodic irrigations water saving techniques are preferred. The opportunity to adopt dry or semi-dry cultivation is confirmed by previous surveys carried out in the same area: during the season 2004-2005 5.4% of the denounced rice-fields in S. Giorgio di Lomellina area were soil-seeded, and from 2008 so far this percentage is passed to almost 30%, with peak values of 37%[1]. The volumetric

[1]These results derive from a study carried out at the experimental farm of Centro Ricerche sul Riso (*Rice Research Center*) in Castello d'Agogna (PV), which pertains to Ente Nazionale Risi (www.enterisi.it).

fee hypothesized to be adopted, equal to 0.219 €/m^3, has also allowed to identify cost levels favoring different irrigation techniques: its application demonstrates that soil-seeding is generally not encouraged with a continuous supply and it would lead to the cancellation of gross margin for most of the farms provided continuously, as shown by the decrease in the percentage (26.89%), suggesting that the total price to pay would be too high to front the high water consumptions required. For these farms it would be then unsustainable the adoption of a volumetric fee.

Table 5. Cultivated areas for each crop type (% of UAA).

Crop type	Currently	Scenario #0	Scenario #1_all	Scenario#1_selection
CFW	50.31	58.76		26.89
CFS	8.45		23.27	
SCFW	8.18	41.24		
SCFS	10.22			39.85
SIW	0.48		76.73	
SIS	22.36			33.25

Economic results

Costs analysis

Fee type currently adopted links proportionally water supply cost to irrigated areas, independently from the amount of available water. However irrigation water supply costs expressed in a volumetric rate seem to contradict this affirmation, because the lower are costs, the higher is water consumption (table 6). So, paradoxically adopting productive and managerial water saving techniques seems to determine for farms increasing in supply costs, which in itself could mean, in the future, a change in farming systems; actually, the adoption of periodic irrigation is independent of the farmers' will; since the fee is set by consortium, whenever it was modified it would consequently affect these aspects.
If optimal allocation of cultivated areas occurs, it does not modify water supply costs. All these values are lower than those deriving from the application of a volumetric fee, which, both before and after the optimization are highest for a unite size.

Table 6: irrigation water supply cost (€/m^3), for each crop type in different cases analyzed

Crop type	Currently	Scenario #1	Scenario #0.1	Scenario #1.1
CFW	0.01	0.22	0.02	0.22
CFS	0.01	0.22		
SCFW	0.03	0.22	0.03	
SCFS	0.07	0.22		
SIW	0.61	0.22		0.22
SIS	0.19	0.22		

Total costs related to irrigation (table 7) differ each other according to operative procedures adopted by each farm during irrigation practice. Differences observed among each crop typology, are due to the fact that for farms not using technical means, the costs don't cover expenses related to tractors and operating machinery.

Table 7. Total costs (€/ha) related to irrigation in different scenarios

Crop type	Currently	Scenario #1	Scenario #0.1	Scenario #1.1
CFW	609.08	10,443.79	693.66	5,786.96
CFS	481.28	4,994.70		
SCFW	398.62	1,901.00	286.00	
SCFS	384.17	1,227.14		1,069.09
SIW	638.62	459.34		
SIS	578.62	977.63		658

In these cases higher outputs are due to an increased labor for periodic irrigations, a component that prevails on supply costs, as confirmed considering irrigation water cost deriving from total costs: a higher increase is, in fact, observable in correspondence of periodic irrigations (table 8).
Volumetric fee, instead, significantly increases costs both before and after optimization, leading to values higher for a unit size than those deriving for a fixed fee per hectare.

Table 8. Irrigation water cost (€/m^3) deriving from total costs, for each crop type in different cases

Crop type	Currently	Scenario #1	Scenario #0.1	Scenario #1.1
CFW	0.03	0.45	0.06	0.28
CFS	0.02	0.24		
SCFW	0.05	0.23	0.05	
SCFS	0.09	0.27		0.26
SIW	1.41	1.01		
SIS	0.40	0.42		0.46

Revenues analysis and water productivity

Pricing would not affect total revenues (in €/he), since they depend only on the amount of cultivated area; however very slight differences are observable among both crop types and scenarios (table 9), due to different yields and water flows.

