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RESEARCH ARTICLE

Adoption of crop diversification by specialized grain farmers in south-western France: evidence from a choice-modelling experiment

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Abstract
Farming systems in developed countries have highly specialized to reach economies of scale. In addition to their low economic resilience, specialized agricultural systems face more and more agronomic problems such as yield stagnancy or pest and pathogen resistance. Crop diversification is a lever to overcome these problems and to reduce chemical inputs. But the adoption of diversification crops remains low and heterogeneous, due to both monetary and non-monetary determinants. Unobservable determinants such as the perception of crop characteristics might explain this heterogeneity. The paper proposes an evaluation of farmers' preferences for these characteristics with a choice modelling conducted among 71 specialized grain farmers of south-western France. A random parameter logit model interacting crop attributes with farms' individual characteristics show that, in addition to monetary attributes, crop traits such as the level of nitrogen restitution and the positive effect of the diversification crop on pest management influence adoption. It shows an even stronger impact of these agronomic attributes when soil and agronomic conditions are constraining. Moreover, demand for crop diversification is influenced by the performance of the farm's main crop and by the type of marketing contract adopted, which suggests cross effects with risk management strategies.

Keywords Adoption · Farmer preferences · Crop diversification · Choice modelling

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Introduction

Global grain productivity has increased considerably in Western countries over the past century due to the development of labor-saving technologies such as the substitution of labor for machinery and technologies to improve yield per unit of land like biological and chemical technologies (Ruttan, 2002). "Modern agriculture" has created economies of scale by means of farm specialization, which facilitates labor management and streamlines farming practices by eliminating certain tasks, making it possible to increase the amount of land managed per family worker. Specialization in a small number of crops has improved farmers' management performances and made higher yields possible in favorable climate-soil areas. Yet growth in productivity has its limits and is associated with the depletion of natural ecosystems (Ruttan, 2002; Tilman et al., 2002). France is the leading European Union (EU) grain producer, with more than nine million hectares under grain crops and cereal production accounting for more than 50% of the total French arable area (SSP Agreste, 2014). South-western France is a specialized grain production region where many grain farmers traditionally use the 2-year durum wheat-sunflower rotation system. In 2014, wheat and sunflower are the two main cash crops cultivated in Midi-Pyrénées, with 57% of the total cash crop area (Agreste, 2014). Both scientists and farmers report that this cropping system faces yield stagnancy and challenges the sustainability of agricultural practices. Too short crop rotations reduce soil fertility and imply an intensive and inefficient use of mineral fertilizers and chemical pest treatments. Recurrent use of the same types of molecules increases the resistance of pests and pathogens (Meynard et al., 2018; Schott et al., 2010). Focus groups lead in Spring 2018, in the Midi-Pyrénées region (south-western France), revealed that farmers specialized in durum wheat and sunflower had difficulties controlling weeds and diseases like odium on sunflower and that they face pest and disease resistance. Short rotation of wheat after sunflower also favors nitrogen losses (bare soils in winter), and nitrogen management seems a core issue to improve practices.

At the same time, national and European environmental regulations tend to restrict the negative impacts of farming activities on natural resources. Following the European Directive on sustainable use of pesticides (128/EC, 2009), France introduced a pesticide reduction policy framework in 2008 ("Ecophyto 2018" action plan) to halve the level of pesticide use by 2018. At the same time, the European Union's 2014–2020 Common Agricultural Policy (CAP) reform introduced greening and cross-compliance incentives designed to encourage farmers to switch to lower inputs and more diversified systems. In accordance with these incentives, farmers have to include at least three different families of crops to receive the "green payment."

A major lever to reduce chemical inputs is to increase functional biodiversity, through crop diversification and redesigned cropping systems with longer rotations (Davis et al., 2012). With this aim in mind, crop diversification is not a simple production choice, but the adoption of a new model of cropping system, providing ecosystem services like a better health of agroecosystem and a better management of nitrogen cycle. In addition, having a greater variety of crops can increase income stability facing climate change since it decreases the risk of harvest failure at the farm scale.

