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Innovations favouring environmental sustainability in avocado orchards: an analysis of the Spanish Mediterranean coastlands

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Abstract

Avocado cultivation started to take hold on the southern Spanish Mediterranean coast in the early 1970s. Today, avocado is the most widespread tropical crop in the area, occupying some 8,350 ha; average annual production is around 70,000 Mg. In recent years, several technological innovations have been adopted by avocado growers, some of which favour the environmental sustainability of the crop. Among the practices adopted are several non-tillage or conservation tillage techniques (which use no —or very little— herbicide), flower pruning, the use of weed clearing machines, mulching, and organic and integrated farming systems. This paper reports the results of a survey of avocado growers from the southeastern coast of Spain, and analyses their adoption of environmentally friendly technologies. To identify the grower and orchard characteristics that encourage such adoption, an aggregate innovation index was created and a multinomial ordered probit model constructed. The findings might help in the design of strategies for increasing the adoption of environmentally safe technologies.

Additional key words: adoption of technological innovations, *Persea americana,* sustainable agriculture.

Resumen

Análisis de factores de adopción de innovaciones que favorecen la sustentabilidad ambiental en explotaciones de aguacate del litoral mediterráneo español

El cultivo del aguacate comienza a extenderse en el área meridional del litoral mediterráneo español a partir de los años setenta. Actualmente el aguacate es el cultivo tropical territorialmente más importante, ocupando una superficie de 8.350 ha y con una producción media anual próxima a 70.000 Mg. En los últimos años, los productores de aguacate han adoptado diversas innovaciones tecnológicas, algunas de las cuales favorecen la sustentabilidad ambiental del cultivo. Entre estas prácticas se han identificado las siguientes: varias técnicas de no laboreo o laboreo de conservación sin uso o con uso reducido de pesticidas, poda de floración, uso de desbrozadora, la práctica del *mulching* y los sistemas de producción ecológica e integral. En este trabajo se describen primero algunos resultados de un sondeo a explotaciones de aguacate localizadas en la costa sur-oriental de la península ibérica, para analizar después su situación respecto a la adopción de innovaciones tecnológicas que favorecen el medioambiente. Para identificar y analizar los factores que influyen en la adopción de dichas innovaciones, se ha utilizado un índice agregado de innovación, y se ha ajustado un modelo probit multinomial ordenado. Finalmente, se ofrecen algunas conclusiones que permiten diseñar estrategias futuras para fomentar la adopción de innovaciones positivas para el medio ambiente en el cultivo de aguacate en la costa tropical española.

Palabras clave adicionales: adopción de innovaciones tecnológicas, agricultura sostenible, *Persea americana*.

Introduction

Tropical fruit orchards occupy around 12,500 ha in Andalusia (southern Spain), many of which contain mostly young trees. The avocado (*Persea americana* Mill.) is currently the most important tropical fruit crop, followed by the cherimoya (*Annona cherimola* Mill.), and, at some distance, the mango (*Mangifera indica* L.). Avocado production generates some € 60-65 million at farm prices almost 25% of the income generated by the region's non-citrus fruit crops as a whole.

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The avocado started to take hold on the southern Spanish coast in the 1970s, increasing from 10 ha in 1970 to more than 2,000 ha in 1981 (Calatrava and López, 1981). Today, avocado trees occupy 8,350 ha and annual fruit production is close to 70,000 Mg (Junta de Andalucía, 2002).

The varieties presently grown (basically 'Hass', and to a lesser extent 'Fuerte' and 'Bacon', etc.), as well as the cultivation techniques and practices associated with the crop, are the result of technological adaptations made by the sector. From the early days to the present, growers have had to seek profitability and to respond to constant market demands for higher quality and a reduction in the environmental impact of their activity.

