ASSESSING FARMERS' DECISIONS TO INVEST IN TWO WATER-SAVING IRRIGATION METHODS USING STOCHASTIC DYNAMIC PROGRAMMING

Dorina Grazhdani*

* Agricultural University of Tirana, Faculty of Economy & Agribusiness, Department of Agribusiness Management, Tirana, Albania

corresponding author: Dorina Grazhdani, e-mail: d.grazhdani@yahoo.com

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ABSTRACT

Farmers' decisions on whether to invest in a drip or sprinkler irrigation system are examined using an optimization method in response to weather uncertainties. This was done by looking at the production of five common crops grown on two types of soil and under three different policy scenarios: no policies applied, a water pricing system where farmers pay per millimetre of water used, and a subsidization scheme that reimburses farmers for the capital costs of irrigation equipment. Findings reveal that drip irrigation (DI) is not a financially viable investment option for any soil type and for any crop grown on it in the absence of any applied policies as well as in the presence of alternative water pricing levels. Furthermore, for the pricing system policy scenario, farmers growing certain crops on both soil types decided either to delay the installation of sprinkler irrigation (SI) or not use it all. In addition, the applied subsidies on the capital cost of irrigation equipment significantly influence the farmer's investment decision to switch to SI earlier than in the absence of such policies, but also, depending on the soil and crop type and the level of subsidies, to switch from SI to DI.

Keywords: *optimal irrigation planning, irrigation water pricing system, stochastic dynamic programming, subsidies for capital irrigation equipment, water-saving irrigation methods*

INTRODUCTION

This research was conducted in the semi-arid region of the Korça Plain, southeast Albania, which has a climate with large changes in air temperature throughout the year, with August being the warmest month, and January the coldest. The distribution of rainfall in the Korça Plain region is typically Mediterranean, with heavy rainfall during the cold half of the year and little rainfall during the warm half with a drought that can last for several months. Increased spring temperatures will also affect the growing season of crops. Much of the irrigation infrastructure is outdated and not fully suitable for its intended purpose, therefore requiring improvement. Water management in agriculture is one of the key challenges facing the agricultural sector due to environmental consequences and needs to be properly addressed.

Numerous studies [1 - 7] have examined the impacts of climate change on agriculture in general, in particular, its effects on water availability and quality, as well as the quantity of water needed for agriculture, which is to provide food security for the projected global population of 10 billion by 2050 [8]. On the other hand, numerous other studies [9 - 17] argue that climate change will lead to an increase in the demand for irrigation water, a decrease in crop yields, and a decrease in the supply of water in regions where irrigation is either most needed or has a comparative advantage. According to Alexandratos and Bruinsma [18], Pereira and Marques [19], and FAO (Food and Agriculture Organization of United Nations) [1], irrigated agriculture consumes 70 % of freshwater resources and forecasts an increase to 80 % in many river basins and aquifers in semi-arid and arid regions by 2030. For this reason, as Yang et al. [20] emphasize, agricultural water conservation is of utmost importance, especially for those regions. Given that irrigated agriculture is currently the world's largest user of freshwater [21], the need for effective irrigation water management planning is paramount, as highlighted by Khor and Feike [22], Imran et al. [23], and Siyal et al. [24].

Research on irrigation [25 - 28] has revealed that traditional methods cause overwatering and increase the likelihood of chemicals and nutrients leaching from plants roots into groundwater. This, according to Siyal et al. [29], makes freshwater resources less available. Yang et al. [30] pointed out that the wise use of water in irrigation with technologies that use less water is crucial to sustain agricultural production and meet growing global food needs. Espinosa-Tasón et al. [31] also highlight that when water is scarce, one typical solution is to install water-saving devices and upgrade older ones, i.e., less efficient irrigation systems need to be replaced by newer, pressurized ones like sprinkler irrigation (SI) and drip irrigation (DI). These, as shown by Balana et al. [32], improve irrigation management and increase water use efficiency, addressing the unequal distribution and limited availability of water resources, and as argued by Jing et al. [33] and Krishnan et al. [34], farmers can increase their profits while reducing water consumption, improving agricultural production and adaptability. Furthermore, according to Heumesser et al. [35], water-saving irrigation methods such as DI and SI not only decrease water consumption but also guarantee crop growth in arid and semi-arid regions.