However, farmers' willingness to adopt diversified cropping systems seems heterogeneous. First, the heterogeneity in farmers' adoption can be due to different agronomic situations (see for instance Baumgart-Getz et al., 2012) or to different farm structures and to different farmers' characteristics (Baffoe-Asare et al., 2013; Feder et al., 1985;

Feder & Umali, 1993; Fernandez-Cornejo et al., 1994; Johnson et al., 2010; Paxton et al., 2011). Second, the incentive to diversify is closely associated with the scarcity of the labor resource (Knowler & Bradshaw, 2007). Third, different farmers' attitudes towards risk might explain different levels of adoption (Marra et al., 2003). More specifically, in this article, we want to investigate to what extent the preferences for crop characteristics, such as agronomic benefits or seasonal workload, might explain different levels of adoption. To do this, we assume that specialized grain farmers see the introduction of a new crop in their rotation as the adoption of a new agricultural technology: to introduce a new crop, they have to reshape the entire cropping system. This change in the cropping system is also subject to uncertainties, especially when farmers lack experience and/or information on the agronomic potential of the diversification crop. Farmers develop preferences for the new technology based on their knowledge and on production conditions. In consumer theory, individuals have preferences for a product's characteristics: the total utility of a product is the sum of the utilities of each attribute composing the product (Lancaster, 1966). Applied to production economics, farmers are considered consumers of agricultural technology and develop preferences for the characteristics (attributes) of the technology itself (Asrat et al., 2010; Useche et al., 2013). Stated preference methods can be used to evaluate the potential heterogeneity of demand for a new technology and the weight of each attribute in the adoption decision (Roussy et al., 2017).

In this article, we seek to assess farmers' willingness to pay for different attributes of the diversification crop, combining quantitative monetary attributes with qualitative agronomic attributes, using a referendum discrete choice experiment. The paper is organized as follows. "Literature on adoption behavior and stated preference methods" presents how the review of determinants of technology adoption leads to a conceptual model to assess farmers' preferences for monetary and non-monetary attributes of a diversification crop. "Survey and design of the choice-modelling" provides a description of the survey which is designed to meet two main objectives. Firstly, conduct a choice-modelling where farmers have to choose a virtual crop they have not yet farmed in their field. Secondly, collect socioeconomic data on possible determinants of farmers' adoption (farm and farmer's characteristics, farming context, current practices and financial variables). "Results" presents the main results obtained from both Logit and Random Parameter Logit models where crop attributes interact with farmers' characteristics. "Discussion and conclusion" sum up and discusses the main contributions of this work.

Literature on adoption behavior and stated preference methods

We assume that specialized grain farmers consider crop diversification, consisting in introducing a new crop in their rotation, as the adoption of a new agricultural technology. In the economic literature, different surveys on farm technology adoption have focused on different countries and different technologies. Most of these studies concern the adoption of a technology trait or of a crop variety and very few of them concern the adoption of a diversification crop. Nevertheless, in the following, we use their results to build a choice modelling on the determinants of the adoption of a diversification crop in a long rotation.

Unambiguous determinants of technology adoption

A wide array of socioeconomic, institutional, and agronomic determinants can play a key role in the adoption choice depending on the particular context and technology studied (Knowler & Bradshaw, 2007; Mercer, 2004; Prokopy et al., 2008; Roussy et al., 2017). Among all the determinants usually considered, only a few of them consistently and unambiguously affect adoption behavior, such as education, information, and liquidity constraints (for a review, see Roussy et al., 2017).

Risk perceptions of a new crop

Farming is highly exposed to risk, and farmers' perceptions of technology-related risk and farmers' risk aversion are well-known major brakes on technology adoption. When adopting a new technology, farmers face new uncertainties about yield potential, crop management, and expected prices (Marra et al., 2003). Smale et al. (1994) show that risk aversion is a factor affecting adoption decision of high-yield-potential hybrid varieties in the place of local varieties in Malawi. In their study, farmers who seek to avoid downside risk may choose to grow only local varieties they know better even though hybrid varieties are more profitable (Smale et al., 1994). In Burkina Faso and Guinea, Adesina et al. show that farmers' perception of technology characteristics also influences their adoption decision. A crop perceived as less risky is more attractive than another one with an identical expected profit (Adesina & Baidu-Forson, 1995).

