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Alternative pricing for irrigation water management in the context of climate change

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ABSTRACT

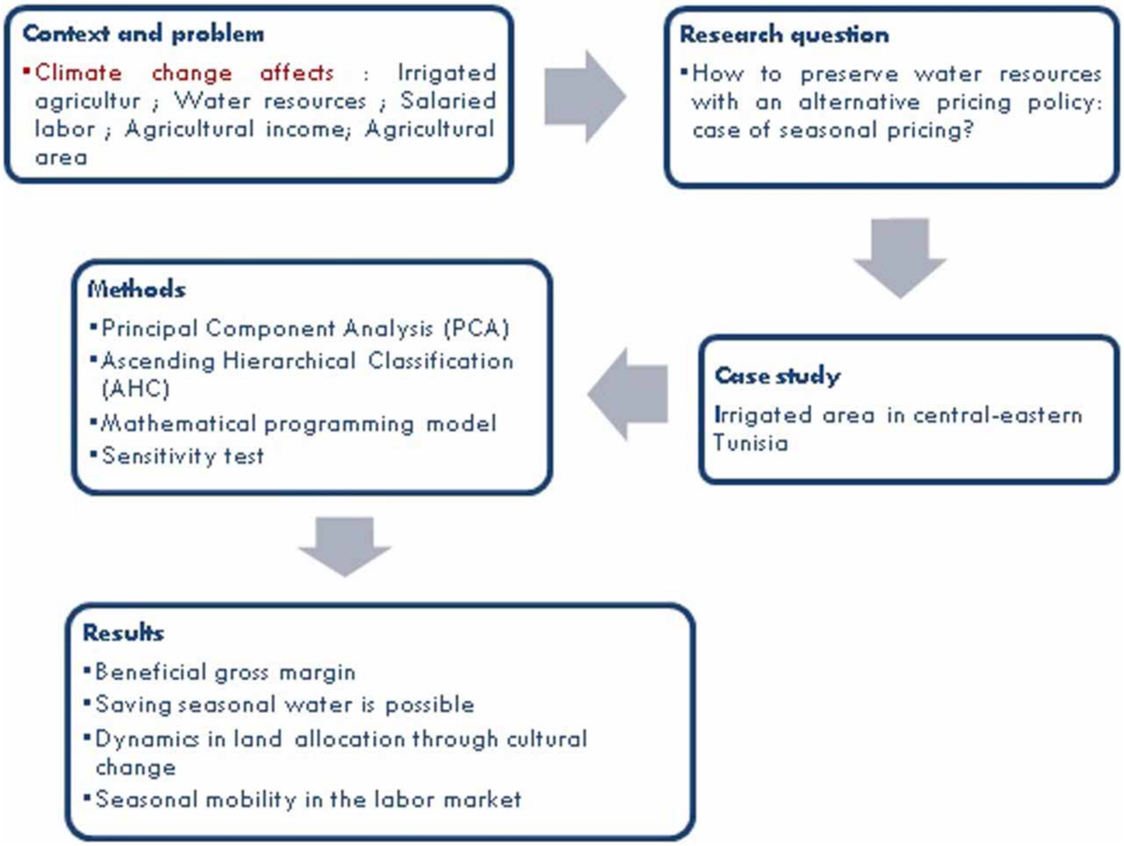
Irrigation water pricing is an economic regulation instrument widely used in agriculture. Constant annual pricing is always criticized by local decision-makers as well as scientific researchers because it does not take into account the seasonal availability of water in the context of climate change. This study proposes a mathematical programming model to test alternative seasonal pricing scenarios in the context of climate change. This model is applied at farm level in the Kalâa Kebira region of East-Central Tunisia. The results show that summer seasonal pricing was economically beneficial for large farms, while winter pricing was beneficial for small and average farms. Water savings were only possible for small farms using 89% of available water in summer and for average farms using 93% of available water in winter. On the other hand, the sensitivity test proved that when water demand is elastic, increasing seasonal pricing of irrigation water by a rate between 20 and 30% generates water savings for different types of farms. This seasonal water saving is also accompanied by optimal use of agricultural labor and diversity of cultivated areas.

Key words: climate change, East-Central Tunisia, Kalâa Kebira region, irrigation water, mathematical programming model, seasonal pricing

HIGHLIGHTS

- Give an idea on the water-saving policy.
- Plan how to manage water resources in the context of climate change.
- Importance of practicing the seasonal pricing policy.
- Propose a strategy for local public actors.
- Modeling as a decision support tool for water resource management.

GRAPHICAL ABSTRACT



1. INTRODUCTION

Water pricing and water markets are economic instruments that can work well when water has private characteristics such as in urban systems, but they work less well when water has private characteristics of a common resource or public good (van der Zaag & Savenije 2006; Davidson *et al.* 2019). Irrigation water from surface water and aquifers has common characteristics in terms of resources in basins or dams, and therefore the use of economic instruments requires transforming the resource into a private good and a tariff reform (Perry *et al.* 1997). Water pricing reforms are designed to encourage the efficient use of water resources.