Table 9. Revenues (€/he) for each crop type

Crop type	Currently	Scenario #0.1	Scenario #2.1
CFW	4,106	4,105	4,133
CFS	3,668		
SCFW	4,077	4,093	
SCFS	3,611		3,607
SIW	3,539		
SIS	3,456		4,558

Similarly, crop water productivity depends essentially on water management of the rice-paddy, and thus on seasonal water consumption. A different management is associated to an increase in the WP value: it is evident that higher values correspond to periodic irrigation. Finally, though independent from the price of the resource, slight deviations are observed if WP is calculated on areas optimizing margin (table 10).

Table 10: Water Productivity (kg/m^3) for each crop type in different scenarios

Crop type	Currently	Scenario #0.1	Scenario #1.1
CFW	430	430	480
CFS	400		
SCFW	570	570	
SCFS	640		640
SIW	8610		
SIS	288		329

Economic water productivity (WPec) shows the same trend as the previous, as they are perfectly correlated (figure 3).

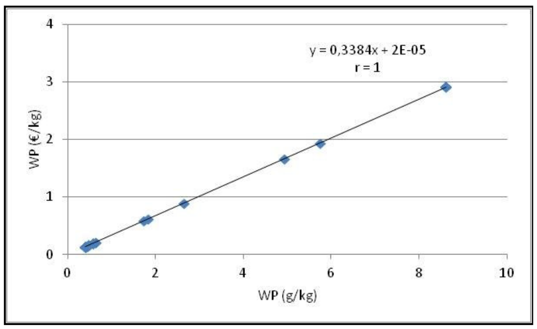

Figure 3. Relation between different WPs

Conclusions

In rice-paddy field the adoption of non-traditional managerial and agronomic techniques allows to achieve positive targets in terms of water saving and use efficiency, expressed by water productivity. From an economic point of view they do not modify substantially revenues of farms but affect their costs; in particular for dry cultivation, it could be necessary to increase workforce or labor per worker, which could lead to higher costs for manpower. The increase in water supply cost could also determine a better allocation of the resource.

However, field analyses and observations have to be replied, confirming (or not) preliminary results introduced. The quantification of each element of water balance in rice-field can determine a more precise estimation of water productivity, that could be used as a benchmark for different managerial typologies.

Moreover, for a complete evaluation of the system, it must be considered that the adoption of these strategies have to be also interpreted according to the consequences they may have on and within the system itself. It is in fact necessary to study in-depth all the environmental aspects of water saving. Soil-seeding flooding may lead to a lower water demand at the beginning of the season, that would increase gradually and show a peak when it has to satisfy the water requirements of other crops, with the advantage to ensure, operatively, the provision of the resource in exceptional cases, such as breakdowns of channels.

The possibility of the consortia suppliers in reducing the amount of water to farms, or increasing its cost (and then a decrease in demand), as well as a factor changing their managerial aspects and their farming systems could determine a less efficient allocation of the resource, affecting hydrological cycle on a local scale, interfering and changing the water returns to farms, surface water bodies and groundwater. In this sense changing irrigation method may result in a delay in the loading of the water table and it can occur a lowering in water table itself (in particular for dry cultivation).

Similarly, a higher technical and infrastructural efficiency able to reduce distribution losses can have implications in recharging and supplying of water sources, eliminating the potential benefits of reallocation, even if in many cases a large part of the water flow available to farms comes from internal recirculation, as a mean to contrast the reduction of the water demand. Finally a dry cultivation could affect paranatural aquatic environments created.

These important considerations must be properly taken into account in order to make a complete economic evaluation of water resource. In this sense it is then important to identify the best method for the estimation of environmental costs, since this step plays a key-role as a starting point towards the quantification of the *full cost,* that represents itself an crucial instrument in order to strength decisional support to policy makers.

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