IRRIGATION TECHNOLOGY ADOPTION: A MULTI-PERIOD APPROACH

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ABSTRACT

Alentejo region of Portugal is characterised by dry and hot summers, with the rain concentrated in the winter. Total annual rainfall can be low and with a very irregular distribution leading to a very risky dryland agriculture. The farm income of the region has been supported by cultural systems based on winter cereals. Although the low yields, these crops are profitable due to the price and subsidy policies which are not in agreement with the real world market situation. Confronted with the future impacts of the CAP reform and forecasted prices, we consider of great importance to study the transition from the typical dryland agriculture to a situation where the dryland systems are assisted by irrigation. The present work intends to evaluate the viability of investments in irrigation equipment's for several capital and water costs combinations. In order to achieve the stated objective a multi-period linear programming model was built where, besides the investment possibilities, the CAP reform measures were included. The results showed the importance of the conversion from dryland to irrigated systems in order to maintain or increase the farmers income that otherwise would heavily decrease.

RÉSUMÉ

Dans une région comme Alentejo, avec un climat méditerranéen, la precipitation totale annuelle a une distribution très irregulière et aussi très basse. Cet évenement peut donner lieu à des conditions critiques pour l'agriculture. Face aux impacts de la Réforme de la PAC et aux prévisions des prix agricoles pour l'année 2000, nous considérons de très grand importance l'étude de la transition de l'agriculture traditionnelle non irriguée pour une agriculture où les systèmes traditionnels sont aidés par l'irrigation. Ce travail vise à évaluer la viabilité des investissements en équipement d'irrigation pour differents combinations de capital et de côuts de l'eau. Un modèle de programmation linéaire multi-période a été utilisé pour décrire les differents possibilitées d'investissements en equipment d'irrigation, et aussi les differentes mésures de la réforme de la PAC. Les résultats revelent l'importance de la reconversion de l'agriculture non irriguée par l'agriculture irriguée.

Alentejo region of Portugal is characterised by dry and hot summers, with the rain concentrated in winter. Total annual rainfall can be low and with a very irregular distribution leading to a very risky dryland agriculture.

The farm income of the region has been supported by cultural systems based on winter cereals such as wheat, barley and oats as well as sunflower in the spring. Although the low yields, these crops are profitable due to the price and subsidy policies which are not in agreement with the real world market situation. The forecasted world prices for the year 2000 and the implementation of the established CAP measures for this period can lead to extreme negative impacts on income at the farm level (Carvalho and Pinheiro, 1994). According to these authors, in a study based on typical Alentejo farms, only irrigated activities will remain profitable. Confronted with the future impacts of the CAP reform and forecasted prices, we consider of great importance to study the transition from the typical dryland agriculture to a situation where the dryland systems are assisted by irrigation, namely supplying water to sunflower and wheat in dry springs. We can even convert some dryland areas to typical irrigated agricultural systems, which will lead to higher and more stable average incomes. It is also of the greater significance that these systems, when compared with the dryland ones, will be more labor demanding with the positive impacts that this will have upper and down stream.

Since nowadays the construction of a very big dam is under way in the region de Fins Múltiplos de Alqueva will irrigate 110,000 hectares of land, makes this study opportune and important because it can provide some guidelines to future research. The shifting from dryland activities to irrigated ones must always take in account that with the current increase in the water demand for agricultural and other purposes, water price will go up due to the increasing scarcity. The present work intends to evaluate the viability of investments in irrigation equipment's for several capital and water costs combinations. To achieve this objective we took a microeconomic analysis of several irrigation technologies and will combine them with different crops and crop technologies, in order to obtain economic and technical efficient combinations. A multi-period linear programming model was built where, besides the investment possibilities, the CAP reform measures were included so that the final result would take in account the present and the forecasted situation until the year 2003/04, the time horizon of the model and also the first year after the end of the specific subsidies to the Portuguese agriculture (Neto, 1995).

