The assessment of economic and environmental impacts of water use efficiency and farm practices through an economic and biophysical integrated model

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Abstract

We implement an integrated economic and biophysical model capable of assessing diverse scenarios of farm and water management practices at a basin scale. We show an application of the model to a particular basin in Uruguay, which is characterized by the importance of agriculture, in particular crop production, both rain-fed and with irrigation. We present a set of scenarios with different levels of water use efficiency, which seek to analyze the (avoided) consequences of water shortages on economic and environmental outcomes. Water use efficiency gains are the result increasing the frequency of channel maintenance in the basin. We find that the optimal frequency of irrigation channels maintenance is every 2 years, highlighting the potential benefits of implementing these farm practices, with direct consequences on water savings, maintaining the water quality outcomes and accompanied by the prospect of increasing crop production. Our model can be applied to other basins provided there exists a calibrated SWAT model.

Introduction

Irrigation is the main approach to mitigating the risk of insufficient moisture for agricultural crops. It is a key for food security, further economic development, and poverty alleviation, especially in developing countries. However, climate change is creating unprecedented challenges for irrigation. These include reduced availability of irrigation water, increased variability of how much water is available for irrigation, and more frequent and severe extreme weather events, like droughts (IPCC, 2022). These challenges are not only present in regions of the world that have traditionally been experiencing water stress and shortages, but also in regions that have relatively high rainfall and plentiful water resources (Zhao, 2023). Climate change is shifting rainfall patterns even in those regions, and we are now witnessing more frequent and more severe droughts in areas that have not experienced them previously, such as in northern Italy in 2022 (Bonaldo et al, 2022) and in Uruguay and Argentina in 2021-2023 (Neumann et al, 2023).

Due to this increased pressure on irrigation water availability, using irrigation water in a more efficient way becomes an important aspect of on-farm adaptation to climate change (Malek and Verburg, 2018). Reducing water losses in conveyance, delivery and application is probably the most straightforward way to improve efficiency of irrigation water use. Reduction in losses can be achieved by improved maintenance of irrigation canals that take the water to the fields where it is applied (Barkhordari and Shahdany, 2022). Irrigators could provide more maintenance of canals, but that involves significant costs (Huppert et al, 2003). On the other hand, the benefits from maintenance are often uncertain. It is difficult for irrigators to know how much water they will save by further investing in canal maintenance, and whether they will need that saved water as there might be sufficient water supply even in the absence of extra maintenance. In this light, investing in maintenance of irrigation canals is in itself a risky proposition, despite being one of the tools to manage the risk of water resource availability.

In this paper we model optimal behavior of an irrigator with respect to their maintenance of irrigation canals in an integrated assessment modelling (IAMs) framework, specifically considering irrigators attitude to risk. The IAM consists of integrating a hydrological model SWAT (Soil & Water Assessment Tool, version 2012) (Gassmann et al 2007; Neitsch et al. 2011) calibrated to a case study of river basin in Uruguay, with an economic model of optimal farmer's decision under uncertainty. The SWAT model enables us to estimate the hydrological effects of various levels of canal maintenance on availability of irrigation water under alternative weather conditions. This allows us to evaluate the expected benefits that the farmer can realize from additional investment in canal maintenance. The economic model takes these expected benefits, and combines them with the cost of investment in maintenance within an expected utility (EU) framework. The EU framework accounts for the various possible attitudes to risk that the farmer might have, and for the effect that these risk preferences have on the optimal investment in canal maintenance.

This type of IAM approach enables us to better understand how irrigators might respond to the increased challenges that climate change is imposing on water availability, and the role that risk, and irrigator's attitudes to risk are playing in determining those responses. This is important because it is often observed that farmers are not investing sufficiently in greater efficiency of natural resource use on farms (Huppert et al, 2003). Uncovering how risk, uncertainty and farmers' responses to them shape farmer behavior is critical for understanding how to best support adaptation to climate change in agriculture.