Studies on the adoption of technology in agriculture started with the work of Ryan and Gross (1943), who examined the phenomenon with respect to the introduction of hybrid corn in IOWA (USA). Following this seminal paper, much empirical analysis was undertaken, and studies on the subject now abound in the international literature (e.g., Feder *et al.,* 1982; Feder and Umali, 1993; Rogers, 1995). In Spain, studies analysing such matters were scarce until the 1980s. Nieto (1968), Jiménez *et al.* (1976), Torralba (1976a,b), Diez Patier (1977 y 1980) and García Fernando (1976, 1977) were among the first Spanish authors to publish on the subject. At later dates, a large number of theoretical contributions and empirical studies were made, but few authors tried to identify relationships between the adoption of technology and the socioeconomic characteristics of growers and their orchards. Some of these investigations used an innovation index, e.g., Casado *et al.* (1983, 1984) with respect to the adoption of technology in peach orchards, Millan and Ruiz (1986, 1987) with respect to the same in greenhouse farming, Navarro *et al.* (1988a,b,c) with respect to strawberry growing, and Calatrava *et al.* (2001) and Parra and Calatrava (2005) with respect to olive cultivation.

Although there are studies that examine the structure of and the problems inherent to avocado growing in the coastal areas of Málaga and Granada (Calatrava and González, 1993), as well as the technical and economic problems such growers face, very few deal with the factors that favour the adoption of innovative technologies and crop sustainability. With this aim, Calatrava and Sayadi (2002) analysed the response of 100 mango growers to a survey on technologies that contribute to environmental sustainability, and on the factors that determine their adoption. The present work reports a similar analysis of the responses of 246 avocado growers. The aims of this work were: i) to identify the technological innovations in avocado cultivation that may have a positive impact on the environment, ii) to analyse all grower and orchard characteristics that favour the adoption of environmentally positive practices, and iii) to help design strategies that encourage the adoption of these practices and favour the environmental sustainability of this crop in the study area.

Material and Methods

Between January and April 2002, a questionnaire was provided to the avocado growers of the southeastern Spanish coast. This contained three sections that collected information on the socio-demographic characteristics of the respondents (n = 246) (age, educational level, agricultural training, time spent in agriculture, etc.), on the characteristics of their orchards (area, number of tropical trees, existing species, etc.), and on the adoption of the following technological innovations identified as having a positive effect on the environment:

— Non-tilling or conservation tilling techniques without the use (or with reduced use) of herbicides.

— Flower pruning (and adding the pruning remains to the soil).

— Grinding of conventional pruning remains and their mixing into the soil.

— Using brush-cutters as a total or partial alternative to the use of herbicides.

— Mulching, using plastic materials, or, more recently, sugar cane pith or almond shells.

— Non-conventional production system (ecological or integrated).

Although drip and other precision irrigation systems save considerable amounts of water compared to traditional flatbed irrigation system, they were not considered as innovations since their use is generalised in avocado orchards. A more detailed analysis of innovation in the use of water by the area's orchards can be found in Calatrava and Sayadi (2001).

The adoption of the above technologies was analysed as a binomial variable (i.e., whether they were adopted or not: ε_t for technology *t*, being ε = adoption). A technological innovation index (I_i) was then defined as follows:

$$I_i = \sum_{t=1}^{6} \varepsilon_t$$

where i is the number of holdings (1-246) and t the number of technologies (0-6). I_i therefore varies between 0 and 6. To identify the structural relationships between I_i and grower and orchard characteristics, an ordered, multinomial probit model was constructed (I_i does not follow a normal distribution, as shown by the Kolmogorov-Smirnov test).

Total independence between variables, ε_i (so $E[\varepsilon_i/\varepsilon_j] \neq E[\varepsilon_i]\ \forall_{ij}$), clearly did not exist due to some effect of the technology adoption package. A strong relationship existed between some technolgies [e.g., in the case of innovations I and VI (Table 2)], but this does not invalidate the use of I_i as an aggregate innovation index since it clearly includes the possibility of a degree of dependence between variables. I_i was therefore considered a qualitative dependent variable at four levels given the following codes: $I_i \leq 2$ for «scarcely innovating» growers, $I_i = 3$ for «somewhat innovating» growers, $I_i = 4$ for «quite innovating» growers, and $I_i \geq 5$ «highly innovating» growers.