METHODOLOGY AND DATA

Whenever one models agricultural activities considering investments, the dynamic perspective is of crucial importance. One of the methodologies suitable for combining production and investment decisions is the multi-period linear programming which allows us to obtain a simulta-

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neous optimal solution for all the future periods given the present information.
In a multi-period model the production process is modelled for several years and the different years are linked by transfer activities. These activities transfer resources, such as cash-flows, from one year to another.
The investment decisions can be modelled as alternative activities and their economic interest evaluated. The final objective will be to optimise the result of the farm at the end of the considered planning horizon.
Among the aspects to be taken in account when building a multi-period linear programming model we can point out the definition of the objective function, the planning horizon, the discount rate and the definition of beginning and ending conditions.
The model we developed has as main objective to evaluate the economic advantage of converting dryland agricultural systems into irrigated ones, when in face of a water supply from a public irrigation system. To model this transition it was considered the necessity of making investments in irrigation equipment.
With this purpose we built a multi-period model with a planning horizon of ten years being the first one the 1993/94 agricultural year. In general terms we have annual dryland and irrigated activities that are undertaken subject to restrictions on land, labor, tractor, harvester and capital. Only land is fixed, the other resources can change by means of renting or borrowing activities.
The objective function of the model is the maximisation of the annual net income summation over the ten years, which is also called Net Present Value (NPV).
The farm considered in this study is located in Évora county, with an area of 225 ha being part of it included in a public irrigation system (70 ha). This area can therefore be converted, with investments in irrigation equipment, in irrigated land. The rest of the farm can be divided in two land use categories.
This public irrigation system supplies water under pressure to the farmers, so the irrigation technologies evaluated will be the ones using sprinklers. These technologies, besides having different investment costs, they have also distinct operation costs. This is due to the fact that they have different needs of labor, energy and water to satisfy identical crop water requirements.
The investment alternatives considered in the model are:
— Center Pivot (CP)
— Multi-Center Pivot (MCP)
— Mobile Rain Gun System (MRGS)
— Sprinkler Permanent System (SPS)
— Sprinkler Semi-Permanent System (SSPS)
Irrigation efficiency is measured by the relation between the crop water requirements and the amount of water supplied. The irrigation equipment will play an important role at the farm level in terms of application efficiency. The irrigation equipment evaluated in this work have considerable high application efficiencies which vary from 0.6 to 0.8 (Sourell et al, 1992).
These investments can take place in one of the first three years of the planning horizon. The capital to make the investments in irrigation equipments in the first year can be supplied by the farmer and/or by bank loans. In the second and third years, capital availability for investments is provided by the returns of bank deposits made the year before, by transferring short term capital of the previous year to long term capital of the next year and again by bank loans. In **table 1** we present a simplified matrix of the investments in irrigation equipments that can be made in the first year.
The crop activities considered in the model are individual crops, irrigated or not irrigated, according to the land use capacity. In the dryland it was considered only the traditional crop rotation for each type of soil. In the irrigated land, the crops could be undertaken with every one of the irrigation technology available through prior investment. For the irrigated crops it was considered for each one and using each technology three technics re-

Table 1 ***Simplified matrix of irrigation equipment investments in the first year.***

	Crop Activities		Irrigation Equipment Investment					Long Term Credit	Long Term Depos	Signal	R H S
	Dryland	Irrigated Land	CP	MCP	MRGS	SPS	SSPS				
Dryland (ha)(Year 1 and following)	a		a	a	a	a	a			≤	b
Irrigated land (ha) (Year 1 and following)											
with CP		a	– a							≤	0
with MCP		a		– a						≤	0
with MRGS		a			– a					≤	0
with SPS		a				– a				≤	0
with SSPS		a					– a				0
Long Term Capital			a	a	a	a	a	– a	a	≤	b
Long Term Credit Limit								a		≤	b