IAM is an interdisciplinary research tool used to analyze complex systems and to provide insights into how different components of these systems interact with each other (Polasky et el. 2019). IAM typically incorporates elements from multiple fields, including economics, engineering, ecology, hydrology, biology and social sciences, and are used to evaluate the potential outcomes of different policy or management actions in various scenarios. They can provide decision makers with a comprehensive understanding of the trade-offs and potential consequences of different actions, and can help inform decisions about how best to manage complex systems in a sustainable and equitable way.

Economic studies of water use and management have been increasingly using IAM to analyze problems that decisionmakers face and to derive optimal solutions to those problems. Many of these studies have used the SWAT model as a biophysical component, as this model is well suited to model hydrology, crop growth, and nutrient dynamics at a spatially explicit scale. Many of these studies focused on water quality problems related to agriculture. Evaluation of environmental policies targeting irrigated agriculture was discussed by Lee et al. (2012) in the case of a water catchment in Australia. The authors developed an integrated model that evaluated the economic and environmental impacts of different irrigation management practices on water quality. Liu et al. (2020) developed an integrated economic-hydrologic model of the Western Lake Erie Basin to evaluate the impact of best management practices and nutrient reduction on water quality. The model estimated the benefits of reducing nutrient loads on water quality and the potential economic benefits of improving water quality. Lupi et al. (2020) evaluated the link between agricultural nutrient pollution and the value of freshwater ecosystem services. The authors developed an IAM that estimated the economic value of different ecosystem services provided by freshwater systems and evaluated the potential benefits of reducing nutrient loads on water quality. Panagopoulos et al. (2014) assessed the cost-effectiveness of irrigation water management practices in water-stressed agricultural catchments.

In the context of Uruguay, where our study region is located, the IAM using SWAT has been growing rapidly over the last ten years. Mer et al. (2020) proposed a multi-institutional approach to use SWAT model scenarios in Uruguay. The authors suggest that a multi-institutional approach that includes farmers, researchers, and policymakers is necessary to build trust in modelling scenarios and promote sustainable water management practices. Souto et al. (2021) assessed the impact of agricultural intensification on water pollution in the San Salvador Basin in Uruguay. The authors developed an integrated model that evaluated the impact of different land management practices on water quality and the potential economic and environmental benefits of improving water quality.

In the current paper, we explicitly consider producers' attitudes to risk, which has been a subject of voluminous literature. Chavas and Shi (2015) analyzed the economic impact of risk, management, and use of agricultural technology on agricultural production. The study used an econometric model to examine how these factors affect production and found that risk aversion, management, and technology have significant impacts on agricultural production. The authors suggest that a comprehensive risk management strategy considering both market and production risks is necessary to achieve sustainable agricultural production. Gandelman and Hernández-Murillo (2015) examine risk aversion at the country level, highlighting the importance of understanding risk attitudes when making policy decisions. In the context of Uruguay and incorporating risk analysis in economic evaluation of irrigation, Rosas et al. (2014) proposed a model to evaluate the benefit of investment projects in irrigation, while Rosas et al. (2017) used a prospect theory approach to quantify benefits due to less volatile yields as a result of supplementary irrigation applied to summer crops in Uruguay.

The present paper combines the IAM approach using the SWAT model with the economic modelling of attitudes towards risk of irrigators in Uruguay. It consequently contributes to these two strands of literature. The IAM approaches to optimal economic decisions about water use and management have typically not dealt explicitly with decision maker's risk preferences, which could play an important role in shaping decisions around irrigation and maintenance of irrigation infrastructure. This paper addresses that omission in the literature. Likewise, the paper contributes to the literature on risk and uncertainty in agriculture, by using the IAM approach to derive estimates and to quantify the uncertainty around the outcomes from management practices, in this case, maintenance of irrigation canals.

The paper proceeds as follows. In the following section we outline the model of risk preferences and how it is articulated with the SWAT model. This is followed by a section that describes the study area, the calibration of the SWAT model for that area, and the setup of SWAT simulation scenarios. In Section 4 we report the results from the simulation modelling and the economic optimization model. Section 5 provides discussion on the results, including their policy/management relevance, and draws conclusions.