Many people see DI as a modern way of watering crops, which, as presented by Ding et al. [36] and Bajpai and Kaushal [37], allows for the efficient and regular delivery of water and fertilizer directly to the plant roots using emitters or drippers, which can improve crop production with more accurate water application [20, 38, 39]. Cetin and Bilgel [40] and Fukai and Mitchell [41] state that DI is better than other systems because it increases crop yields while using less water, which helps minimize water loss due to seepage and evaporation. Additionally, Gebremeskel et al. [42] and Zakhem et al. [43] note that when DI is used with better fertilizer management and proper nutrient distribution, it helps crops experience less stress, allows for earlier harvests, improves crop quality, and leads to more consistent yields.

Previous research [44 - 51] estimates the costs and benefits of technology changes. Due to the potential risks involved, some farmers, particularly those who are risk-averse, may be hesitant to use more efficient irrigation systems. They concluded that improving water-use efficiency requires investment in irrigation technologies. Such investment supports a range of demand-side management policies under the European Water Framework Directive, including the use of water pricing, metering to facilitate volume-based charging, and appropriate subsidy schemes to cover the costs of irrigation equipment.

Numerous researches [52 - 56] have examined the above-mentioned issue, addressing the inherent risk associated with agricultural water management to solve water allocation problems caused by uncertainty, such as unpredictable weather, changes in crop yields, varying prices, and changes in economic policies that affect farmers' cautious choices about investing in water-saving irrigation. They suggest that significant recent advances in mathematical programming methods may help solve these problems. Various model-based optimization functions, as pointed out by Ridier et al. [57], are used to manage irrigation and understand how it is affected by climate [51, 58 - 60]. Many researches, as Ren et al. [61] mention, often use mathematical programming methods to explore these relationships because these methods have solid theories and straightforward approaches. Stochastic techniques are more likely to be relevant in practice because, as Archibald and Marshall [62] and Linker [51] argue, they provide the best tool for explaining risk-averse behaviour in farmers' decision-making. This study used a method known as stochastic dynamic programming, first introduced by Richard E. Bellman in 1957 [63], which represents the problem under examination as a Bellman equation [52].

This study aimed to use a stochastic dynamic programming approach to evaluate a farmer's optimal investment strategy for either a water-saving DI system or an SI system amidst weather uncertainty in the semi-arid Korça Plain agricultural region and to determine the probability of adopting any irrigation system by 2050 for three different policy scenarios. The impact of these scenarios on farmers' optimal investment strategies was examined, as well as whether they were affected by crop type and soil type.

The novelty of the study is twofold. First, the analysis relies on a combination of simulation and survey data. Second, during the estimation process, more appropriate stochastic techniques solved the study's recent optimization function.

MATERIALS AND METHODS

Case study

The Korça Plain is located in the southeastern part of Albania with an area of 806 km². It is situated under the Seman water basin, which is crossed by the Devoll River in its northern part, and is known for its considerable dynamic groundwater resources. Korça Plain has a transient Mediterranean climate (or Mediterranean continental climate) with large temperature changes and an average annual rainfall of 710 mm, occurring mainly between April and October. It is considered one of the most important locations for the production of field crops in Albania. It is distinguished by numerous positive essential elements, such as extensive fertile land, a semi-arid climate, and an exceptional tradition of renowned farmers.

Although Korça also widely grows vegetables, cereals are the most important crops. In the Korça Plain, intensive agriculture with excessive irrigation expanded from the 1970s to the end of the 1990s. This resulted in a decrease in the annual groundwater level and adversely affected the quality of groundwater by increasing the level of nitrates penetrating it. Korça currently uses mainly surface irrigation; however, DI and SI are also applied on a limited area and for specific crops. The implementation of a DI system in Korça could potentially be a realistic option in the future.

No previous studies have been conducted in the Korca plain to analyse farmer's decision to invest in a more water-efficient irrigation system. These considerations led to this study.

Model used

The model described in [35] was used in this study. It is an optimization model solved by a stochastic dynamic programming model in which the farmer decides in each planning year whether to invest in a drip or sprinkler irrigation system and whether to use it in the following year, depending on the information about the annual amount of rainfall. This is why the model assumes that there are 200 possible annual precipitation events, $P_t \sim f(\rho_t^1, ..., \rho_t^n)$, that can happen with equal probability in every given year.