The literature shows that impact studies of new regulations on irrigated agriculture, including water pricing, are widely discussed. In India, there are huge variations in irrigation water pricing from state to state. Revenue collection from irrigation water charges imposed by states is not encouraging. It was observed that the low revenue collection is mainly due to the low rate of water taxes, lack of periodic review and flaws in the current revenue collection mechanism in the states. The water regulatory authority should become a statutory body responsible for managing the different uses of water and their fair pricing (Parween *et al.* 2021). Viaggi *et al.* (2020) suggest a policy recommendation that in the absence of water metering, a broader set of incentive pricing options should be considered, the performance of which should, however, be assessed based on the specificities of each irrigated region. Johansson (2000) reviews current and past views on many aspects of irrigation services and their pricing. The result will be useful in developing comprehensive guidelines for water policy practitioners as they respond to the growing demand for these services and the need to allocate scarce water resources efficiently. Credible evidence of water pricing experiences in various countries around the world was assessed such as new reform mechanisms, achieving social goals through water pricing, revenue recovery, water use efficiency and customer equity and pricing of the poor (Dinar *et al.* 2015).

Crase *et al.* (2015) provide a review of water pricing arrangements in each of the Australian states. They concluded that there remain opportunities for improvement that would eliminate artificial differences in the way water is billed to different users and thus support water distribution at its highest values.

In northern Italy, a study on the pricing policy for irrigation water showed that the price could help reduce water demand in a situation that depends on asymmetric information and costs which require the need for more in-depth research to analyze the incentive mechanisms in the absence of water metering (Galioto *et al.* 2013). Iglesias & Blanco (2008) showed that the introduction of water prices reflecting the real cost of irrigation is one of the most innovative elements in the new water framework directive in the European Union and the modeling approach can be used as a management tool to help implement the cost recovery approach of the new Water Framework Directive.

In the North-West (NW) region of Bangladesh, Mainuddin *et al.* (2021) showed for the case of irrigated rice cultivation, that the different pricing systems, the cost of irrigation water varied from one site to the next and from one year to the next, but always represented the highest input costs between 20 and 25% of total production. These results clearly show that seasonal variability is valuable information for policy-makers to adjust their water-saving policy.

Other works on the global management of water resources have been developed in the Middle East region. An example case study of the Nile Delta in Egypt, Abd-Elaty *et al.* (2023) demonstrated that the drawdown of the water table was significant and the future infrastructure should take into account land subsidence due to modern irrigation systems. Also in Iraq, groundwater potential can be better exploited to overcome water scarcity; however, it should not be exploited intensively as it could have irreversible environmental impacts (Khafaji *et al.* 2022). A positive mathematical programming model is applied to farms in the Hamadan-Bahar plain, Iran. The results of this programming model revealed that a pricing policy can incentivize farmers to use a modern and more efficient irrigation system which could improve water productivity and also reduce the amount of water used (Zamani *et al.* 2021).

In Tunisia, studies addressing the issue of water pricing have multiplied in recent years. Pricing of irrigation water is an important economic instrument in agriculture but it is insufficient for sustainable management of water resources and environmental externalities (Chebil *et al.* 2010; Frija *et al.* 2015; Jeder *et al.* 2019a, 2019b). However, the conclusions of these different case studies, comparing the performance of water pricing criteria between different countries, agree on the fact that there is no good practice that can be recommended for a country or sector (Tsur *et al.* 2004; Kahil *et al.* 2016). Indeed, the pricing of irrigation water in Tunisia cannot be conceived as a financial doctrine which aims to recover the costs of production and water distribution service from the previous year. This procedure for developing a constant water price for the next agricultural season presents a major limitation in that it does not take into account the possible climatic situation of water shortage.

In this sense, this study aims to raise this limit, by trying to adjust seasonal water pricing according to climatic conditions. The objective of this article is to test the impact of two seasonal pricing scenarios on farms in the Kalâa Kebira region in East-Central Tunisia in the context of climate change and scarcity of water resources. To meet this objective, a methodological framework based on the typology of exploitation types and a mathematical programming model was developed.

2. STUDY AREA AND DATA

As shown in Figure 1, the agricultural perimeter of Kalâa Kebira is located in the governorate of Sousse in the Center-East of Tunisia. This perimeter covers a total area of 24,904 ha which represents 9% of the total area of the governorate of Sousse. It is identified as being an agricultural area par excellence since 90% of the total area of the delegation is an agricultural area which extends over 22,455 ha. This perimeter is characterized by a system of production of vegetable crops, in particular potatoes, intercropped with arboriculture (olive trees). Data collection is based on a survey conducted during 2019–2020 covering 150 farms. The binomial water pricing is applied in the public perimeter of Kalâa Kebira, it is approximately equal to 0.240 TD/m^3 (Tunisian dinar/m^3) (Ben Hamza 2017). The technical-economic coefficients associated with the productive activities come from the technical-economic sheets of each crop practiced. These sheets are filled by the farmers and the experts in the region.

3. METHODS

3.1. Farm mathematical programming model

The farm mathematical programming model is widely used to analyze the effects of agricultural policies on the consumption of water resources and on agricultural production systems (Jeder *et al.* 2020). Thus, a linear programming (LP) model under a set of constraints was adopted, which represents the following optimization problem:

Figure 1 | Case study area of Kalâa Kebira region in East-Central Tunisia.