Model

In this section we outline a model that can be used to investigate decisions about optimal investment irrigation canal maintenance, and how it is used in combination with SWAT in an IAM framework. Consider an economic agent (agricultural producer) maximizing the expected utility of uncertain profits through the selection of production activities and practices. For a producer with exponential utility as a function of the uncertain profit ($\tilde{\pi}$), $U(\tilde{\pi}) = -e^{-r\tilde{\pi}}$, the certainty equivalent (CE) is defined as the monetary amount the producer is willing to accept in order to avoid the uncertainty about the profit that they can obtain from implementing a given practice (e.g. maintenance of irrigation canals). Maintaining the same level of expected utility, CE is given by:

$$\begin{aligned} CE(\tilde{\pi}) &= U^{-1}(E[U(\tilde{\pi})]) \\ &= E[\pi] - RP(\tilde{\pi}) \\ &= -\frac{1}{r} log[\,E(e^{-r\pi})] \end{aligned} \tag{1}$$

where RP is the risk premium. Given the expression in Eq. 1, it is evident that the CE increases with expected profits, and decreases with the RP, implying that riskier activities are associated with a lower CE.

Assuming that the producer can allocate i ($i = 1, \ldots I$) units of production, aggregate profits are defined as the sum of per-hectare profits over units of production ($\tilde{\pi}_i$), which are defined as

$\tilde{\pi}_i = \sum_j yield_{ij} \times price_j - cost_{ij}$, where j indexes the crops $(j = 1, \dots, J)$ in the unit of production. Crop yields are random and are the source of uncertainty in the profit equation. In the context of the current paper, the crop yield uncertainty stems from the uncertainty about the availability of irrigation water. The per-hectare costs of crop *j* in unit *i* include the cost of materials, chemicals, labor (all together denoted as c_{ij}, and the costs associated with the irrigation practices, in particular, as it is the focus of the current paper, the maintenance costs of the conveyance system attributed to that unit and crop (m_{ij}) plus the costs of water (given by the irrigation rate times the price of water, i.e., $w_{ij} \times p_w$). That is: $costs_{ij} = \sum_j \ c_{ij} + m_{ij} + w_{ij} \times p_w$.

For the IAM model integration, we obtain the relevant biophysical variables for the economic model from the SWAT model. In particular, we obtain the yields for each crop and unit of production, the information necessary to compute the costs related to water use, such as irrigation rates, and environmental variables such as water flows, nutrient loads, and sediment loads at selected points of interest in the basin. SWAT (Arnold et al., 1998), models a set of biophysical processes spatially distributed and on a daily time steps, using a number of nested modules. These include hydrological processes (runoff, evapotranspiration, transit, storage and exfiltration); nutrient processes (production of nutrients, such as mineralization, and their transportation through the nitrogen and phosphorous cycles including their runoff to water bodies); pesticides and other bacteria processes and their runoff to water bodies; and soil processes (erosion using the MUSLE (Williams and Renard 2015) and the deposit of sediments). It also includes a crop growth module comprising the interactions among water, plants, soils, atmosphere, and landscape, which produces simulations of yields per hectare by crop. It contains a set of routines capable of representing other features of the basin such as reservoirs, and also farm practices such as irrigation, and buffer strips, among others (Neitsch et al. 2011). Besides the set of parameters driving equations in the mentioned modules, SWAT takes climatic variables (e.g., precipitation, temperature, radiation) as inputs to the model, which drive some of the biophysical processes mentioned above.

Irrigation can be adopted to meet the specific water needs of each crop, taking into account either the water demand of the plants or the soil moisture content. The former addresses the plants' water requirements, while the latter focuses on maintaining soil saturation, typically implemented in SWAT for rice production to simulate flooded irrigation. The sources of water can be either reservoirs or pumping directly from the water streams in the basin. There is also a variable driving the amount of water that can be imported to the basin from other basins. WUE is determined by a parameter that measures the percentage of the irrigation water volume that effectively reaches the crop. When farm and water management practices are implemented to improve WUE, they imply changes on this parameter that we calibrate to replicate the scope of these interventions. This is of particular interest for our application in which these interventions arise as increasing the frequency of maintenance of conveyance channels.

