Methodological aspects of a linear programming model for the economic evaluation of alternative soil tillage technologies

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Abstract

The introduction of new agricultural technologies of soil tillage, as direct seeding and reduced tillage, brings to discussion some critical aspects that should be taken into account when we study the economic interest of these technologies. These critical aspects are the available days to operate in the field, that depend on precipitation, evaporation, soil and traffic (depending on the selected technologies) and the possibility of considering tractors with different horsepower. How to incorporate these aspects is the main purpose of this paper. Results show that all the critical aspects have been considered and that the proposed methodology permits achieving the objectives.

Résumé

L'introduction de nouvelles technologies en agriculture pour le travail du sol, comme le semis direct et la réduction des labours, nous incite à discuter des aspects critiques qui devraient être pris en compte quand on entend évaluer l'intérêt économique de ces technologies. Ces aspects critiques sont représentés par le nombre de journées utilisables pour ces opérations qui dépendent des précipitations, de l'évaporation, des conditions du sol et du trafic (selon les technologies retenues) et par la possibilité de considérer des tracteurs avec une différente puissance. Comment intégrer ces aspects dans l'évaluation est le principal objectif de ce travail. Les résultats montrent que tous les aspects critiques on été pris en considération et que la méthodologie proposée nous permet d'atteindre les objectifs fixés.

1. Introduction

Linear Programming is one of the most commonly used economic methodologies since, being very flexible, it permits the representation of diverse situations. Therefore, it is a technique with great potentialities for modelling the specifics and details of the agricultural sector and their implications when analysing the effects of the policies or of the technological modifications (Lucas, 1995). Whenever it is possible to specify an objective and the quantity, quality and seasonal variability of the resources, linear programming can be used to determine the optimum combination of the production systems, technologies and techniques (Conway & Killen, 1987).

With linear programming models it is possible to compare various technological options and consider natural and economic factors that influence the rate of the adoption of technology (Spharin & Seligman, 1983). The possibility of modelling the production system allows for the definition of a set of efficient combinations of the factors and production, and the selection of the best (Bousard, 1970), considering also the existing interactions in the system (Knipscheer et al., 1983), among the various products (Colman, 1983), and their characteristics.

The main purpose of the present paper is to demonstrate the potential use adaptability of linear programming for economic evaluation in case of alternative soil tillage technologies. The evaluation is carried out on a farm typical of the Beja clay area (Cary, 1985). The model assesses whether the introduction of alternative soil tillage technologies, along with the associated investments, according to the seasonal variation in the use and availability of the various traction equipment, has a positive economic impact for the farmer. Its solution for the base year and for other years, incorporating the foreseen evolution of farm product prices and the aids provided by the agricultural policy announced for those years, makes it possible to know the necessary long-term adjustments both in the combination of the activities carried out, as well as in the farm machinery.

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2. The problem

The technologies that are alternative to the traditional soil tillage practices for planting cereals, namely reduced tillage and direct seeding, play an important role, from the technical point of view, in reducing soil degradation and soil and water conservation, as well as root growth and nitrogen mineralisation rate (Chan & Mead, 1992; Hamblin et al, 1982). Consequently, a higher production level can be maintained for a longer period than with the traditional tillage (Knipscheer et al., 1983).

Comparison of soil tillage systems is, basically, a comparison between the existing technology (traditional technology) and the alternative technologies. The challenge of assessing the benefits of a new technology, for a farm, is to evaluate precisely the return for a set of various physical, technical and economic parameters (Bowman et al., 1989). The introduction of new tillage technologies requires modelling the coefficients related to two critical aspects: 1) the need to carry out the cultivation operations during the number of days available for this purpose, which depend on the different cultivation operations (the type and number of tillage already carried out), precipitation and soil type; 2) the number of hours and horsepower necessary, in each of the technologies, for establishing the cereal. The problem is to develop the methodological modelling that contemplates these two aspects, incorporates their variations and captures their implications for the different technologies on which the economic and company adaptations depend (Klemme, 1985).

3. The mixed model of whole programming with special emphasis on modelling the investment in traction

The developed model is a mixed model of the whole programming, static and deterministic, the objective of whose structure is to incorporate the most relevant aspects for the economic evaluation of the alternative soil tillage systems, that is, to allow consideration for an economic choice among different compositions of the farm machinery, based on the necessary horsepower and the required number of hours as well as the available days for carrying out the cultivation operations of the alternative technologies.

The modelling of the whole component, which refers to the annual investment in traction, is presented in a simplified manner in table 1. Taking into account the different needs for machinery on the farm and their horsepower, as well as the differences in the available days for carrying out the different operations, five investment activities were considered, corresponding to sets of traction equipment, necessary for each type of tillage considered (Martins, 1994, pp.34).