The question of who uses it can be framed as an optimization problem including the timing of investment decisions, a_t, and the selection of operational actions, u_t, to maximize the predicted total profit over the planning period, as shown below:

$$\max_{a_t,u_t}\left\{E\left[\sum_{t=1}^{31} e^{-rt}\left(\pi\left(u_t,\rho_t^i\right)-c(x_t+a_t)\right)\right]\right\} \quad (1)$$

where the term represented by the $\pi\left(u_t,\rho_t^i\right)$ refer to the annual operational profit in period t, $c(x_t+a_t)$ denotes the annual capital cost, and e^{-rt} represents the discount factor used to calculate the present value of the future profit received at time t.

The annual profit in period t, which depends on the operational actions u_t and the annual precipitation amounts ρ_t^i, is represented by equation (2):

$$\pi\left(u_t, \rho_t^i\right)=y\left(u_t, \rho_t^i\right)p_c-(c_{Lh}c+Varc)-q_e\left(u_t, \rho_t^i\right)p_e-i\_Lh\left(u_t, \rho_t^i\right)c-q_n\left(u_t, \rho_t^i\right)p_n \quad (2)$$

Equation (2) includes two types of parameters. The first are those that are assumed to be constant over time: p_c, the constant market price for each crop; c, the pay per hour; p_e, cost of electricity per kWh; p_n, the price of fertilizer, and Varc, the variable cost calculated per crop, including reparation costs, fuel costs, licensing fees, herbicide costs, fungicides, pest control, and seeding costs. The other parameters depend on operational decisions and the annual precipitation. These include crop yield, $y\left(u_t, \rho_t^i\right)$, the labour requirement per crop, $q_e\left(u_t, \rho_t^i\right)$, the annual labour requirement for irrigation activity, $i\_Lh\left(u_t, \rho_t^i\right)$, and the annual amount of nitrogen fertilizer used, $q_n\left(u_t, \rho_t^i\right)$.

Annual operating profit is mainly influenced by changes in precipitation; therefore, any changes in farmers' operational choice, i.e., whether to invest or not, u_t, must arise from changes in precipitation. Just to emphasize this fact, the terms on the right-hand side of equation 2, except for the term (c_Lh c+Varc), depend on the operational choice u_t and the amount of rain that falls each year ρ_t^i. While referring to mathematical operations, each term is given as a product of the model's term value and its corresponding price.

The annual fixed cost of the corresponding irrigation systems in the year following the investment decision, $x_{t+1}=x_t+a_t$, is equal to the annual capital cost, $a\_Capc(x_t+a_t)$, plus the annual cost of building the well, $a\_well(x_t+a_t)$:

$$c(x_t+a_t)=a\_Capac(x_t+a_t)+a\_well(x_t+a_t) \quad (3)$$

where, in the context of the model, the variable 'x_t' indicates the operational action in year t, which can take values of 0, 1, or 2: 0 indicates that the irrigation system is not established, 1 indicates drip irrigation, and 2 represents sprinkler irrigation. Additionally, the variable 'a_t' refers to the investment decision in year t, and can have values 0, 1, or 2: 0 indicates no investment, 1 corresponds to drip irrigation, and 2 indicates sprinkler irrigation. More information about x_t and a_t can be obtained in reference [35].

The optimal time for investment and operational decision in each year is obtained recursively by solving the Bellman equation as described by Heumesser et al. [35]. More details about this model can be found in reference [35].

This study conducts separate estimations for each crop and soil type to calculate the probability of a farmer's decision to choose whether to invest in a drip irrigation system or sprinkler irrigation system as an irrigation method.

Data collection and analysis

The procedure of collecting and analysing the necessary data for this study was as follows: First, through consultations with local stakeholders and authorities, the selection of crops that are more commonly grown on the Korça Plain and soils to simulate the production of these selected crops was conducted. Five crops were selected: winter wheat, sugar beets, potatoes, corn, and tomatoes, which cover more than half of the agricultural land of the Korça Plain. Therefore, their biophysical impacts on farmers' decisions to invest were modelled. Two different soil types were selected: Soil 1 is characterized by fine silt and loess development. It has a water supply capacity of 204 millimetres and a humus content in the surface layer of 3.1 %. It covers almost half of the area of Korça. Soil 2, which has a water supply capacity of 52 millimetres and a humus content in the surface layer of 1.1 %, i.e., less fertile soil, making up about fifteen percent of the region's agricultural land.