Among the environmental variables provided by SWAT that are of interest for our application, are the nitrogen loads, the phosphorous loads, sediments, and water flows. Based on these variables we compute N and P concentration levels, sediment concentration levels, and flows at specific spatial and temporal points in the basin. We also calculate the percentage of time that the N and P concentration exceed the thresholds established in current regulations.

Basin description, scenario setup, and calibration.

The Tala River basin, a subbasin of the Arapey Grande River basin, is located in the north-western region of Uruguay (Figure 1). It has an area of 15,900 ha and its main river is 23 km long (SGM 1994). In the last 10 years annual precipitation ranged from 998 mm (in 2013) to 1850 mm (in 2014), with an average of 1415 mm, and a high inter-annual and intra-annual variability. For example, monthly precipitations ranged from 28 mm (February 2018) to 642 mm (February 2010). Temperatures range between 31°C in the summer months and 7°C in winter. The dominant soil types in the study area are Eutric Brunisols and Haplic Vertisols, with Subeutric Lithosols as their main associated group (DSF/MAP 1976). These soil groups exhibit high fertility, low erodibility, and are well-suited for crop production.

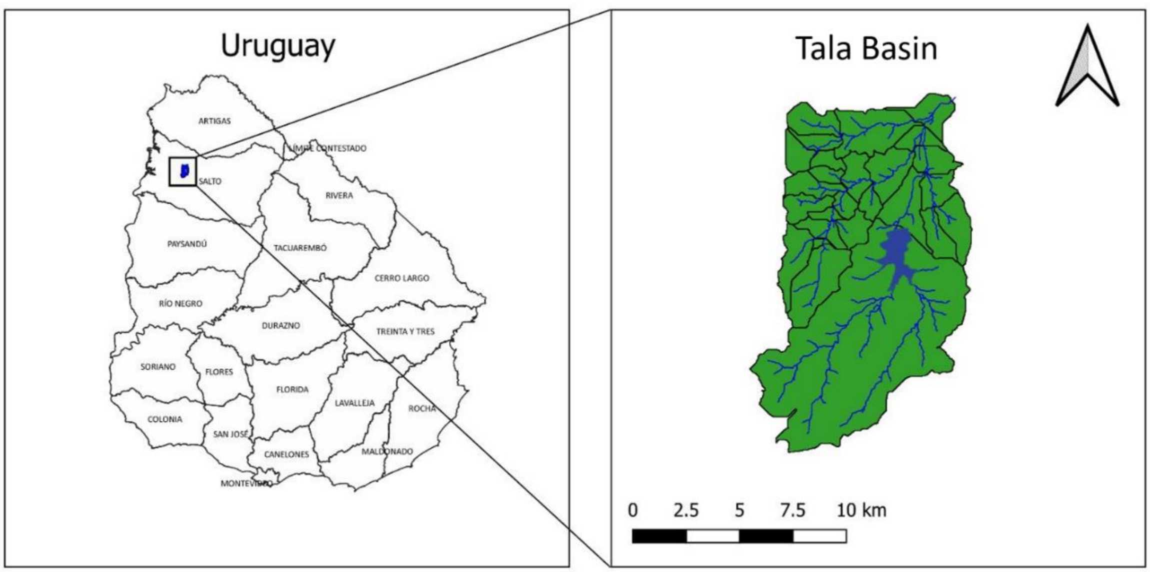


Figure 1. Location of the Tala River Basin in Salto, Uruguay.

Rain-fed crop production was widespread in the basin in the 1970s, which transitioned to livestock production in the 1980's. Rotations including rice (flooded), rainfed and irrigated crops, and planted pastures were introduced in the 1990s, and coexist with natural grasslands in mixed crop-livestock production systems. In the last 15 years, diversification was enhanced with the inclusion of other summer crops such as soybean, corn and sorghum in the lower portion of the basin. Also, supplemented irrigation was introduced mainly in corn. There are currently about 5,000 ha dedicated to crops, and the remainder of the basin is devoted to livestock production in natural grasslands. Soybean and rice are the main crops (45% and 23% of the basin area, respectively) and sorghum, pastures and corn (15%, 15%, and 6%, respectively) have lower shares.