The seasonal variability in performing the cultivation operations that involve traction and as a consequence the need and availability of traction is evaluated for periods of the year in which it is technically possible to carry out the different groups of necessary cultivation operations. The following were considered (Martins, 1994, pp.38):

Period 1 (September 15 to December 15): Soil preparation and plantation of winter cereals.

Period 2 (December 15 to April 30): Soil preparation and plantation of spring/summer cereals; cover fertilisation and application of herbicide in winter cereals.

Period 3 (May 1 to May 31): Application of herbicide in spring/summer cereals.

Period 4 (June 1 to August 15): Harvesting of winter cereals for grain.

Period 5 (August 15 to September 15): Summer fallow.

Sometimes there are sub-periods within these periods, which may eventually cause an overlap of some days, according to the crops involved (for example, period 1 can be sub-divided, taking into consideration whether the cereals are more precocious (with planting dates between October 1 and November 30), or late (with planting dates between October 1 and December 15).

Presented in a simplified manner, the model defines, in lines 1 and 2, the number of traction sets that the farmer needs on the farm in order to carry out the cultivation calendar, taking into consideration the needs of the productive activities (column 1 and 2). Traction is provided by activities that represent the investment in traction sets typical of each tillage system (columns 3 and 4) and which provide a determined capacity per period of time available for carrying out the cultivation operations, according to its seasonal variation.

Table 1. *Simplified Matrix for investment in traction*

			1	2	3	4	5	6	7	8	
	Activities		Productive w/tractor 80 CV	Activities w/tractor 105 CV	Investment in traction *(whole tractors)* 80 CV	Activity 105 CV	Activity Use of traction/period *(hours)* 80 CV Per. 1	Per. 2	105CV Per. 1	Per. 2	Disp.
			Xa	Xb	Xg	Xh	Xt1	Xt2	Xz1	Xz2	
	Objective function		Ca	Cb	-Cg	-Ch	-Ct1	-Ct2	-Cz1	-Cz2	
1	Traction: 80CV/activ. & per.	Per. 1	-Aa1		+Ag1						>= 0
2		Per. 2	-Aa2		+Ag2						>= 0
3	Traction: 105CV/activ. & per.	Per. 1		-Ab3		+Ah3					>= 0
4		Per. 2		-Ab4		+Ah4					>= 0
5	Traction: Hours 80 CV/activ.	Per. 1	+Aa5				-1				<= 0
6	& period	Per. 2	+Aa6					-1			<= 0
7	Traction: Hours 105 CV/activ.	Per. 1		+Ab7					-1		<= 0
8	& period	Per. 2		+Ab8						-1	<= 0

Table 2. *Real market prices of the products, during the two years under evaluation*

PRICES	Year 1995/96	Year 2003/04
Cereals intervention price (esc/Kg)	22$20	21$00
Price of sunflower (esc/Kg)	36$30	34$40
Aid per hectare (esc./ha)		
- Cereals	33.495$00	30.256$00
- Oil seeds	58.065$00	52.443$00
Specific aid (esc/Kg)		
- Wheat	17$00	
- Barley, rye and triticale	11$30	
Aid/hectare durum wheat (esc/ha)	63.823$30	57.630$00
Support for setting aside land		
- Base value (esc/ha)	42.455$00	38.324$00
- Supplementary compensation.(esc/Kg)	14.840$00	
Ovine subsidy (esc/animal)	5.893$00	5.340$00
Price of lamb (esc/Kg)		
- June	288$00	261$00
- July	322$00	291$00
Retiring animals (esc/animal)	4.108$00	3.724$00
Wool (esc/Kg)	103$00	93$00

Source: Adapted from IMAIAA, 1994, IEADR, 1993 and SIMA, 1992.

This availability of traction hours per set in each period and sub-period is limited to the days in which the soil conditions, according to the weather conditions, namely rainfall, allow for the performance of the various cultivation operations that need traction. Considering the two periods that have a tendency to be most critical, that is period 1, when the planting is carried out, and period 4, when harvesting is done, there are no changes in availability during period 4 in the different traction sets, since in this period of the year, the beginning of the summer, there is no significant rainfall, and the effects of the tillage carried out at the time of planting are no longer felt in terms of soil conditions for machinery operation. However, there are differences among the traction sets, with regards to their availability in period 1, which reflect the soil conditions due to precipitation and the machinery that have previously worked the soil.

The investment activities include, in the objective function, the cost that represents the fixed cost of traction set. The restrictions expressed in lines 1 and 2 allow the model to select the number of sets according to the most critical period in terms of need versus traction availability. In lines 5 to 8, the actual number of hours during which each traction set is operated per period is determined according to the selected cultivation occupation (activities of columns 5 to 8). These activities, that is, the number of hours of operation per set, has a cost in the objective function corresponding to the variable hourly cost of operating each one of the sets.