Objective function

$$\text{Max } Z = \sum_{c,t} (p_c y_c - CO_{c,t}) x_{c,t} - \sum_{c,t,s} (pw_s * bw_{c,t,s}) x_{c,t} - FAB - \sum_{s} p_l wl_s \quad (1)$$

Under constraint

$$\text{Land constraint: } \sum_{c,t} x_{c,t} \le Sat \quad (2)$$

$$\text{Arboriculture constraint (olive growing): } \sum_{cp,t} x_{cp,t} = S_{cp0} \quad (3)$$

$$\text{Cereal cultivation constraint: } \sum_{cer,t} x_{cer,t} \le 1 \quad (4)$$

$$\text{Vegetable crops constraint: } \sum_{cm,t} x_{cm,t} \le S_{cm} = (Sat - S_{cp0}) \quad (5)$$

$$\text{Crop rotation constraint: } \sum_{cer,t} x_{cer,t} = \frac{1}{4} * \sum_{cm,t} x_{cm,t} \quad (6)$$

$$\text{Constraint of water resources: } \sum_{c,t,p} bw_{c,t,s} x_{c,t} \le Disp_w(s) \quad (7)$$

$$\text{Agricultural labor constraint: } \sum_{c,t,p} bl_{c,t,s} x_{c,t} \le disp_l(s) + sal_l(s) \quad (8)$$

where C refers to crops; T refers to techniques ($T1$: irrigated; $T2$: dry); S refers to Season ($S1$: autumn–winter; $S2$: spring–summer). cer refers to cereal crops; cm refers to vegetable crops; cp refers to arboriculture (olive).

The variables:

Z refers to gross margin (function of objectives to be maximized) in Tunisian dinars (TD); pc refers to price of the crop (average price) (dinars per ton); y_c refers to crop yield (ton per ha); $CO_{c,t}$ refers to operational cost by crop and by and technique; $x_{c,t}$ refers to area per crop (decision variable); pw_s refers to water tariff per season TD/m^3; $bw_{c,t,s}$ refers to water requirement per crop, per technique and per season in (m^3); FAB refers to annual subscription fee (fixed price) in dinars

(30 TD per year and per farmer); *pl* refers to daily salary of temporary labor in dinars (15 TD) per day); wl_s refers to number of days of salaried labor used.

Equation (1) is the objective function of maximizing *Z*.

Equation (2) is a land constraint, indicating that the total cultivated areas in each farm type should not exceed the currently observed agricultural areas, *SAT*.

Equation (3) bounds the annual trees area (olives) expansion to the observed area S_{cp0}.

Equation (4) is the cereal cultivation constraint means that the sum of cereal cultivation area by technique is less than or equal to 1 to encourage farmers to practice soil rotation to avoid degradation and intensification.

Equation (5) is the constraint of vegetable crops intercropped with olive trees, their areas (*cm)* must be less than the total area minus the area allocated to arboriculture (*spo*).

Equation (6) is the constraint of the crop rotation which indicates that the area of cereal cultivation must be equal to ¼ of the area allocated to vegetable crops.

Equation (7) indicates that the sum of water requirement of all crops cultivated should not exceed the water availability by seasons at farm-type level, $Disp_w(s)$.

Equation (8) is the labor constraint, indicating that the sum of labour required for each crop, expressed in an hour per period, should be less than the amount of labour available in the farm, $disp_l(s)$, plus the amount of temporary labour (salaried) if needed, $sal_l(s)$. Temporary labour is an endogenous variable calculated by the model itself.

The resolution of the linear mathematical programming model is carried out through the GAMS software (General Algebraic Modeling System).

3.2. Alternative pricing simulation scenarios

The objective of this research work is to test alternative pricing and see its impacts on production systems and water resources at the farm level. So three scenarios were tested:

Basic scenario 'Standard binomial pricing': initial optimal solution

Alternative scenario 'Seasonal binomial pricing': this scenario aims to save water and adapt to climate change in the event of water shortage, it is formalized in two scenarios:

Scenario 1 (*winter seasonal binomial pricing*): 25% drop in seasonal water availability 'in winter' leading to an increase in the seasonal water tariff 'in winter' of 25% while keeping the seasonal tariff water 'in summer' when there is a 25% increase in the seasonal availability of water 'in summer'.

Scenario 2 (*summer seasonal binomial pricing*): the reverse is true of scenario 1: 25% drop in seasonal water availability 'in summer' leading to an increase in the seasonal water tariff 'in summer' of 25% while keeping the seasonal water tariff 'in winter' when there is a 25% increase in the seasonal water availability 'in winter'.

4. RESULTS

4.1. Farm typology

The survey involving 150 farms showed heterogeneity in terms of structural variables and socio-economic variables. Certain relevant classification criteria have been retained to develop a typology of typical farms. These criteria are: source of water (Dam or public water well), area, level of education, residence (on or off the farm), mode of land ownership (Tenant or owner of the land) and the rate of agricultural intensification which expresses the ratio between the irrigated and the irrigable areas. This rate of intensification is variable and is linked to water availability at the farm level. The majority of irrigated farms in the study area have an average and almost similar intensification rate between them. According to Figure 2, a principal component analysis (PCA) accompanied by an ascending hierarchical classification (AHC) identified a typology of three farms types. These farms types are:

(1) Large farm: It is a representative of the farmers in the area residing outside the farm who have a level of primary education and who are tenants and irrigate from public water wells. This large farm is characterized by a large agricultural area of approximately 12.5 ha. These farmers practice arboriculture, cereal crops (wheat and beans) and market gardening such as peppers and particularly seasonal and late-season potatoes. The rate of cultural intensification does not exceed 100% with beans in the crop rotation and a total absence of fallow.