Second, the biophysical process simulation model by Izaurralde et al. [64] was used to identify important factors for a stochastic dynamic programming model for the period from 2025 to 2050. This model automatically simulates important biophysical processes in agricultural land use management based on five thematic datasets: weather, cropland management, topography, soil, and land use. In this study, the values of annual crop yield for the period 2025 - 2050 were automatically simulated by this model using survey data collected from 2000 to 2004 for each of the five common crops grown on the two different soil types described above. Also, production inputs for nitrogen fertilizer and irrigation water were also simulated based on levels of nitrogen and the number of water stress-free days during the growing season, as determined by the survey.

Third, the climate model for Albania, created by the former Albanian Hydro-meteorological Institute, uses weather data collected in site from 1975 to 2024 to obtain the data needed for the climate in the model. Therefore, using the above-mentioned climate model for Albania, a trend was first derived for each weather parameter needed for this study for the Korça meteorological station for the period 1975 - 2024, and then they were extrapolated for the study period, 2025 - 2050. This procedure is used to generate the simulation data for solar radiation, wind speed and direction, relative humidity, and precipitation. Since the biophysical process simulation model takes meteorological data as direct inputs, 200 "weather scenarios," generated by the bootstrapping process, are collected for each year and for its output parameters simulated as previously described, which allows for a deeper understanding and functioning of the model behaviour. In addition, annual precipitation is projected to decreases by -5 % by 2030, -10 % by 2035, -15 % by 2040, and -20 % by 2045.

Fourth, annual crop yields, variable production costs, and average commodity prices from 2020 to 2024 were used, as well as the costs of irrigation systems and the labour hours required to install and operate these systems per hectare to calculate annual profit. Simulation data for these parameters were generated using the average values from survey data collected between 2000 and 2004, together with future inflation projections produced by the Albanian INSTAT Institution, which is similar to EUROSTAT.

Fifth, Matlab 5.0 was used for all operational data management and analysis in this study.

RESULTS AND DISCUSSION

Summary statistics of relevant model parameters for the period 2020 - 2050

To save space, this subsection provides only a brief summary of statistics on dry matter crop yields, irrigation water input, and corresponding profits. Table 1 shows these estimates for the period from 2025 to 2050, taking into account more than 200 different weather scenarios. The required information on crop yields in t/ha/year and irrigation rates in mm/year comes from the biophysical process simulation model and a statistical climate model for Albania, and these data are used to calculate profits.

The summary statistics presented in Table 1 suggest the following conclusions: In the period from 2025 to 2050, for all crops and two soil types, sprinkler systems require more irrigation water inputs, while DI generally leads to lower average profit, which is highest for tomatoes and decreases in the following order: potatoes, sugar beets, corn, and wheat. In addition, SI results in lower average dry matter crop yields compared to DI for soil 1, while it produces higher yields for soil 2.

Model results when no specific policies are applied

This section of the paper shows the results of farmers' decisions on whether to invest in a drip or sprinkler irrigation system and use it during the planning period, without following any specific policies, based on the stochastic dynamic programming model used in this study. Table 2 shows the modelling results.

The obtained results presented in Table 2 show that the type of soil (soil 1 or soil 2) and the crops grown on it influence the decisions made by farmers. First, they show that for both soil types and the five crops grown on them, the probability of farmers investing in DI is zero in any given year. Significant operating or capital costs make DI unfeasible, which may explain the obtained result.

Furthermore, the probability that farmers will invest in a SI system in any given year is positive, depending on soil types and crops grown on them. Therefore, the results show that on soil 1 there is a 100 % probability that this type of irrigation will be used in 2037, 2041, and 2043, but only for three crops, i.e. tomatoes, potatoes, and sugar beet. On soil 2 there is a 100 % probability of using SI for the production of tomatoes, potatoes, sugar beets, and corn in 2036, 2038, 2039 and 2040, respectively. Also, there is a 100 % probability of using SI for winter wheat cultivation in 2044.