4. Results

In order to study the adaptability of the proposed methodological development to the modelling of the two critical aspects considered, namely incorporating the variables in the required hours and horsepower, in each technology, to carry out the cultivation operations, and the necessity that these be carried out in the available number of days, capturing their implications for the different technologies, two models were developed, one in which only the crops planted with traditional technology were considered, which was called traditional model and another in which the three tillage technologies were considered and was called innovative model. Both models were evaluated in the base year of the study, 1995/96 and in 2003/04. In 1995/96 the totality of the measures brought about by the CAP reform were implemented, and in 2003/04 there will no longer be specific aids to Portuguese agriculture. The prices and aids considered for these years are represented in table 2. The two models considered include the critical aspects: the crops have different needs of number of hours, depending on the technology, and the availability of the number of hours for working is also different, depending on the technology and the soil type.

In a first stage, the main concern was to know exactly the critical periods that determined the selection of the necessary number of sets in each model; for this, results were obtained taking into account the available number of days, for each technology. These results are presented in table 3.

In the traditional model, in 1995/96, the clay textured soils are occupied with a three year rotation which, along with the non-cultivated area, occupies the available 237 ha; the sandy-loamy soils are used exclusively for fallow, destined to animal feeding. In this way, the critical period that determines the number of necessary traction sets is exclusively determined by the occupation of the clay soils, and the summer fallow is carried out in period 5. In the innovating model, the soils have the same cultivation occupation, although all the crops are produced with reduced tillage or direct seeding. The fact that in this model, both reduced tillage and direct seeding are used, is certainly due to the fact that it is always necessary to have a reduced tillage set to plant sunflower, which still cannot be done with direct-sowing technology. Since the needs and the availability are different for the different traction sets, it is natural that the critical period should also be different in each one of them. And that is exactly the case: the critical period that determines the quantity of traction sets for direct seeding is sub-period 4.2, and that for reduced tillage is period 2.1.

Once the critical traction periods in each model were identified, it was sought to isolate the critical aspects considered, to appreciate their influence on the results of the model. Results were obtained considering availability of

Table 3. *Results of traditional and innovative models in two consecutive years: net margin (thousands of escudos), vegetable activities (ha), animal activities (units of typical production) and farm machinery (number and type of tractors)*

	Traditional	Model	Innovative	Model
YEARS	1995/96	2003/04	1995/96	2003/04
NET MARGIN	3.332	-	12.537	3.147
VEGETABLE ACTIVITIES				
- CLAY SOILS				
Sunflower - traditional technology	67,15	-		
Sunflower -reduced tillage			67,15	67,15
Durum wheat - traditional technology	67,15	-		
Durum wheat - direct seeding				67,15
Wheat – traditional technology	67,15	-		
Wheat – direct seeding			50,71	29,82
Wheat – reduced tillage			16,44	37,33
Barley (Hordeum Distichon) – direct seeding			67,15	
Set aside	35,55	-	35,55	35.55
SUB-TOTAL		-	237	237
- SANDY LOAMY SOILS				
Oat - direct seeding for grain + pasture			6,67	6,67
Oat - direct seeding for grain			35,83	35,83
Triticale - direct seeding			42,5	42,5
Fallow in rotation			100	100
Fallow for animal feeding	200	-		
Set aside			15	15
SUB-TOTAL	200	-	200	200
ANIMAL ACTIVITIES				
Sheep, born in march, sold when 3 months old, with 25 Kg	741	-	399	399
FARM MACHINERY				
- Traction sets				
Traditional with 120 HP tractor	2			
Reduced tillage with 105 HP tractor			1	1
Direct seeding with 105 HP tractor				
Direct seeding with 80 HP tractor			1	1

Source: Results from the model

hours was equal to the smallest considered availability, that of the traditional technology, for all the technologies. The results of this model are presented in table 4.

Although the differences in the available days for the different technologies is not that great for the proposed modifications to lead to changes in the number of tractors used, here are two aspects that reveal the adaptability of the nodel to the problem being studied. In the first place, the fact that modifications in the availability of the number of hours in the critical period for the sunflower crop lead to some changes in the model: it becomes necessary to diversify the sunflower crop, with part of the crop planted using reduced tillage in the traditional date, which is later and less productive; in the second place, although the most critical period for direct seeding is sub-period 4.2, the decrease in the number of hours in period 1 makes it necessary to slightly increase the number of direct seeding traction sets in the sandy-loamy soils, with a consequent decrease in the availability of these sets to work the clay soils. Therefore it is necessary to change the farming plan of these soils, decreasing the area of directly sown soft wheat, and increasing the area of reduced tillage in soft wheat, as this tillage technology is less demanding in period 4.2. In this way the net margin of the model decreases by about 880 thousand Escudos, 690 thousand of which come from the difference in the production of sunflower and the rest from the difference in the variable costs of traction. For 2003/04 it is no longer profitable to produce with traditional technology and in the innovative model there is a reduction of about 9 million Escudos relative to 95/96 which is essentially due to the difference in the income from crops and sheep and, in a much smaller scale (about 470 thousand Escudos) to an increase in the costs of traction, due to the necessary adaptations in the exploitation plan.