sulting from different water supplies as we will see further ahead. To obtain the average yields for the crops considered in the model we used a crop growing simulator, the Erosion Productivity Impact Calculator - EPIC, developed by Blackland Research Station, Temple. EPIC is a sophisticated mathematical model that simulates the interaction between soil, climate, plant and plant management in agricultural production. Thus EPIC model allows for the simulation of several plant species growth, taking in account on one hand the soil and climate conditions of the considered region, and on the other hand specific variables for each crop as well as the technological schedules (**figure 1**). So, when we supply a data series and the physical constraints, the model optimises the agronomic yield of the crop. In that sense, EPIC is a real simulator of production functions (Deybe and Flichman, 1991, Blaskovic, 1992). The use of EPIC in the present work was very useful to analyse the impacts of water supply reduction in the yields of irrigated crops. The EPIC can be a very useful tool in what concerns water management, specially in irrigation problems, when adjusted to the individual behaviour of the crop water use (Quinones e Cabelguenne, 1990). Using EPIC, we made thirty years simulations for the considered crops using Évora weather data for the 1961-86 period and crop technology information collected from the farmer and crossing information from the Agricultural Accounting Information Network and the University of Évora experts. Using this information we defined three technics for each irrigated crop, Technic 1 consisting in the water supply leading to the optimal yield. Technic 2 and 3 correspond to 80 and 60% of the water supplied by Technic 1, respectively. In **table 2** we can see the annual activities considered in the present work according to the land use categories and the irrigation technological investment.
The predicted prices and exchange rate were obtained by a simulation model developed by the Agricultural Economics Department of the Instituto Superior de Agronomia de Lisboa. The present and future subsidies and other measures of the CAP are the ones stablished by the CAP Reform. The discount rate used was of 9%, which corresponds to the long term bank deposit rate,

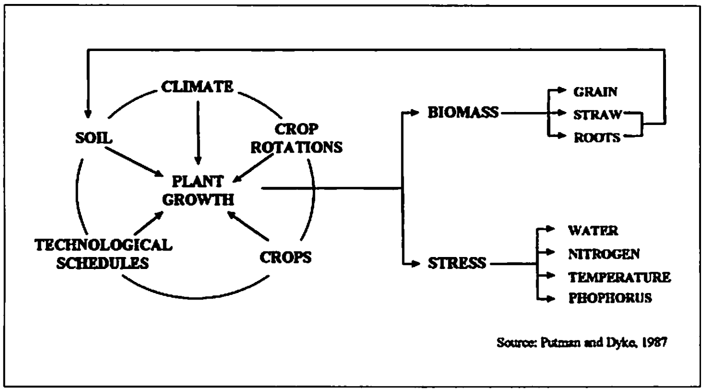

Figure 1 - EPIC model interactions.

Table 2 ***Proposed crop activities.***

Land Use Category	Agricultural System	Irrigation Equipment	Crop
I	Dryland		Sunflower Wheat Barley
	Irrigated Land	Center Pivot Multi-Center Pivot Mobile Rain-Gun System Sprinkler Permanent System Sprinkler Semi-Permanent System	Sunflower (T1) Sunflower (T2) Sunflower (T3) Wheat (T1) Wheat (T2) Wheat (T3) Maize (T1) Maize (T2) Maize (T3) Sungarbeet
II	Dryland		Sunflower Wheat Barley

Note: T1 - Technic 1; T2 - Technic 2; T3 - Technic 3.

following the opportunity cost principle (Gittinger, 1982). Since the technical and economical coefficients definition was done in strait cooperation with the farmer, it was possible to obtain a very good validation of the model.

Results

In order to achieve the proposed objective we built two models; one where we will not allow for investments in irrigation equipment (Model 1), and another where such investment is possible (Model 2). In **table 3** we present the main results of these two models. As we can see, in Model 1 optimal plan the traditional dryland activities "Sunflower " are chosen at full extent of the farm land. As expected, since future prices and subsidies will decrease, annual net income will decline over the ten years of the planning horizon. In this situation, only with dryland activities, the objective function which is the Net Present Value (NPV) achieves 59 thousand contos. This value will remunerate land, capital and management. In Model 2, when we allow for investments in irrigation equipment, that will make possible the conversion of 60 hectares of dryland in irrigated land, through the purchase of a Multi-Center Pivot in the first year of the planning horizon. This kind of equipment has a higher application efficiency then the Sprinkler Systems or the Mobile Rain Gun System, and when compared with the ordinary Center Pivot is much more efficient because it allows the irrigation of twice as much land. This investment and the possibility of choosing irrigated activities, will minimise the negative impacts of the forecasted product prices and subsidies decrease, as well as the disappearing of the specific subsidies to the Portuguese agriculture. This can be observed in the evolution of the annual net income when compared with the one obtained in Model 1. In