The introduction of rice and the use of supplemental irrigation in corn required the development of the irrigation infrastructure, including three dams and a conveyance system of irrigation canals that is approximately 60km long. Flooding irrigation is used in rice and pressurized irrigation with center pivots is used in corn. Based on the suitable land and water available, the system can irrigate up to 700 ha of rice.

An important aspect of the agricultural area that we model using SWAT is that all cropping land is under management of a single farmer. This situation is rarely observed with IAMs using SWAT, as typically it has not been possible to define the exact ownership and management at the scale at which modelling is conducted (i.e., the Hydrologic Response Units – HRUs). Having a single decision maker for each HRU in the model, makes our IAM approach consistent with behavioral assumptions inherent in the economic component of the model, which in turn gives us greater confidence in the findings.

Scenario setup

Irrigation water losses in storage, conveyance, and application, which determine the overall efficiency of the irrigation system, are affected by different factors such as i) direct evaporation or percolation in dams, ii) direct evaporation and percolation in conveyance (main and secondary) channels, and iii) losses depending on the irrigation technology used in the fields. The efficiency levels respond to various dynamics and different mitigation actions can be used to modify the efficiency at the different stages (dams, conveyance, or in the fields). Our analysis focuses on the losses occurring in the conveyance canals and the decisions to invest in canal maintenance in order to mitigate those losses. The other two sources of losses are also very relevant, but are not treated here, and are left for future research.

The improvements in WUE through investments in canal maintenance means that less overall amounts of water need to be stored and delivered in the irrigation system in order to meet crop water demand. Improved WUE will reduce the occurrence of water stress for irrigated crops as a result of water shortages. These are among the key economic benefits of increased irrigation efficiency. Enhanced water flows and reduction in the stored volumes improve overall water quality in the basin and facilitates the compliance with environmental flows required by current regulations. In addition, there is likely to be a reduction in sediment and in nutrient (N and P) concentration levels because, everything else equal, a fixed level of sediment or nutrient enrichment diluted in higher water volumes will reduces their concentration.

Equally important, improved efficiency in conveyance will mean that an expansion of the irrigated area is feasible, for a given level of water stored in the reservoir. In this case, there will be a tradeoff between the (economic) benefits from an increase in crop output and some key water quantity and quality attributes such as water flow reductions, the occurrence of water shortages, and higher concentration levels of sediment and nutrients. Our IAM approach can assess these tradeoffs within a consistent model that combines an economic model of farmer decisions under uncertainty with a biophysical model that represents production and environmental variables to simultaneously capture their feedbacks.

IAM typically incorporates elements from multiple fields, including economics, engineering, ecology, hydrology, biology and social sciences, and are used to evaluate the potential outcomes of different policy or management actions in various scenarios. They can provide decision makers with a comprehensive understanding of the trade-offs and potential consequences of different actions, and can help inform decisions about how best to manage complex systems in a sustainable and equitable way.

We set up four scenarios of improved water use efficiency as a function of investment into canal maintenance (95%, 88%, 80%, and 73% efficiency) and a baseline representing the current situation with a 65% of efficiency. The baseline efficiency which implies that out of the total water withdrawn from the reservoirs, only 65% ends up being applied to the agricultural crops.