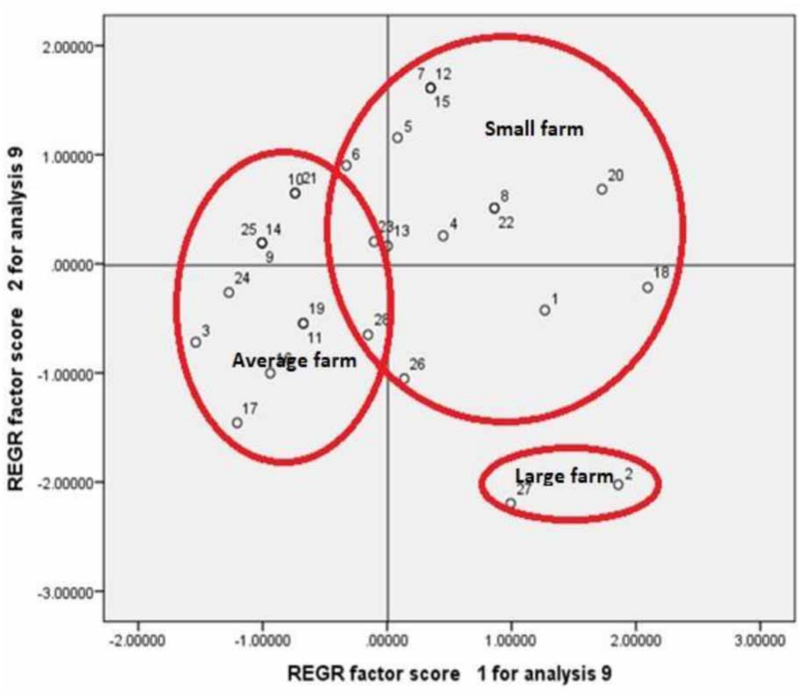


Figure 2 | Typology of farms types.

(2) Average farm: It is a representative of the majority of farmers residing inside and outside the farm, who have university-level training (agronomist) and who own land and irrigate from public wells. This average farm is characterized by an area of approximately 5 ha. These farmers practice arboriculture and market gardening, in particular seasonal and early potatoes, with an intensification rate of 84.16%, sometimes practicing cereal farming or fallowing in the crop rotation.

(3) Small farm: It is a representative of the majority of farmers residing on the farm and having a secondary education level and who own land and irrigate from a water dam. This small farm is characterized by a small agricultural area of approximately 2.37 ha. These farmers practice arboriculture and market gardening, particularly early potatoes, with an intensification rate of 96.56%, sometimes practicing fallowing and cereal crops in the rotation.

According to Table 1, the characteristics of these farm types show heterogeneity in terms of resource availability (labour, water and land) and land use, but they have almost the same type of agricultural production system (a system of intercropping of vegetable crops, cereals and olive trees) with a slightly different rate of intensification.

4.2. Economic impact

The price policy scenarios showed that farm income decreased for all farms compared to the reference scenario. These results confirm the theory of economic good according to which the increase in the price leads to a decrease in its demand and they are justified in other works on the policy of water prices in others papers (Dinar *et al.* 2015; Jeder *et al.* 2019a, 2019b; Albiac *et al.* 2020). In Figure 3, the comparison between Scenario 1 (winter pricing) and Scenario 2 (summer pricing) showed that Scenario 1 was beneficial for small and average farms who, respectively, maintained their farm income at order of 47,400.77 TD and 75,694.96 TD while scenario 1 was beneficial for large farms which even recorded an increase compared to winter scenario 1 to reach an agricultural income of around 155,700.25 TD. The economic impact of seasonal pricing on agricultural income shows the diversity of farmers' behaviors and the existence of preferential pricing for each farm type to maintain an acceptable agricultural income. This diversity of behavior of farmers can be explained from an economic point of view by the criterion of land ownership. Indeed, farm owners, who mainly represent typical farms (large farms1), always seek to cover a greater share of their production costs and their implementation costs, which always encourages them to favor high-value

Table 1 | Characteristics of the different types of farms

Farm types	Large farm	Average farm	Small farm
Water available in P1 (m^3)	13,824	8,400.74	4,749.78
Water available in P2 (m^3)	21,060	8,390.77	6,770.77
Labor available in P1 (day)	90	33.85	38.46
Labor available in P2 (day)	90	30	26.15
Olive trees	0.32	0.27	0.16
Total area (ha)	12.5	5	2.37
Irrigated area (ha)	12.5	4.20	2.28
Intensification rate	100%	84.16%	96.56%

Source: data survey.