Table 3 ***Results of the models in the present scenario.***

Model 1 (only with dryland activities)

	NPV (contos)*	ANI (contos)*	Sunflower-Wheat-Barley Land Use Category I (ha)	 Land Use Category II (ha)
Year 1	59,176	9,413	170.1	21.3
Year 2		5,277	170.1	28.2
Year 3		7,328	170.1	21.3
Year 4		7,124	170.1	21.3
Year 5		6,631	170.1	21.3
Year 6		6,265	170.1	21.3
Year 7		4,966	170.1	21.3
Year 8		4,503	170.1	21.3
Year 9		4,058	170.1	21.3
Year 10		3,612	170.1	21.3

Model 2 (with the possibility of investment in irrigation equipment)

	Sunflower-Wheat-Barley				Land Use Category I with Multi-Center Pivot (ha)			
Year	NPV (cts)*	ANI (cts)*	Land Use Category I (ha)	Land Use Category II (ha)	Sugar Beet T1	Maize T1	Sunflower T1	Wheat T1
1	81,172	4,703	100.0	31.8		60.0		
2		3,020	105.0	36.2	60.0			
3		12,327	100.0	31.8		60.0		
4		12,153	100.0	31.8				60.0
5		9,493	100.0	31.8			60.0	
6		10,466	100.0	31.8				
60.0								
7		7,290	100.0	31.8				60.0
8		7,739	100.0	31.8				
60.0								
9		7,239	100.0	31.8				60.0
10		6,111	100.0	31.8				
60.0								

* 1 conto ≅ 5 ECU's
NPV - Net Present Value
ANI - Annual Net Income

what concerns crops selection in Model 2 optimal plan, we can see that in the dryland there is a decrease in area resulting from the conversion to irrigated land and the selection of the same activities of Model 1. In the irrigated land the choices of the model will vary over the years, according with the forecasted evolution of prices and of the CAP measures. In the first three years the optimal solution will lead to more factor intensive activities such as maize and sugar beet, afterwards the solution will turn to the sunflower - wheat rotation. All these irrigated crops are undertaken using Technic 1, which will lead to the maximum yield using the agronomical optimal water supply. By looking at **figure 2**, where we can observe the evolution of the annual net income of Models 1 and 2, it is notorious the importance of investments in order to make possible the practice of irrigated activities. These activities will lead to a strong increase in the Net Present Value (NPV), in opposition to the income decrease over the years in Model 1 in which annual net income of the last year is only 3.6 thousand contos against almost the double in Model 2. If we look to the objective function, we verify that the NPV between the two models is significantly different, leading to the conclusion that the irrigated activities are an alternative to take in account to shift the negative evolution forecasted for dryland traditional activities in Alentejo. Comparing again the results of Model 1 and 2, we came to the conclusion that the average annual net income per hectare of dryland is of 24 contos, while for the irrigated land is of 80 contos. Which again proves the interest of these kind of investments. The observed decrease in the second year annual net income of both models is due to a strong fall in the prices. After analysing the present price and policy frame, it is important to make an effort in order to withdraw some conclusions about this kind of investment in the future. Namely after the prices stabilisation at world market level and also after the ending of specific subsidies to the Portuguese agriculture. Thus, we developed two more models in a different scenario. In this scenario the prices are the ones resulting from the converging of EC and world prices over the ten years of the planning horizon, and the CAP measures are the ones forecasted for the year 2000 and without specific subsidies to Portuguese agriculture. In this scenario we have again two models, Model 3 where we will not allow for investments in irrigated activities, and Model 4 where the investment activities are possible inducing the possibility of practising irrigated activities. The results of these two models are presented in **table 4**. In this scenario the optimal plan of Model 3 show us how difficult will be to continue with