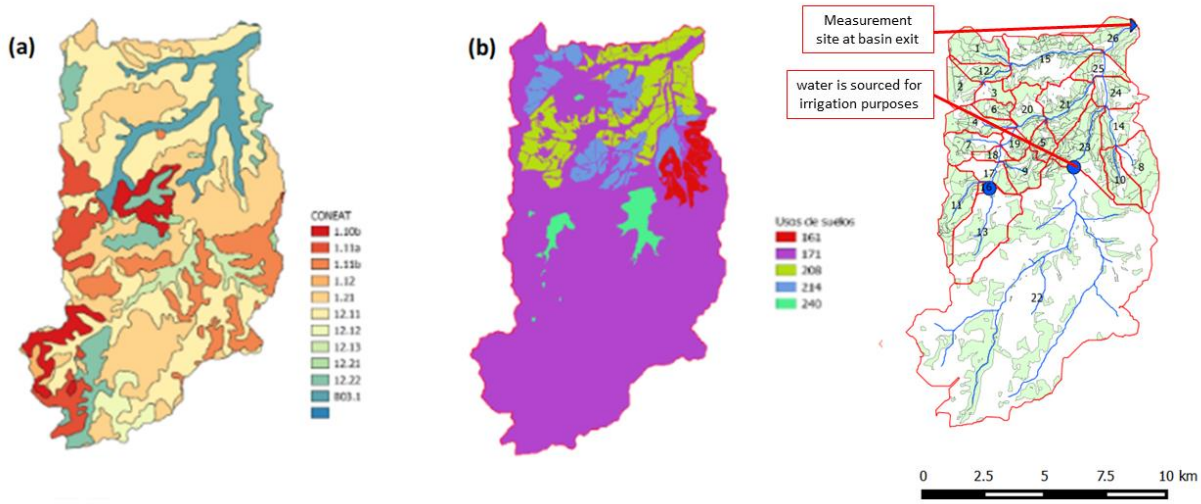
The calibration in the SWAT model is straightforward because it only implies a change in the parameter value driving the water use efficiency. Additional costs of the improved canal maintenance needed to achieve those increased levels of efficiency in conveyance are reflected in the per hectare cost of crop production included in the economic model. The economic model accounts for the additional expenses associated with enhanced canal maintenance required to achieve higher levels of water use efficiency. These costs are incorporated into the per hectare cost of crop production within the economic model.

Model calibration

The calibration of the Soil and Water Assessment Tool (SWAT) model involved the use of Geographic Information Systems (GIS) to compile and analyze essential geographic data. GIS allows gathering information on soil characteristics, climate variables, land use, and agricultural practices, which were inputted into the model.

For soil distribution, we utilized the CONEAT distribution map specific to the Tala Basin, revealing the prevalence of Vertisoils and Brownsoils in the region. Additionally, a reference map of land use during the 2018/2019 season was integrated with an elevation map to determine slopes, resulting in a sub-basin map with 150 Hydrological Response Units (HRUs).

The environmental results were obtained from a representative point on the sub-basin map, in particular the basin outlet (point 26), enabling us to assess the localized impacts of water use efficiency and farm practices.



(a) CONEAT Map, (b) 2018-2019 crop land use map, and (c) sub-basin subdivision of the Del Tala basin

Figure 2. Data required for SWAT calibration at a basin scale.

Our approach involves calibrating the SWAT model for the Tala Creek basin and integrating its output with an economic model based on expected utility and the certainty equivalent concept. By combining these two models in an innovative fashion, we were able to automate scenario analyses, simultaneously evaluate the economic and environmental impacts, and assess the associated tradeoffs. The primary decision-maker in our analysis is the farmer who manages the agricultural areas, and who could utilize this comprehensive analysis to determine the optimal investment level in irrigation channels, thereby influencing water use efficiency.

To represent the agronomic conditions, we set up three crop sequences that seek to represent the observed activities in the Tala River basin and account for the specific requirements and economic objectives in the corresponding Hydrologic Response Units (HRU). We incorporate the knowledge and insights from local technical advisors ensuring consistency and bolstering the reliability and applicability of our findings. Each sequence follows a well-defined three-year rotation. The first crop sequence (named Soybean rotation) spans two consecutive years of soybeans followed by an annual pasture. The second crop sequence (named Cron rotation) encompasses a more diversified approach in which soybeans in the first year is followed by corn in the second year, and the third years is devoted to rice. The third crop sequence (referred to as the Rice rotation), has rice in the first year, then a second year with corn, and the third year with pasture. These crop sequences comply with the current regulations of responsible soil use and management plans of the 'Ministerio de Ganadería Agricultura y Pesca' (MGAP, Ministry of Livestock, Agriculture and Fisheries), which among other requirements, guarantee a soil erosion level below the threshold established by these regulating authorities.