The explanatory variables considered in the model were the area of tropical crops (SUR_TROP), orchard type (distinguishing between those growing avocado exclusively and those that also grow other tropical fruits: FARM), avocado yield in Mg ha^{-1} (AVOC_YLD), number of avocado trees (NUM_AVOC), membership of a cooperative or other agricultural association (COOP), satisfaction with the marketing system (SATISFAC), dedication to agricultural activity (DEDICAT), self-evaluation on a 0-9 scale of the level of risk willing to be taken in adopting technological innovations (RISK), years dedicated to the activity (DED), travel for agricultural purposes to other parts of Spain or abroad (TRAVEL), attendance of agricultural courses (COURSE), habitual reading of books on tropical fruit growing (BOOKS), age (AGE), agricultural training (AGRTRAIN), type of labour used in the production process (LAB), and educational level (EDUCAT). To avoid colinearity effects, the variables SUR_TROP and NUM_AVOC were considered alternatively in the model. Table 1 shows these variables plus the levels of the multinomial variables.

Results and Discussion

Table 2 shows the frequencies of adoption of the innovations considered. In general, a high level of knowledge concerning them was found to exist, except

Table 1. Independent variables in the ordered probit model

Variables	Description	Variables	Description
Constant	Constant term	BOOKS	«1» if grower read books on tropical crops, «0» if not
SUR_TROP	Total area of tropical crops (ha)	AGE0	«1» if age is ≤ 35, «0» if not
FARM	«1» if orchard grows only avocadoes, «0» if not	AGE1	«1» if age is between 35 and 45, «0» if not
AVOC_YLD	Avocado yield (Mg ha^{-1})	AGE2	«1» if age is between 45 and 55, «0» if not
NUM_AVOC	Number of avocado trees	AGE 3	«1» if age is ≥ 55, «0» if not
COOP	«1» if a member of a co-op’ or similar, «0» if not	AGRTRAIN	«1» if grower has any type of recognised agricultural training, «0» if not
SATISFAC	Satisfaction with the marketing system	LAB 1	«1» if only family labour is employed, «0» if not
DEDICAT	«1» if exclusively dedicated to agriculture, «0» if not	LAB 2	«1» if family and temporary labour is employed, «0» if not
RISK	Growers’ risk taking level on a scale of 0-9	LAB 3	«1» if only temporary manual labour is employed, «0» if not
DED1	«1» if dedicated to agricultural activity for < 5 years, «0» if not	LAB 4	«1» if permanent and temporary labour is employed, «0» if not
DED2	«1» if between 5 and 10 years, «0» if not	EDUCAT1	«1» for no studies, «0» if not
DED3	«1» if more than 10 years, «0» if not	EDUCAT2	«1» for primary education, «0» if not
DED4	«1» if respondent has always been a grower, «0» if not	EDUCAT3	«1» for secondary education (baccalaureate, Tech. Ed., etc.) «0» if not
TRAVEL	«1» if grower has made any trips for agricultural purposes to other parts of Spain or abroad, «0» if not	EDUCAT4	«1» for higher education (university), «0» if not
COURSE	«1» if grower has attended any agricultural training course, «0» if not		

Table 2. Sampling frequencies of the technologies considered (% of orchards)

	Environmentally friendly technological innovations					
	I	II	III	IV	V	VI
Adopted	8.94	65.86	21.14	36.59	14.63	3.25
Not adopted but known about	61.99	19.51	69.11	58.13	23.99	47.36
Not adopted and not known about	29.07	14.63	9.75	5.28	61.38	49.39
Total	100	100	100	100	100	100

I: non-usage of herbicides in non-tilling or conservation tilling. II: flower pruning. III: grinding of pruning remains. IV: use of brush-cutters. V: mulching. VI: organic or integrated agricultural methods.

for mulching and organic and integrated farming (especially the last of these, with which familiarity was minimal). This finding agrees with the results obtained in the analysis of technological innovation in mango orchards (Calatrava and Sayadi, 2002).

Figure 1 shows the distribution of frequencies of I_i, converted by stratification into a multinomial variable.

Table 3 shows the final probit model after eliminating the following, non-significant ($P \leq 0.95$) variables: area occupied by tropical crops; number of avocado trees; avocado yield (Mg ha^{-1}); satisfaction with the marketing system; total or partial dedication to agriculture; travel for agricultural purposes to other parts of Spain or abroad; habitually reading of technical books on tropical fruits; agricultural training; and educational level.