Perception of the crop characteristics and use of stated preference methods

In addition to the risk associated with a new technology on the farm, farmers also have different perceptions of the characteristics of the technology itself. They develop individual preferences for innovation's attributes based on their perceptions and beliefs. Stated preference methods form a group of preference elicitation methods used to study the unobservable determinants of technology adoption, such as preferences for the technology's attributes. The underlying choice model is the random utility model (Train, 2009). The perceived expected utility of a product is the sum of two components: a deterministic component and a stochastic component. The observable, deterministic part of the utility function is a function of the product attributes, the individual's characteristics, and the characteristics of the context in which the choice is presented. The unobservable, stochastic part contains the error term that captures unobservable factors influencing utility (Walker & Ben-Akiva, 2002). Stated preference methods have been used in environmental and agricultural economics for years (Adamowicz et al., 1998; Hanley et al., 1998). The use of choice-experiment approaches has grown in environmental and public economics research in recent years to inform the design of environmental policies and projects (Beharry-Borg et al., 2013; Birol et al., 2006; Broch & Vedel, 2012; Espinosa Goded et al., 2010; Greiner, 2015; Hanley et al., 2001). In a choice-modelling approach, individuals are asked to evaluate alternatives presented in a choice task and choose their preferred alternative. By varying the levels of the different alternatives' attributes, presented repeatedly to the respondent, the experiment reveals the respondent's preference structure. This enables an assessment of the farmer's willingness to adopt a policy instrument or innovation. Here, we rely on these methods to analyze the choice of a diversification crop.

Survey and design of the choice-modelling

The choice modelling (CM) had a twofold objective: hierarchize farmers' preferences for the crop's attributes and analyze the observed and unobserved heterogeneity of preferences within the sample. Based on these results, we estimated farmers' marginal willingness to pay for the different attributes of the diversification crop in order to assess their willingness to adopt the crop.

Experimental design

Proposing a virtual crop in the choice modelling rather than an existing crop placed all respondents in a similar knowledge situation with respect to the crop. In doing this, we also controlled for risk in the survey design since data mentioned on cards did not refer to an existing crop that farmers could have kept in their memory.

Demand for diversification crop derived from wheat and sunflower

The diversification crop is introduced in the following cropping system sunflower/ diversification crop/durum wheat. Durum wheat is considered the main crop in the rotation, and the diversification crop is considered the previous crop. The diversification crop is replacing sunflower before wheat in the rotation, therefore its characteristics are derived from those of wheat and sunflower. The choice-modelling design consisted in defining a set of attributes and their levels to credibly characterize this virtual diversification crop.

Attribute levels

Consistent crop attributes and levels were defined in consultation with experts during focus group discussions involving eight farmers, four researchers from the French research institute INRAE, six experts from the French arable crops R&D institute, Arvalis Institut du Vegetal, and seven cooperative experts. The first four types of existing diversification crops cited by the focus groups were *soft wheat, rapeseed, sorghum* and *pea*. In the region, the shares of these crops in the total cash crop area is respectively 27% for wheat, 4.8% for rapeseed, 2.8% for sorghum, and less than 0.5% for pea (Agreste, 2014). Each of these crops presented different agronomic pros and cons, and the appropriate diversification crop probably varies according to soil-climate conditions and to farmer's experience. This exploratory phase gave rise to the selection of five relevant attributes for the definition of a virtual diversification crop, divided into two categories: crop-intrinsic attributes and crop rotational attributes. The attribute levels were then selected in reference to the four existing diversification crops proposed by the experts during the focus groups (Table 1). The crop-intrinsic attributes were (i) gross margin (*Margin*), (ii) cropping season (*Season*), and (iii) technicality of crop management[1] (*Tech*). *Margin* is the monetary attribute expressed in hundreds of euros per hectare. This attribute was composed of five levels representing the current levels of