Per-hectare crop costs including materials, chemicals, labor and irrigation. The information on these costs also come from technicians working in the basin. The irrigation costs are constructed with the irrigation rate coming from the SWAT and the current price of water. Expenditures in the maintenance of the conveyance canals depend on the scenario. The baseline is consistent with a 5-year frequency of maintenance, and then, the scenarios of 73%, 80%, 88% and 95% represent increasing this frequency to every 4, 3, 2 and 1 year, respectively. We model the cost effects of this increased frequency as a commensurate increase in the costs of cropping. Crop costs are shown in Table 1 together with crop prices, which are calibrated at 2022 mean values, and extracted from the 'Camara Mercantil de Productos del Pais' (Mercantile Chamber of Agricultural Products) and from the 'Asociación de Cultivadores de Arroz' (Rice Growers Association). Beef prices are required because some HRUs are pastured with calves of +180kg. We consider the revenues for this land use based on the beef output. Beef prices are obtained from the 'Asociación de Consignatarios de Ganado' (Livestock Auctioneers Association), and the pasture dry matter to beef conversion rate.

Table 1. Prices and costs by output.

Item	Price (USD/Ton)	Cost (USD/ha)
Rice	229	1310
Corn	292	1278
Soyean	574	538
Pasture		351
Beef	2250	

Sources: Mercantile Chamber of Agricultural Products, Rice Growers Association, Livestock Auctioneers Association, Uruguay.

Yields, prices and costs are plugged in the per-crop profit function and used to compute the certainty equivalent (CE) based on Eq (1). Attitudes towards risk and uncertainty in the decision-making process are driven by the absolute risk aversion (ARA) parameter. Agents with higher ARA are consistent with more risk-averse behavior, inducing a higher penalty on the CE of a risky activity relative to a less risk-averse individual. An ARA equal to zero is consistent with a risk-neutral individual, in which case the CE is equal to the expected value of that activity. Absolute risk aversion coefficients come from the literature (Babcock et al. 1993; Gandelman and Hernández-Murillo 2015). We set four levels of risk aversion corresponding to the range of values most used in the literature.

Results

Table 2 shows the CE of each scenario for different levels of risk aversion. We find that the optimal frequency of irrigation channels maintenance is every 2 years (Scenario 2), i.e., an investment plan that yields an 88% of water use efficiency. While, as expected, the CE decreases as we consider more risk-averse individuals, this result holds for all levels of risk aversion, including the case of risk neutrality. Importantly, panel (b), which presents the percentage change of the CE in each scenario with respect to the baseline (65% efficiency and canal maintenance every 5 years), shows that the optimality of scenario 2 is achieved with a higher difference relative to the baseline in the case of more risk-averse individuals; for example, 5% in the case of an ARA of 0.014. In other words, as we take into account higher levels of risk aversion, the benefits of enhancing expected utility and reducing return volatility becomes more apparent. This means that the advantages of the investment also stem from the decreased volatility of profits. We highlight the potential of investing in irrigation canal maintenance to promote both an improvement in expected returns but also in their volatility.

Table 2. Certainty equivalent (CE) by scenario and by coefficient of absolute risk aversion.

Panel (a)

Scenario	ARA_0	ARA_0.007	ARA_0.014	ARA_0.021	ARA_0.028	ARA_0.035
1(95%)	639	250	158	121	100	86
2(88%)	647	261	170	133	112	98
3(80%)	645	260	169	132	111	97
4(73%)	640	258	166	129	107	93
Base(65%)	636	256	162	124	102	87

Panel (b)

Scenario	ARA_0	ARA_0.007	ARA_0.014	ARA_0.021	ARA_0.028	ARA_0.035
1(95%)	0.5%	-2.3%	-2.7%	-2.3%	-1.8%	-1.5%
2(88%)	1.8%	2.2%	4.8%	7.7%	10.5%	13.1%
3(80%)	1.4%	1.8%	4.1%	6.7%	9.3%	11.7%
4(73%)	0.7%	0.8%	2.1%	3.7%	5.4%	6.9%