The non-significance of the relationship between I_i and some of these variables is surprising since in many

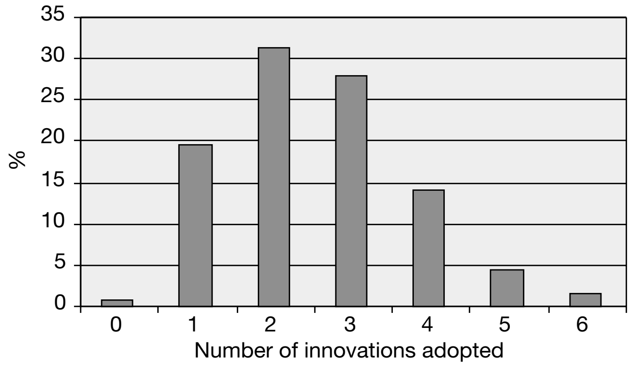

Figure 1. Sampling distribution of the innovation index I_i.

Table 3. Results of the multinomial probit model

Variable	Coefficient	t	α
Constant	0.138633	0.301	0.7638
ORCHARD	0.481100	2.298	0.0215
COOP	0.438723	2.451	0.0142
RISK	0.107887	2.334	0.0196
COURSE	0.826135	2.959	0.0031
AGE2[1]	–0.684758	–2.752	0.0059
AGE3	–0.617698	–2.630	0.0085
AGE4	–0.673885	–2.938	0.0033
LAB1[2]	–0.717252	–3.085	0.0020
LAB2	–0.712391	–3.214	0.0013
LAB3	–0.614719	–1.682	0.0926
DED2[3]	–0.531973	–1.732	0.0833
DED3	–0.556998	–2.696	0.0070
DED4	–0.941760	–3.076	0.0021

[1] Reference Variable AGE0 (fruit grower ≤ 35 years old). [2] Reference Variable LAB4 (orchard with permanent salaried manual labour). [3] Reference Variable DED1 (dedication to the activity ≤ 5 years). Verisimilitude logarithm without restrictions: –219.0090. Restricted verisimilitude logarithm: –256.4933. Chi squared: 74.96863. Degrees of freedom: 13. Level of significance, $\alpha = 0.00001$. Correct classification percentage (CCP) = 60.16%.

studies they explain the adoption of innovations. This might be due to the peculiarities of the Spanish tropical fruit sector. For instance, with respect to dedication to agriculture, it should be noted that growers reporting «partial dedication» were often businessmen from non-agricultural sectors (construction, high income professions etc.) who invested their surplus profits in fruticulture. The modern orchards thus created, under the assessment of technicians, usually showed greater adoption of technology than did small family holdings (see Calatrava and González, 1993; Calatrava and Sayadi, 2003).

Orchard type showed a direct, significant relationship ($\alpha = 0.0215$) with I_i. Orchards that produced only avocado had a higher I_i than did those that also cultivated other tropical crop species. Similarly, growers who were members of an agricultural association (cooperatives, agricultural transformation societies, etc.) were more innovative ($\alpha = 0.0142$). This is probably due to the counselling they receive from these associations' technicians. A direct relation also existed (logically, at least to a certain extent) between the level of risk that growers were willing to take in adopting technological innovations and their actual adoption ($\alpha = 0.0196$).

Attendance at agricultural courses was directly and significantly ($\alpha = 0.0031$) related to the adoption of innovations. Thus, those who attended training courses were habitually more innovative than those who did not. Such attendance is, of course, associated with the level of knowledge of the technology. Oddly, general educational level had no influence on the adoption of innovations. Growers attending tropical fruticulture courses with regularity are probably more aware of environmental issues and innovations in the sector. It is also possible that some growers attend courses as a requisite for the receipt of subsidies and grants. This funding might also demand the modernization of their orchards. Any such growers would probably be much more inclined to adopt new practices.