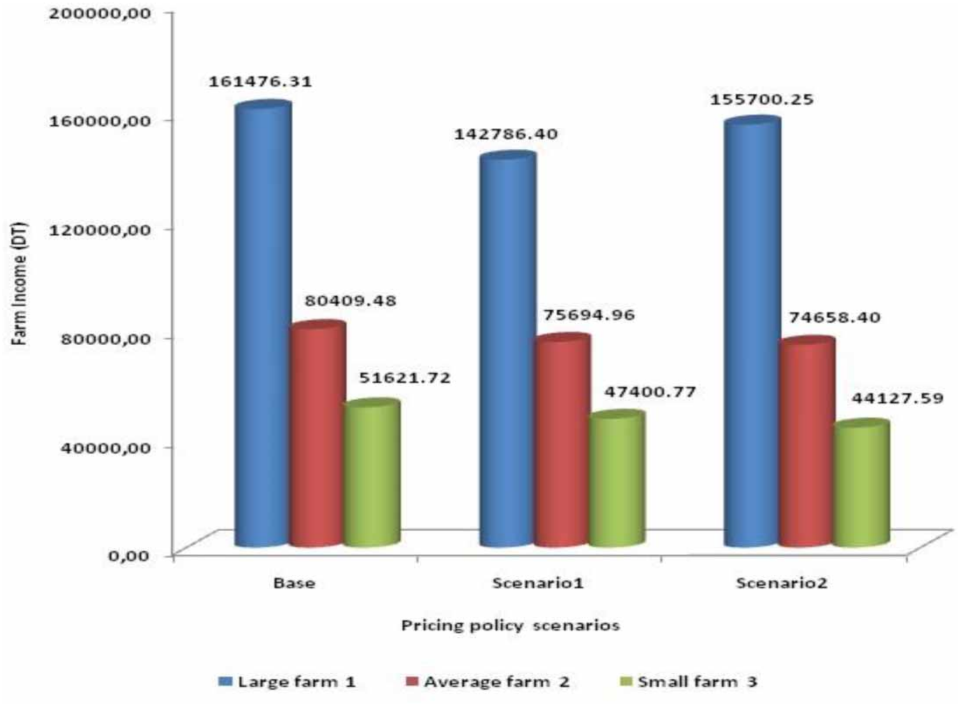


Figure 3 | Economic impact.

crops added even at high intensification. The decline in farm income following the increase in water prices is also justified in other case studies such as the case of the Karkheh River basin in Iran under the effect of climate change. Indeed, the results showed using a complex simulation-optimization tool that the drop in future income is due to a substantial shift in growing areas currently devoted to high-priced wheat and barley during the winter season to areas covered with low-cost corn over the next few summers, due to a future seasonal change in expected irrigation water available, i.e. less in winter and more in summer (Fereidoon & Koch 2018).

4.3. Labor impact

The social impact is measured by the employment of agricultural labor and the use of the labor market for the employment of temporary (salaried) workers. In rural areas, the use of temporary labor contributes to the greater integration of women in agricultural activity. Table 2 shows that the application of winter seasonal pricing (scenario 1) resulted in a reduction in

Table 2 | Quantity of salaried labor (per day)

Farm Scenarios	Large farm 1		Average farm 2		Small farm 3	
	Scenario 1	Scenario 2	Scenario 1	Scenario 2	Scenario 1	Scenario 2
Salaried labor used (%)	−21	19	−21	15	−26	−8

Source: model used.

the use of working time for the three farms. Note that there was a significant drop of 26% for the small farm, but for the large farm and the small farm, the drop was 21%. On the other hand, we observed with summer seasonal pricing (scenario 2), an increase in the use of salaried labor, respectively, for large farms and medium farms of around 19 and 15%.

These results can be explained by the fact that the increase in the price of water and the decrease in water availability has led to a new land occupation plan for the most profitable crops that are less demanding in water but require more salaried labor in order to guarantee an acceptable income. On the other hand, small farms which are mostly farm owners, their agricultural activities are based on family labor and the use of salaried labor is economically unprofitable. The results show a relationship between agricultural employment and irrigation water efficiency introduced by seasonal pricing. This relationship is justified in other works; indeed, for the case of Hebei province located in North China, Yin *et al.* (2016) found that households with a higher proportion of workers and those with greater land ownership are associated with lower irrigation water efficiency. Also, Franco-Crespo & Sumpsi Viñas (2020) showed that the decision of agri-food farmers in Ecuador is oriented toward completely abandoning agriculture or toward a change toward crops more favorable to rainfed cultivation. This has a direct effect on the reduction of employment and income. Booker & Trees (2020) also that focusing on crop choices is essential to understanding changes in water productivity, labor demand and technological innovations in response to the water shortage.

4.4. Consumption water impact

The impact of the tested pricing scenarios on water consumption was not the same. Indeed, for the base scenario, we notice that the water constraint is almost saturated for all farms. The application of winter seasonal pricing resulted in a reduction only for large and small farms with water consumption rates of 93.93 and 91.85%, respectively. While, with the application of seasonal summer pricing, we notice a return to water constraint saturation for large farms, a slight decrease for medium farms with a rate of less than 1%, a regression still important for small farms and a consumption rate does not exceed 89.39% (Figure 4).

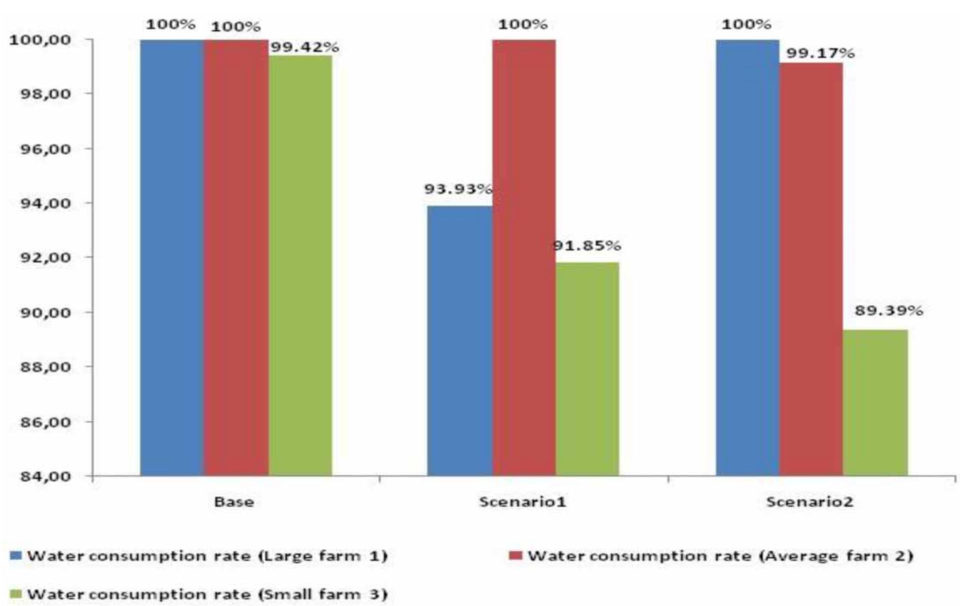


Figure 4 | Water consumption rate.