Table 1. Brief summary statistics (mean value and standard error in brackets) on crop yields, irrigation water input, and profits for each crop type, soil type, and irrigation method (sprinkler irrigation (SI) and drip irrigation (DI)) for the period 2025 - 2050

Variable		Agricultural crops				
		Wheat	Corn	Sugar beets	Potatoes	Tomatoes
Soil 1	Crops yields (t/ha/y)					
	SI	5.8(0.8)	7.6(0.6)	40.8(3.8)	13.8(2.5)	61.8(4.9)
	DI	5.9(0.8)	8.1(0.5)	43.1(4.1)	14.9(2.3)	65.3(5.3)
	Irrigation water input (mm/ha/y)					
	SI	72(24)	207(47)	264(52)	223(31)	259(41)
	DI	48(19)	168(34)	208(46)	186(34)	211(54)
	Profits (€/ha)					
	SI	132.4(39)	86.4(18)	132(32)	987(71)	2431 (281)
	DI	46.7(25)	62.1(43)	86.4	964(83)	2232 (187)
Soil 2	Crops yields (t/ha/y)					
	SI	4.9(0.8)	5.2(0.4)	38.2(9.7)	12.5(0.8)	58.7(6.7)
	DI	4.1(0.9)	4.9(0.3)	36.4(10.7)	12.1(0.9)	56.6(4.6)
	Irrigation water input (mm/ha/y)					
	SI	92(34)	311(61)	384(73)	251(48)	382(69)
	DI	84(27)	277(39)	339(72)	223(51)	333(64)
	Profits (€/ha/y)					
	SI	98.5(22)	87.8(24)	196.4(31)	764(67)	2097 (115)
	DI	57.6(33)	67.3(57)	138.4(47)	737(51)	1957(134)

Table 2. Year from which sprinkler irrigation will begin to be installed with a probability of 100 % on soil 1 and soil 2 in the scenario without applied policies

Year	Wheat		Corn		Sugar beet		Potatoes		Tomatoes	
	Soil 1	Soil 2	Soil 1	Soil 2	Soil 1	Soil 2	Soil 1	Soil 2	Soil 1	Soil 2
2036										+
2037									+	
2038								+		
2039						+				
2040				+						
2041							+			
2043					+					
2044		+								

Model results when irrigation water pricing system is applied to sprinkler irrigation

This study also aims to investigate whether the implementation of a policy scenario - an irrigation water pricing system ranging from 0.1 to 1.0 € per millimetre - affects farmer's optimal investment strategy when choosing between drip and sprinkler irrigation. In this policy scenario, stochastic dynamic programming is used to analyse whether increased operational costs lead to implementation of the DI system at a given point in time, and it also investigates whether these costs delay or prevent the use of SI on certain crops compared to situations where no policies are applied. Table 3 presents the findings on the year when SI will be installed with 100 % probability on soil 1 and soil 2 for each of five different water price levels.

Based on a brief look at Table 3, two important conclusions can be made. First, farmers do not use DI at any irrigation pricing policy level, regardless of the soil type or crop. Second, the farmers are less inclined to invest and install SI for certain crops on both soil types due to rising irrigation costs, which either delays their implementation or prevents their use.

The results in Table 3 for soil 1, i.e. the more fertile type, show that farmers will not use SI for growing wheat and corn regardless of the water price level. The year for applying SI remain the same as in Table 2 for tomatoes (2037) and potatoes (2041) at 0.1 €/mm. Farmers delayed the use of SI for sugar beet cultivation at water prices of 0.1 €/mm and 0.3 €/mm and do not use it at other water price levels compared to the situations where no policies are in place. Regarding tomato production, it is worth noting that the optimal time for setting up and implementing an SI system remains the same as in Table 2 at a water price of 0.1 €/mm, but at a water prices of 0.3 - 1 €/mm, it is delayed, also compared to the situations where no policies are applied.