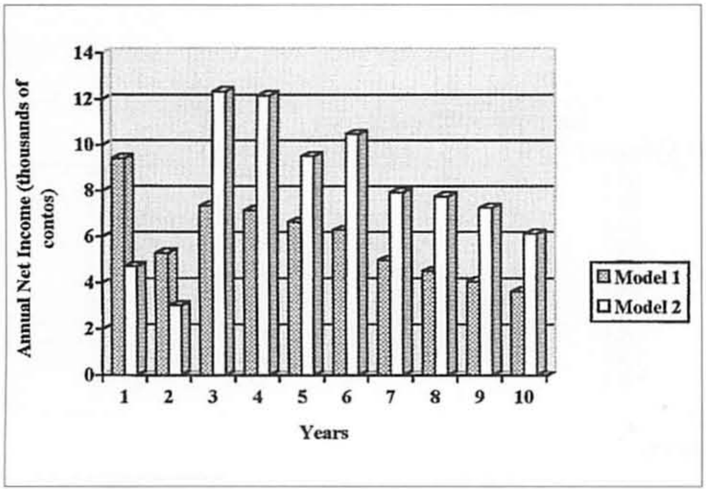

Figure 2 - Annual net income evolution for models 1 and 2.

dryland activities with the forecasted prices and subsidies. The NPV although being positive, it is low and in average terms can make the agricultural activity unprofitable.

By looking at the results from the Model 4 optimal plan, we can see that the investment in irrigation equipment can reverse the devaluation process that occurred in Model 3. The selected irrigated activity is sunflower - wheat rotation, again with an investment on a Multi-Center Pivot for an area of 60 hectares. The selection of these crops in the optimal plan is also of great importance because they are activities in which the farmer as already know-how. This rotation is the one he is used to undertake in dryland, decreasing in this way the problems arising from new technologies adoption. In terms of water saving the sunflower - wheat rotation is the one who leads to the use of lower amounts of water per hectare.

As we can observe in **figure 3**, the possibility of making investments in irrigation equipment has a much stronger impact; it will make again the farmer's activity undoubtedly profitable.

In this future scenario it is important to analyse the problem of the water price. In general we can expect a decrease, in real terms, of the production inputs prices. In water price such is not expected. In what concerns this input we can predict that the water price will have a tendency to a strong increase either by it scarcity or by an increasing demand of water for other uses.

Thus, using Model 4, we parametrized water price in order to evaluate the impacts of water price variations in income as well as in selected crop activities combination. The results are presented in **figure 4**.

Water price increasing will naturally lead to a lower NPV. This effect induces the change in production technolo-

Table 4 ***Results of the models in the future scenario.***

Model 3 (only with dryland activites)

	NPV (contos)*	ANI (contos)*	Sunflower-Wheat-Barley Land Use Category I (ha)	Sunflower-Wheat-Barley Land Use Category II (ha)
Year 1	13,310	–116	170.1	21.3
Year 2		657	170.1	21.3
Year 3		1,017	170.1	21.3
Year 4		1,236	170.1	21.3
Year 5		1,433	170.1	21.3
Year 6		1,600	170.1	21.3
Year 7		1,686	170.1	21.3
Year 8		1,822	170.1	21.3
Year 9		1,938	170.1	21.3
Year 10		2,038	170.1	21.3

Model 4 (with the possibility of investment in irrigation equipment)

			Sunflower-Wheat-Barley		Land Use Category I with PM (ha)	
Year	NPV (cts)*	ANI (cts)*	Land Use Category I (ha)	Land Use Category II (ha)	Sunflower T1	Wheat T1
1	30,420	–4,018	100.0	31.8	60.0	
2		–238	105.0	31.8		60.0
3		4,612	100.0	31.8	60.0	
4		3,377	100.0	31.8		60.0
5		4,836	100.0	31.8	60.0	
6		3,791	100.0	31.8		60.0
7		4,848	100.0	31.8	60.0	
8		4,009	100.0	31.8		60.0
9		4,968	100.0	31.8	60.0	
10		4,237	100.0	31.8		60.0