Table 3 | Variation in water consumption (m^3) per period (%)

Farm Scenarios	Large farm 1		Average farm 2		Small farm 3	
	Scenario 1	Scenario 2	Scenario 1	Scenario 2	Scenario 1	Scenario 2
Change in water consumption (%)						
Period 1	0	0	0	−1.32	0	−19.89
Period 2	−8.46	0	0	0	−11.58	0

Source: model used.

To better understand these results, an analysis of the percentage change in water consumption per period according to these tested scenarios is calculated in the following table (Table 3). The results showed that seasonal pricing could lead to a decrease in consumption during the agricultural campaign depending on the type of farm, whether in winter or summer, regardless of the variability of water availability. Indeed, we note that the seasonal pricing saturates the water constraint when the availability is poor in favor of a drop in consumption for the other season. For example, a decrease in water consumption for period 2 (summer) of −8.46 and −11.58%, respectively, for large farms and small farms against a water constraint saturation in period 1 (winter) with scenario 1 (winter seasonal pricing). Conversely, a decrease in water consumption is of −1.32 and −19.89%, respectively, for large farms and small farms against a saturation of water constraint in period 2 (summer) with scenario 2 (summer seasonal pricing). On the other hand, we noticed a saturation of water constraints, respectively, for winter pricing (scenario 1) for average farms and summer pricing (scenario 2) for large farms. These results show that small farms are the most affected by summer seasonal pricing. We can deduce that land and water are limiting factors of agricultural activity and to guarantee an agricultural income, the search for the agricultural activity that consumes the least water and is the least expensive will be the most favored in the land occupation by crops.

4.5. Land allocation impact

According the Figure 5, the results for large farms 1 with winter seasonal binomial pricing (Scenario 1) showed the appearance of the area cultivated with seasonal potatoes of 4 ha compared to the early potato crop which was not retained by the model. There was also an increase in the area cultivated with wheat by one hectare (1 ha). Thus, the results show a decrease in the pepper area of 3.02 ha to reduce water consumption. By applying the summer seasonal pricing, we noticed in particular an increase in the area cultivated with early potatoes by 4 ha because this crop consumes less water. On the other hand, the wheat crop recorded a slight increase of 0.65 ha. We also note the decrease in the area allocated to the cultivation of pepper

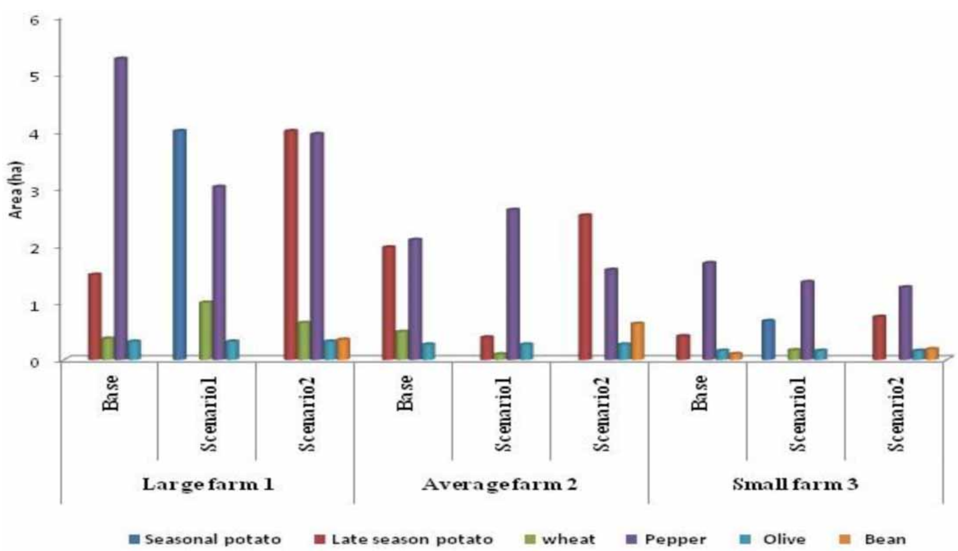


Figure 5 | Occupation of cultivated area.

by 3.95 ha because this crop requires more water and on a regular basis. An appearance of the broad bean crop of 0.35 ha is recorded.