Table 3. The year when sprinkler irrigation will be installed with 100 % probability on soil 1 and soil 2 for each of five different water price levels

Variable		Water pricing policies levels (in €/mm)				
Soil type	Corp	0.1	0.3	0.5	0.8	1.0
Soil 1	Wheat	-	-	-	-	-
	Corn	-	-	-	-	-
	Sugar beet	2046	2046	-	-	-
	Potatoes	2041	-	-	-	-
	Tomatoes	2037	2042	2042	2044	2048
Soil 2	Wheat	2049	-	-	-	-
	Corn	2046	-	-	-	-
	Sugar beet	2042	2042	2045	-	-
	Potatoes	2038	2038	2045	2045	2048
	Tomatoes	2036	2036	2040	2040	2046

The data in Table 3 for soil 2, i.e. less fertile soil, show that farmers growing winter wheat and corn decided to delay the use of sprinklers for irrigation at a water price level of 0.1 €/mm. They also decided not to use sprinklers for other water prices during the study period. Regarding the sugar beet crop, if water price is 0.1 and 0.3 €/mm, the optimal year for farmers to start using SI on sugar beets will not be before 2042. This will be delayed until 2045 if the water price reaches 0.5 €/mm. At water prices of 0.8 and 1 €/mm, farmers decided not to use SI. The probability of using SI for growing potatoes and tomatoes will be the same at water price levels of 0.1 €/mm and 0.3 €/mm compared to situations where no policies are applied (Table 2). It is delayed at water prices from 0.5 to 1 €/mm.

The results presented in this section of the study are similar to those in references [35, 65]. Other researchers [66 - 69], whose results differ from those already mentioned, say that putting water prices at the top of the priority list is necessary to reduce the impact of water use in agriculture on the environment, because by increasing water prices, farmers will invest in more efficient technologies, i.e. this would lead to an increase in the adoption rate of drip irrigation and thereby contribute to a reduction in the total amount of water used. They also emphasize the need to increase agricultural output, improve water sustainability and conservation, and increase overall water use efficiency in agriculture by facilitating the use of SI and DI technology, especially in semi-arid areas such as the one studied in this research.

Based on the findings in this subsection, it can be concluded that the farmers in the study area are aware of their own economic interests, but they are not inclined to invest in DI and SI. To mitigate this behaviour of farmers, local politicians and decision-makers should implement educational initiatives to improve farmers' ability to adopt new water-saving technologies. Policymakers should collaborate with administrative units to organize and promote training initiatives that provide technical expertise and operational direction. These initiatives will improve the distribution and use of water-efficient irrigation systems. Furthermore, structural elements such as regional economic composition, infrastructure development, and the institutional framework significantly influence farmers' decision-making processes. Therefore, prioritizing the improvement of regional water conservation infrastructure, establishing a comprehensive monitoring and evaluation system for water-saving irrigation technologies, and improving relevant laws and regulations can create a supportive environment for adopting these technologies, ultimately encouraging more sustainable and efficient agricultural practices.

Model results when sprinkler and drip irrigation capital cost subsidies are applied

The study considered five levels of subsidies, ranging from 30 to 90 % of the total capital cost of irrigation equipment, to evaluate the impact that these subsidies have on the farmers' investment decisions. Table 4 shows the results obtained by the stochastic dynamic programming model. Considering the results in Table 4 for soil 1, the following conclusion can be drawn: A 30 % subsidy has no impact on farmers' investment choices compared to situations where no policies are applied (Table 2). This means there is a 100 % probability that they will use SI only for sugar beets, potatoes, and tomatoes, and will not use any irrigation method for wheat and corn crops. As for 50 % subsidies, farmers will decide to invest and start installing SI for corn, sugar beets, potatoes, and tomatoes (Table 4).

Table 4 shows that the situation is different for subsidies ranging from 70 to 90 % of the capital costs of irrigation systems on soil 1. For this range, farmers have decided to switch from SI to DI, except for the wheat crop, for which SI starts with a subsidy of 70 % in 2049, with 80 % in 2047, and with 90 % in 2043. For other crops, the switch from sprinkler to drip occurs if farmers receive subsidies of 70 %, 80 %, and 90 %. However, the year when the switch will occur is different for different crops.