* 1 conto ≅ 5 ECU's
NPV - Net Present Value
ANI - Annual Net Income

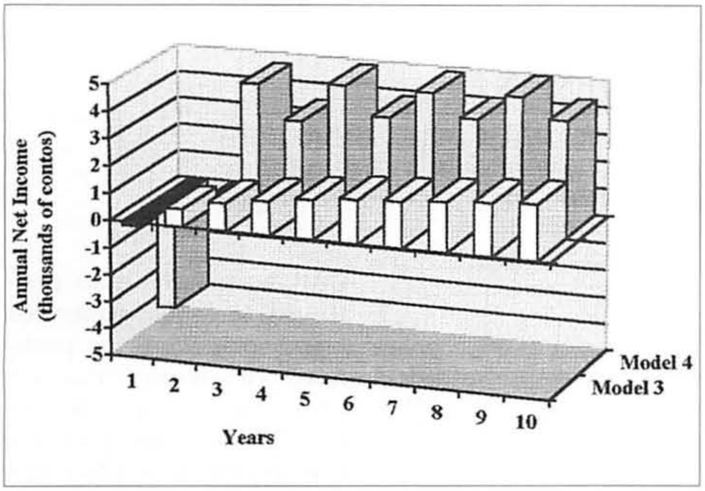

Figure 3 - Annual net income evolution for models 3 and 4.

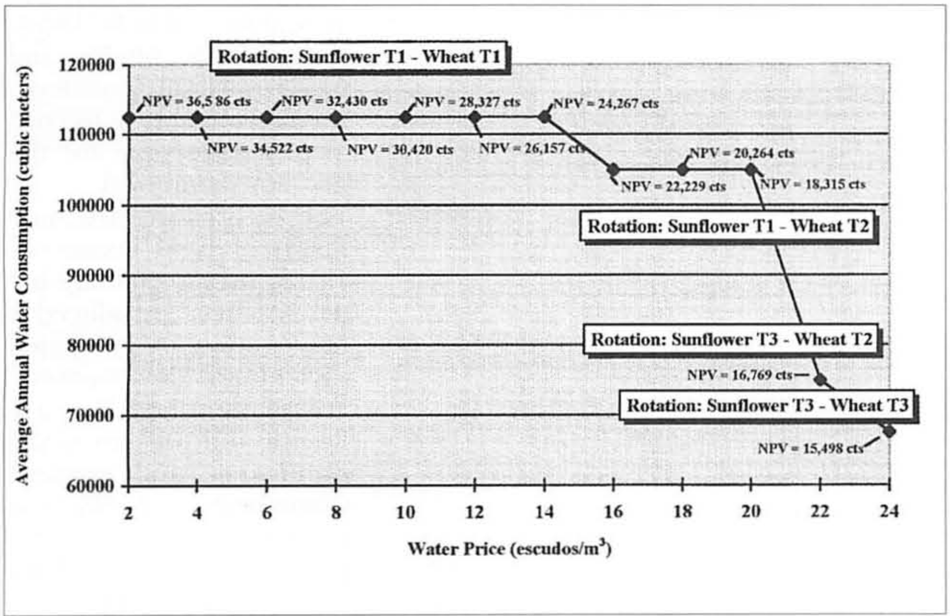

Figure 4 - Water price parametrization.

gies, which will go from Technic 1 to Technic 2 and finally to Technic 3 which will lead to decreasing water requirements.

Conclusion

Forecasted prices and the CAP reform evolution will lead to extreme negative impacts in dryland farmer's income. As showed in this work, trough investments that will allow the practice of irrigated activities, it is possible to reverse this process.

Both scenarios have revealed the importance of converting dryland to irrigated one. Problems related with new technologies adoption can arise, but the selection of sunflower and wheat requires for few changes in the technological schedules presently undertake in these activities. On the other hand, this crop selection reinforces the idea that the dryland agricultural systems "helped" in dry Springs are in fact an alternative to take in account.

The irrigation equipment selected in the optimal plans, the Multi-Center Pivot, has a very good relation between investment and operation costs on one hand and converted area on the other hand. It has proven to be a very good choice, namely by the increasing demand we had in recent years for this kind of equipment. An expected increase in water price will induces changes in the technological schedules but will not put in risk the investment in irrigation equipment. The irrigated activities remain profitable, although being necessary some adjustments in the irrigation schedules at the farm level. Another aspect to be taken in account is the yield risk over the years, which is very important in the Mediterranean regions. It as been showed by previous works, that irrigated activities suffer from a lower income variability when compared with de dryland ones (Hoffman et al, 1990). More stable incomes increases the interest of making these kind of investments. Finally, it would have been very interesting to consider the environmental impacts of the undertaken activities. Such could be done with EPIC, but for that to happen we will have to proceed with an extensive validation of these environmental parameters based in field research. ●

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