For average farms 2, the results of the model with winter seasonal binomial pricing (*Scenario 1*) showed a decrease in the area allocated to early potato cultivation in favor of seasonal potato cultivation which was not retained by the model because this crop requires more water and more salaried labour. There was also a decrease in the area cultivated with wheat by 0.1 ha because this crop is of low added value. Thus, the results show an increase in the area of pepper of 2.62 ha; this is explained by the inelasticity of pricing with crops with high added value for this type of operation. The broad bean crop was not retained by the model in the new rotation because this crop needs water on a regular basis but its added value is low. By applying the summer seasonal binomial pricing (Scenario 2), we will notice in particular an increase in the area cultivated with early potatoes by 2.53 ha and an appearance of the area allocated to broad bean cultivation by 0.63 ha to contribute to soil fertility in favor of wheat cultivation and a slight decrease in pepper cultivation 1.57 ha. In the search for an acceptable income, seasonal pricing encourages farmers to practice crops that consume less water and are less expensive

For small farms 3, the binomial seasonal winter pricing (*Scenario 1*) recorded the appearance of the area cultivated in season potatoes of 0.68 ha and the area cultivated in wheat of 0.17 ha in favor of the cultivation of potatoes primer land and the reduction in the surface area of peppers and for the cultivation of broad beans was not retained in this rotation. With the summer seasonal pricing (Scenario 2), there was a slight increase in the area cultivated with early potatoes by 0.75 ha. For season wheat and potato crops were not retained by the model in the new rotation. This is a slight increase in bean cultivation of 0.19 ha.

4.6. Sensitivity test for water saving

A sensitivity test for water saving was applied for the three farm types. Figure 6 shows the response of the farm to the seasonal water price increase. Water saving is possible during the winter season for large farm 1 (Figure 6(a)) and during the summer season for small farm 3 (Figure 6(c)). On the other hand, for the average farm 2, water savings only begin to be significant from a price increase of 10% in summer and 20% in winter (Figure 6(b)), the specification of this farm that the quantity of water saved becomes greater in the winter season from a price increase rate of 30% unlike other farms 1 and 2. These results also show that when demand is elastic, water saving is possible and pricing becomes an incentive instrument, which has already been shown in other works. Martínez-Dalmau *et al.* (2023) showed that the water pricing policy has an effect on reducing water consumption water and therefore gross margin. Water pricing therefore remains a decision-making tool for decision-makers but is insufficient and requires a process of adaptation (Grafton *et al.* 2020).

According to Figure 6, when the increase in pricing rate exceeds a certain threshold, the quantity of water saved remains constant and in this case, the pricing instrument becomes ineffective in terms of water saving and it is affected negatively by farmers' income considerable way. Given this heterogeneity of responses, effective pricing which can lead to savings in irrigation water for different types of farms lies between an increased rate of 20 to 60%. We can deduce that seasonal pricing remains an effective instrument but it introduces a dynamic for the water-saving strategy which increases water productivity not at the individual scale but at all the public perimeter. This dynamic water saving encourages farmers to diversify crops between early, seasonal and late-season crops by integrating the crop rotation for each season (Jeder *et al.* 2014).

5. DISCUSSION

It can be deduced that alternative seasonal pricing can be interpreted as an appropriate regulatory instrument for better allocation of water resources throughout the agricultural season. Indeed, alternative pricing can be modulated taking into account the seasonal availability of water resources depending on climatic conditions. The response of farmers' behavior to seasonal pricing and water availability is an incentive for crops that consume less water, are more profitable and also improve soil fertility. This heterogeneity in behavior of farmers in the Kalâa Kebira region reflects the possibility of having a better reallocation of resources. Indeed, seasonal winter pricing (scenario 1) was favorable to large farms since it allows farmers to achieve maximum income with better water management thanks to a production system based on the most profitable crops and the least water-consuming. On the other hand, summer seasonal pricing (scenario 1) was favorable to small and medium-sized farms where farmers grow cheaper crops that can guarantee an acceptable income in favor of water-consuming and labor-intensive crops.

To summarize, the results of this paper showed a differential impact induced by a seasonal pricing policy for irrigation water on irrigated farms in Tunisia. These results are justified elsewhere, as from the Duero Valley in Spain. Sensitivity