[1] The degree of technicality reflects the intensity of monitoring requirement and the number of technical operations necessary to manage the crop

gross margin of four possible diversification crops: 300 for pea, 375 for sorghum, 525 for rapeseed, and 600 for soft wheat. The fifth level, 450, was the reference level of this attribute and corresponded to the average gross margin of sunflower. The *Season* attribute was a dummy variable equal to 1 for summer and 0 for winter (which corresponds to wheat). The cropping season determines peak labor periods. Considering the current trend towards "simplified" cropping systems with low crop diversity, the experts suspected that workload and the desire to spread labor peaks might influence the crop choice. The *Tech* attribute had three levels; the reference modality was "medium technicality" in reference to wheat (while "highly technical" referred to rapeseed and "low technical" referred to sorghum). The level of technicality reflects the intensity of disease monitoring requirements and the number of operations required during the growing season to prevent disease and pest hazards. Crop rotational effect attributes represented the benefits for the subsequent rotation crop in terms of (iv) nitrogen restitution (*Nitro*) and (v) avoided pest treatments (*Pest*). The *Nitro* attribute was a quantitative variable expressed in units of nitrogen per hectare and the reference level 0 corresponded to sunflower (while +25 referred to rapeseed and +50 to pea). The *Pest* attribute had three levels, the reference modality being "0 additional treatment" in reference to sunflower also (+1 pest treatment referred to sorghum and −1 referred to pea) (Table 1).

Experimental plan

As mentioned earlier, the diversification crop proposed in the choice modelling (CM) was virtual, its characteristics resulted from the combination of different attributes and did not correspond to an existing crop. Given the different attributes and their levels, 270 attribute/level combinations were possible[2], and, using an orthogonal fractional-factorial design, 15 series of choice sets were ultimately proposed to each farmer (an example of a choice set is presented in Fig. 1). The experimental plan checked the conditions of orthogonality and minimized the probability that the level of an attribute was repeated in another map of choice (equilibrium of levels, minimal overlap). The 15 cards were presented to farmers randomly to avoid a wear and tear effect on the last cards (Appendix Table 6).

Presentation of cards to the respondents

Starting from these attributes, we used a referendum format for the choice set (Breffle & Rowe, 2002). Respondents had to choose between two alternative answers to the question, "Would you introduce crop X before wheat?": (i) the business-as-usual (status quo) situation associated with the answer "no," and (ii) the diversification choice associated with the answer "yes." In addition, farmers who answered "yes" were asked to choose the level of area dedicated to the diversification crop on their farm. This placed farmers in a situation they face every year in the shape of the crop acreage choice, which limited hypothetical bias. Given that the crop acreage decision is a complex decision for farmers, the choice/no choice format presented the advantage of reducing the complexity of the issues that respondents had to address. In addition, it

[2] Three attributes with three levels, one with five levels and the last with two levels: $3^3 * 5^1 * 2^1$.

Table 1 Attributes and levels of the choice modelling

Attribute	Description	Levels
Gross margin (*margin*)	Gross margin per hectare (€/ha)	300, 375, 450†, 525, 600
Cropping season (*season*)	Cropping season of the crop	Summer/Winter†
Technicality of the cropping management (*Tech*)	Technicality of the crop management including monitoring requirement and number of technical operations	Low technicality (e.g., sunflower) Medium technicality (e.g., wheat)† High technicality (e.g. rapeseed)
Nitrogen restitution (*Nitro*)	Number of additional nitrogen units available for durum wheat (UN)	0†/25/50
Rotational effect on pesticide (*Pest*)	Additional pesticide treatments comparatively to sunflower (treatment)	−1/0†/+1

† These modalities are used as references in the analysis

avoided potential violations of the Independent and Identically Distributed (IID) conditions in multinomial logit models (Rolfe & Bennett, 2009). The order of the choice sets proposed was changed for the different respondents to prevent order effects.