Table 4. The year when drip irrigation (DI) and sprinkler irrigation (SI) will be installed with 100 % probability on soil 1 and soil 2 for each of five different values of irrigation subsidies

Variable		Subsidies									
		30 %		50 %		70 %		80 %		90 %	
Soil	Corp	DI	SI	DI	SI	DI	SI	DI	SI	DI	SI
Soil 1	Wheat	-	-	-	-	-	2049	-	2047	-	2043
	Corn	-	-	-	2044	2045	-	2043	-	2040	-
	Sugar beet	-	2043	-	2040	2041	-	2038	-	2034	-
	Potatoes	-	2041	-	2036	2037	-	2035	-	2031	-
	Tomatoes	-	2037	-	2034	2036	-	2033	-	2029	-
Soil 2	Wheat	-	2044	-	2040	-	2038	-	2036	2042	-
	Corn	-	2040	-	2038	-	2035	-	2031	2038	-
	Sugar beet	-	2039	-	2034	-	2030	2044	-	2040	-
	Potatoes	-	2038	-	2032	-	2029	2040	-	2033	-
	Tomatoes	-	2036	-	2031	-	2028	2037	-	2031	-

Regarding soil 2, it can be seen from the results in Table 4 that a 30 % subsidy has no impact on the investment strategy for any crops (refer to Table 2). Subsidies of 50 and 70 % encourage farmers to invest earlier in SI. At a subsidy of 80 %, there is a 100 % probability that there will be a transition from SI to DI, except for wheat and corn crops, for which the investing in DI may start with a subsidy of 90 %. With a 90 % subsidy, investment in DI for sugar beets, potatoes, and tomatoes will start earlier than with an 80 % subsidy.

The findings of this subsection show that investment in DI is unlikely unless subsidies ≥ 50 % are granted for equipment costs. It shows how these subsidies could have crowding out effects by offering incentives to switch from non-irrigated crops (like wheat) to the production of crops that require irrigation, like potatoes. This could lead to even higher water withdrawal rates. Farmers may also face adverse circumstances due to this increased rivalry for water resources. The findings obtained indicate that subsidies in the region are insufficient to encourage the use of DI, despite the fact that subsidies have been proven to have a good effect.

CONCLUSION

The results of this study lead to three main findings. The first one is that DI is not a financially sound investment option for farmers to produce the five mentioned crops on two soil types when no policies are applied. Farmers are likely to invest in an SI system in any given year of the research period, except for wheat and corn grown on less fertile soil. The probability of investment in SI depends on the soil type and crops grown, with earlier investments occurring in fertile soil compared to less fertile soil.

Second, the study results show that: a) contrary to expectations, the introduction of higher operating costs due to an increase in irrigation price affected the farmers' decision not to use the DI for both soil types and all crops, and b) farmers' decisions are that certain crops on both soil types are less likely to have SI systems installed, which either delays their installation or results in their non-use.

The third finding was that farmers' decisions to invest in DI are highly unlikely unless subsidies greater than fifty percent are granted for the cost of equipment. The gradual transition from SI to DI occurs only when subsidies amount to 70 - 90 % of the capital costs of the DI equipment, indicating that the timing of this transition depends on the amount of subsidy, as well as on the soil and crop type.

Based on the above findings, the following policy implications can be drawn: First, local government agencies and policymakers ought to use the findings of the current study on the implementation of water-pricing policies or equipment subsidies to guide the development of sustainable irrigation adaptation strategies. These strategies should help farmers to optimize agricultural water resources, prevent their deterioration, influence cropping patterns by shifting to more water-efficient crops, change irrigation systems from furrow to modern methods such as drip irrigation, increase water productivity, and limit the total amount of water used in Korça Plain and similar areas. Second, local policymakers and officials should offer education and training programs, provide technical expertise and operational guidance, establish a robust monitoring and evaluation system for water-saving irrigation technology, and improve relevant legislation and regulations to help farmers adopt innovative water-saving technologies that increase their ability to apply advanced irrigation methods.

This study, while offering helpful details about the farmer's optimal investment strategy to determine the probability of using either a water-saving DI system or an SI system amidst weather uncertainty for three different policy scenarios in semi-arid regions, has several limitations that should be addressed in future research. First, the relatively limited sample size at the farm level may raise concerns about the validity of the farm-level estimates. A larger and more diversified sample at the farm level, and even at higher administrative levels, or in other geographical semi-arid regions, would undoubtedly improve the generalizability of the study findings. Future research should address this issue to enhance the robustness of the results. Second, the limitation of this study is that the model of this study operates on a farm size, and the economies of scale for irrigation investment have not been included. Therefore, this issue should be one of the main focuses of future research.

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