Source: Own calculations

We present the main environmental results in Table 3, in particular, water quantity (water flows and water saved) and water quality (concentration levels of nitrates and phosphorus, and percentage of days above the allowed nutrient limit) at the basin outlet. While no significant changes in nutrient concentration relative to the baseline are observed, it is worth noting that the analyzed practices do not exert a detrimental impact on the environmental attributes analyzed; on the contrary, a modest improvement is found. For example, a mild reduction in both the nutrient concentration levels, and in the percentage of days that the maximum allowable nutrient concentration levels are exceeded (panel b).

The main result is on the water quantity side, where the implemented practices of irrigation canal maintenance achieve substantial water savings, in particular, in Scenario 2 there is a 4%

increase in water flows at the basin outlet (see Table 4, panel b). To illustrate these findings with a more tangible farm practice, it implies an estimated equivalent of 129 ha of additional land that can be cropped under irrigation.1

Table 3. Environmental results (flow, water saved, N and P concentrations, days above N and P limits) by scenario.

Panel (a)

Scenario	Mean_Flow (L/sec)	Water Saved (Cubic meters)	Adicional Rice (Ha)	Median_NO3	Days_above_limit_NO3 NO3_lim < 0.1	Median_P	Days_above_limit_P P_lim < 0.025
1(95%)	1.362	2064662	159	0.047796	33.22%	0.06230	64.47%
2(88%)	1.349	1671723	129	0.047803	33.39%	0.06248	64.69%
3(80%)	1.333	1160525	89	0.047775	33.59%	0.06203	64.93%
4(73%)	1.316	638919	49	0.047971	33.62%	0.06245	65.02%
Base(65%)	1.296	0	0	0.048678	33.85%	0.06243	65.11%

Panel (b)

Scenario	Mean_Flow	Water Saved	Adicional Rice	Median_NO3	Days_above_limit_NO3	Median_P	Days_above_limit_P
1(95%)	5.05%	2064662	159	-1.81%	-1.89%	-0.21%	-0.31%
2(88%)	4.09%	1671723	129	-1.81%	-1.38%	0.08%	-0.20%
3(80%)	2.84%	1160525	89	-1.85%	-0.77%	-0.64%	-0.10%
4(73%)	1.56%	638919	49	-1.46%	-0.67%	0.03%	-0.02%

Source: Own calculations

Our findings reveal promising results, highlighting the potential benefits of implementing farm practices of water use efficiency, with direct consequences on water savings, maintaining the water quality outcomes and accompanied by the prospect of increasing crop production. This integrated approach demonstrates the feasibility of balancing economic benefits with sustainable agricultural practices.

[1] Note that the economic returns from this additional rice area is included in the results presented in Table 2.

Conclusion

We present an assessment of the economic and environmental impacts of water use efficiency and farm practices through the use of an integrated economic and biophysical model. By calibrating the SWAT model for the Tala basin in Uruguay and incorporating the yield output into an economic model, we were able to evaluate the trade-offs between increased crop output and the associated effects on water flow and water shortages. Our innovative approach allowed for the automatic generation and assessment of multiple scenarios, providing valuable insights for decision-making processes.

It contributes to the understanding of what would be optional actions in terms of improving resource use efficiency on farms considering the pressures imposed by climate change. Results show that as water becomes scarcer due to climate change, investment in improved water efficiency by reducing conveyance losses is going to be beneficial for farmers. Moreover, risk aversion in decision-making was considered, as it plays a crucial role in shaping the economic outcomes of such investments.

Our results show the successful integration of the economic and biophysical models, enabling a comprehensive assessment of the economic and environmental implications of water use efficiency actions and farm practices. These results offer valuable insights to decision-makers, particularly farmers, empowering them to make informed choices regarding investments in maintenance of irrigation canals. By presenting the economic and environmental tradeoffs associated with different investment levels in canal maintenance, our study contributes to the literature in sustainable agricultural practices and supports evidence-based decision-making for the improvement of both farmers and the environment.

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