A first version of the questionnaire was tested on a sample of eight farmers to check respondents' understanding of the survey. The final farmer sample (100) was randomly selected from among cooperative members based on two selection criteria. Firstly, the farm

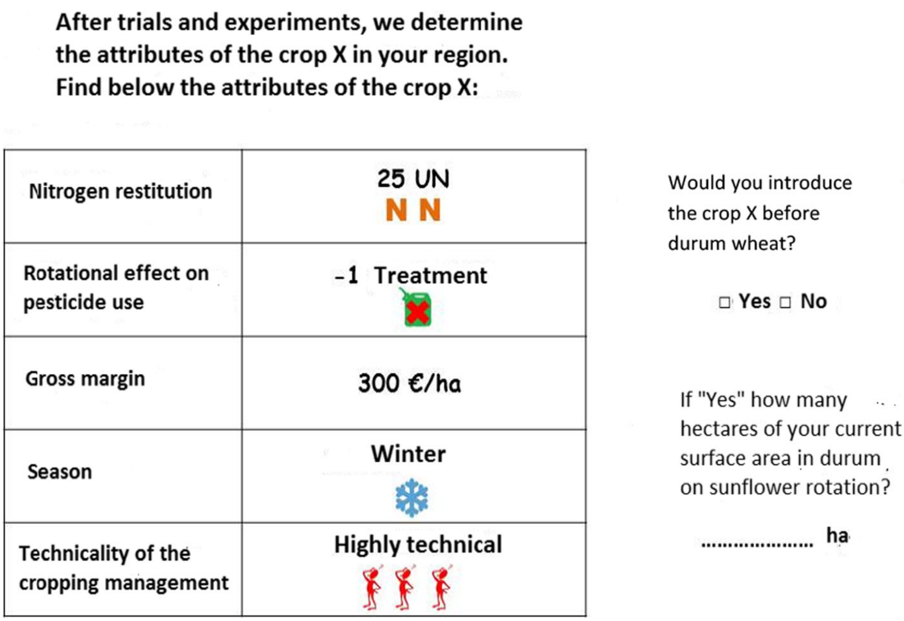

Fig. 1 Example of choice task

had to be located in a specialized durum wheat-sunflower rotation production area. Secondly, this rotation had to account for at least 50% of their cropping area. This sampling procedure not only ensured that farmers were mainly grain farmers but also allowed for farm diversity, in size, location, and structure within the sample. From January to July 2014, 100 farmers were surveyed. To limit the survey cost and maximize the number of respondents, farmers were met in two types of places: directly on their farms or during a professional meeting to which they were invited by their cooperative. In both cases, a surveyor, who introduced the questionnaire always the same way, asked them to fill the paper-questionnaire individually. The surveyor ensured that there was no interaction between farmers when they completed the paper questionnaire at the meeting, so that the conditions for carrying out the survey were the same when they were on their farms or at the meeting. In the questionnaire, an introduction first presented the survey's purpose and how it was to be conducted. It was specified that the data were anonymous and not available to the cooperative but only to the research team. The survey concluded with an oral debriefing open to farmers' questions about the survey. Average survey length was about two hours in total.

Econometric models

In our choice model, the adoption choice of a diversification crop, characterized by a set of attributes, is reduced to a binary choice of adoption or rejection. According to the random utility framework, the unobserved utility is composed of two components (Walker & Ben-Akiva, 2002) (Eq. 1).

$$V_{ij} = U_{ij} + \varepsilon_{ij} \text{ with } U_{ij} = \beta_j X_{ij} \tag{1}$$

V_{ij} is the utility of technology j for individual i, U_{ij} is the observable deterministic part of the utility function. In a first step, we assume that U_{ij} is a function of the vector of attributes of technology X_{ij} and β_j is the vector of technology-specific parameters, ε_{ij} represents the error terms (model 1). If error terms are assumed to be Independent and Identically Distributed (IID), the analysis can be conducted by comparing the deterministic parts of utilities U_{ij} (Eq. 1).