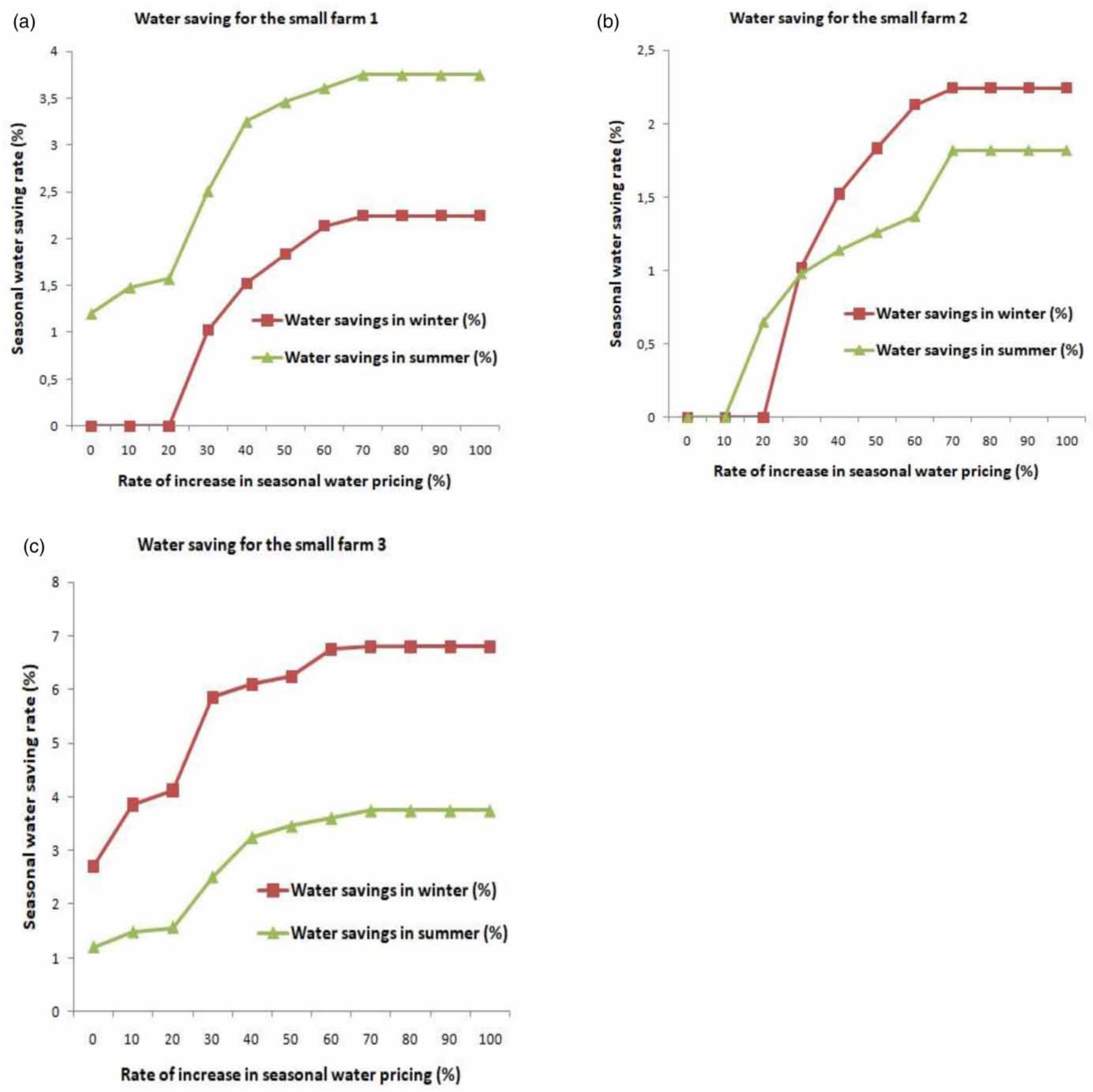


Figure 6 | Sensitivity test for water saving of three farms types: (a) large farm 1; (b) average farm 2; (3) small farm 1.

test and differential analysis to assess the impact of a water pricing policy made it possible to observe significant differences in the evolution of agricultural income, as well as the demand for agricultural employment and the consumption of products agrochemicals resulting from the increase in irrigation water prices (Gómez-Limón & Riesgo 2004).

6. CONCLUSION

In the context of climate change, the degradation of water resources will be accelerated in terms of quality and quantity. Therefore, the distribution of irrigation water between farmers is linked to their availability of water throughout the agricultural campaign. Taking into account the significant increase in water demand for irrigated agriculture in public areas, agricultural policy in Tunisia has always made water pricing policy a regulatory instrument and provides policy-makers with crucial information and guides government policies (Hossain *et al.* 2022). This instrument was always interpreted as an accounting rate determined beforehand according to the result of the financial balance sheet of the previous year of the Agricultural Development Group without any adjustment during the agricultural campaign and without taking into account climatic conditions. To highlight the flexibility and advantage of using an alternate pricing method, this work is a contribution to clarify the possibility of practicing alternative seasonal pricing for the case of the study region of Kalâa Kebira in the center-east of Tunisia.

The model results showed that the adoption of the seasonal winter pricing policy was favorable for large-scale farms since farmers can have an increase in maximum income with better management of water resources by resorting to more profitable and less water-consuming crops. On the other hand, summer seasonal pricing is more advantageous for farmers on both medium-sized farms and small-scale farms who can maintain an acceptable income with a production plan that uses the available water resources more sparingly. We can also deduce that the seasonal alternative pricing has contributed to combining winter and summer crops according to the farmers' ability to cover the production cost in terms of salaried labor and water consumption. Testing sensitivity to seasonal water pricing can lead to water savings whether in winter or summer by encouraging farmers to behave strategically in land use by diversifying early, seasonal crops and late seasons which also makes it easier to integrate rotation into the crop rotation to preserve not only water resources but also soil fertility. Pricing can be effective for public areas irrigated from dams, as in the case of the Kalâa Kebira region, not only to take into account the availability of water throughout the agricultural campaign but also to encourage farmers to adjust their production plan at the most probable climatic condition.

This study confirms the main idea that water pricing is an effective regulatory instrument for saving water in agriculture as other research studies have already reported this effectiveness (Albiac *et al.* 2000; Dinar *et al.* 2015; Jeder *et al.* 2019a, 2019b). With the same objective of strengthening farmers' behavior in adapting to climate change, seasonal pricing could play a very important role not only for water saving but for the different aspects of the production system in rural areas. These results will be deepened by an integrated approach that will simultaneously improve environmental factors through a better irritation pattern and reduce greenhouse gas emissions (Carrillo Cobo *et al.* 2014). In this sense, a bioeconomic modeling based on positive mathematical programming that takes into account both climate change and environmental externalities will be of interest to assess the mitigation of greenhouse gas emissions and the resilience of agricultural systems in Tunisia to climate change.

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DATA AVAILABILITY STATEMENT

Data cannot be made publicly available; readers should contact the corresponding author for details.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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