For the independent multinomial variables, included in the model, that were significant in explaining the I_i (orchard type according to manual labour, grower age and years dedicated to agricultural activity), the corresponding fits were made by changing the corresponding reference level. Table 4 shows the resulting levels of significance (a, b and c). With reference to manual labour use, owners of orchards of a more business-like type (level 4: salaried, permanent manual labour) were significantly more innovative ($\alpha \geq 0.001$) than those that only used family members or family members and/or temporary workers (levels 1 and 2). No significant difference was detected ($\alpha \leq 0.05$) between orchards exclusively employing temporary workers and other family-type orchards. With respect to age, growers under 35 were more prone to adopt innovations than older growers. Similarly, those who had been involved in the agricultural sector only for the past ten years adopted more technologies than more longstanding growers. In principle this (along with age) should explain much of the variance in I_i, but this is not the case for this particular part of the agricultural sector which commonly involves investors with outside capital. Table 5 shows the significance of the different variables under consideration.

In addition to identifying the factors that influence the adoption of technologies, the probit model also predicts the probability of their adoption by any individual grower or by any profile of orchard. For example, a 35 year-old grower who has only been in the business for 5 years, who is a member of an agricultural association and who attends training courses on a regular basis, who ranks him/herself as a person who takes risks (as far as adopting innovations is concerned), and who is the owner of a business-like holding in which only avocados are cultivated, would have a probability of 0.97991 of being very innovative ($I_i = \leq 5$) (the probability of being scarcely innovative is 0.00001, of being somewhat innovative is 0.00098, and of being quite innovative is 0.01913). A 65 year-old grower who has always been a grower, who is a member of no agricultural association, who attends no training courses regularly, who takes low level risks,

Table 4. Significance of levels of variables AGE (a), LAB (b) and DED (c)

a)	**AGE4**	**AGE3**	**AGE2**	**AGE1**
AGE1	**(+AGE1)	**(+AGE1)	**(+AGE1)	—
AGE2	NS	NS	—	
AGE3	NS	—		
AGE4	—			

b)	**LAB4**	**LAB3**	**LAB2**	**LAB1**
LAB1	**(+MLAB4)	NS	NS	—
LAB2	**(+MLAB4)	NS	—	
LAB3	NS	—		
LAB4	—			

c)	**DED4**	**DED3**	**DED2**	**DED1**
DED1	**(+AGE1)	**(+AGE1)	*(+AGE1)	—
DED2	NS	NS	—	
DED3	NS	—		
DED4	—			

* Significantly different at $\alpha \geq 0.05$. ** Significantly different at $\alpha \geq 0.001$. *** Significantly different at $\alpha \geq 0.0001$. NS: not significantly different at $\alpha \leq 0.05$.

Table 5. Outline of the relationship between I_i and the variables initially specified in the model

Variable	**Relationship with I_i**
Grower age	S ▼
Years dedicated to agriculture	S ▼
Level of risk-taking	S ▲
Business-like character of the orchard	S ▲
Attendance of courses on subjects related to these technologies	S ▲
Membership of a cooperative or similar body	S ▲
Exclusive planting of avocado trees	S ▲
Area of tropical crops	NS
Number of avocado trees	NS
Grower's educational level	NS
Trips and technical visits	NS
Habitual reading of technical books	NS
Total or partial dedication to agriculture	NS
Satisfaction with marketing system	NS

S▲: direct relationship. S▼ :indirect relationship. NS: non-significant.

who owns a family-type holding and who also cultivates other tropical species, would have a probability of 0.92624 of being scarcely innovative, 0.06847 of being somewhat innovative, 0.00512 of being quite innovative, and only 0.00015 of being very innovative.

In summary, the probit model showed that the adoption of the environmentally friendly technologies studied was closely related to certain grower and orchard characteristics: belonging to a cooperative or similar body; the assumption of greater risk on the part of the grower; the character of the holding being more business-like or entrepreneurial; the attendance of agricultural courses; being under 35 and having taken up agricultural activities recently.

Neither educational level, having made technical-type visits, nor partial nor total dedication to agriculture had any significant influence on the adoption of innovations. Neither was any significant scale effect detected.

The analysis of technology adoption presented here provides an overall view since an aggregate index is used. An analysis of the adoption of individual technologies is the subject of a future paper.

In conclusion, if environmentally friendly practices are to be encouraged among avocado growers, the following strategies are recommend: the promotion of cooperativism, the rejuvenation of the growing community through early retirement programmes and the incorporation of young entrepreneurs, and the implementation of training programmes to increase growers' knowledge of these technologies.

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