5. Conclusions

The developed mixed whole programming model is well suited to the proposed objectives. Analysis of the results demonstrates that this model is sensitive to the need of carrying out the cultivation operations during the available days using the necessary number of hours and horsepower, in each one of the technologies, for the establishment of the cereal. Thus, the economic result of the farm is a consequence of the two aspects that were considered critical for evaluating the soil tillage technologies.

Références

Boussard, J.-M. Programmation Mathématique et Théorie de la Production Agricole. Ed. Cujas, Col. Recherche et Structures Agricoles, Paris, 1970, 251 pp.

Bowman, P. J., Wysel, D. A., Fowler, D. G. & White, D. H. Evaluation of a New Technology When Applied to Sheep Production Systems: Part I - Model Description. Agricultural Systems, 1989, 29, 35-47.

Cary, F. C. Enquadramento e Perfis do Investimento Agrícola no Continente Português. Banco de Fomento Nacional | Estudos, Lisboa, 1985, pp.

Chan, K. Y. & Mead, J. A. Tillage-Induced Differences in the Growth and Distribution of Wheat-Roots. Aust. J. Agric. Res., 1992, 43, 19-28.

Colman, D. Review of the Arts of Supply Response Analysis. Review of Marketing and Agricultural Economics, 1983, 51(3).

Table 4. *Results of innovative model in year 1995/96 presuming equal number of available days for all technologies: net margin (thousands of escudos), vegetable activities (ha), animal activities (units of typical production) and farm machinery (number and type of tractors)*

YEAR	1995/96
NET MARGIN	11.656
VEGETABLE ACTIVITIES	
- CLAY SOILS	
Sunflower - Reduced tillage with traditional sowing date	48,57
Sunflower - Reduced tillage with early sowing	18,58
Wheat - reduced tillage	22,05
Wheat - direct seeding	45,10
Barley (Hordeum Distichon) - direct seeding	67,15
Set aside	35,55
SUB-TOTAL	237
- SANDY LOAMY SOILS	
Oat - direct seeding for grain + pasture	6,67
Oat - direct seeding for grain	35,83
Triticale - direct seeding	42,5
Fallow in rotation	100
Set aside	15
SUB-TOTAL	200
ANIMAL ACTIVITIES	
Sheep, born in March, sold when 3 months old, with 25 Kg	399
FARM MACHINERY	
- TRACTION SETS	
Reduced tillage with 105 HP tractor	1
Direct seeding with 80 HP tractor	1

Source: Results from the model

Conway, A. G. & Killen, L. A Linear Programming Model of Grassland Management. Agricultural Systems, 1987, 25, 51-71.

Hamblin, A. P., Tennant, D. & Cochrane, H. Tillage and the Growth of a Wheat Crop in a Loamy Sand. Aust. J. Exp. Agric., 1982, 33, 887-97.

Klemme, R. M. A Stochastic Dominance Comparison of Reduced Tillage Systems in Corn and Soybean Production under Risk. Amer. J. Agric. Econ., 1985, 67, 550-557.

Knipscheer, H. C., Menz, K. M. & Verinumbe, I. The Evaluation of Preliminary Farming Systems Technologies: Zero-Tillage Systems in West Africa. Agricultural Systems, 1983, 11, 95-103.

Lucas, M. R. A Competitividade da Produção de Borrego no Alentejo Dissertação apresentada à Universidade de Évora para obtenção do grau de Doutor em Gestão, Évora, 1995, 410 pp.

Martins, M. B. Avaliação Económica de Tecnologias Alternativas de Mobilização do Solo numa Exploração Agrícola Característica da Zona dos Barros de Beja Dissertação Apresentada como Requisito Parcial para a Obtenção do Grau de Mestre em Economia Agrícola, Universidade de Évora, 1994, Évora, pp.

Spharin, I. & Seligman, N. G. Identification and Selection of Technology for a Specific Agricultural Region: A Case Study of Sheep Husbandry and Dryland Farming in the North Negev of Israel. Agricultural Systems, 1983, 10, 99-125.