But the literature on adoption behavior underscores the importance of heterogeneity in preferences due to individuals' unobservable characteristics (Marra et al., 2003; Useche et al., 2013). In a second step, we allow for correlation between utility levels across alternatives through a farmer random specific effect. In keeping with Blazy et al. (2011) and Asrat et al. (2010), we estimate a *random parameter logit* (RPL) model, which considers not only the utility of the attributes of technology X_{ij} but also the vector Z_i of respondents' observable characteristics and of production choice context, interacting also with technology attributes (Eq. 2). In model 2, the deterministic part of utility U_{ij} of choice j by farmer i was given by Eq. (2):

$$U_{ij} = \beta_i' X_{ij} + \delta_j' Z_i \text{ with } \beta_i' = b + \mu W_i + e_i \tag{2}$$

where β_i' is the vector or farmer-specific parameters, δ_j' is the vector of technology-specific parameters. W_i is a subset of farm and famer's characteristics Z_i interacting with technology attributes X_{ij} and influencing their marginal utility β_i'; b and μ are vectors of parameters and e_i is a farmer random effect (Eq. 3).

$$V_{ij} = U_{ij} + \varepsilon_{ij} = bX_{ij} + \mu X_{ij} W_i + \lambda \,\text{Margin}_i + \delta'_j Z_i + u_{ij} \qquad (3)$$

where $u_{ij} = \varepsilon_{ij} + e_i X_{ij}$

The vector of coefficients β'_i is a vector of random variables with density function $f(\beta'|\theta)$, where θ are the parameters of the distribution of β'_i over the population (Train, 2009). Conditional on β'_i, the probability p_{ij} that individual i adopts technology j over rejection (j=0) follows a logistic distribution. Since β'_i and γ'_i are random and unobservable, the choice probability p_{ij} is (Eq. 4):

$$p_{ij} = P\left[V_{ij} - V_{i0} > 0 | \theta \right] = \int P\left[V_{ij} - V_{i0} > 0 | \beta'_i \right] f\left(\beta'_i | \theta \right) \mathrm{d}\beta'_i \qquad (4)$$

From this model, the marginal willingness to pay (WTP) for a given attribute is the negative ratio of the attribute coefficient to the marginal utility of the monetary attribute (here *Margin*). This represents the marginal monetary value of an attribute (Hanemann, 1984). The WTP for the attribute of the diversification crop is the opposite of the willingness to accept (WTA) the crop with this specific attribute: WTP = −WTA (Eq. 5)

$$\text{WTP} = -\frac{\beta_{\text{attribute}}}{\beta_{\text{monetary}}} \qquad (5)$$

Results

Descriptive statistics of the sample

Among the 100 farmers surveyed, considering that 15 cards were presented to each farmer, possibly 1500 choice cards were collected. But some responses were unusable or some data were missing, thus only 71 farmers' answers could be utilized[3] and finally, only 1065 choices were analyzed. Positive responses to the 1065 choices totaled 43%, which means that farmers accepted a new crop 6 times out of 15 on average. Among these positive answers, 60% would adopt the diversification crop on more than 10% of their total agricultural area. With respect to the farmers' characteristics, the mean age of the farmers was 50 years old, which is the same as the regional mean (Table 2). Respondents had been farmers for more than 20 years, and most of them did not have secondary school graduation qualifications (*baccalauréat*). More than one-third of the farmers had off-farm employment. The mean total agricultural area was over 150 ha, compared with approximately 100 ha in the region. Regarding the production context, the data show that half of the farms had sloping plots. Farmers faced on average 1.5 recurrent difficulties on their farm on the following list: soil

[3] But of missing values or incoherent answers

fertility, soil structure, weed pressure, crop pest and disease, water management (drought or excess), labor management, and crop management technicality. The current level of gross margin for durum wheat was in line with the regional average (€770/ha compared to €777/ha in the Midi-Pyrenees region in 2014), even though the standard deviation was high (€230/ha). Lastly, most of the farmers were cooperative members. Almost 60% of the farmers had already conducted technical trials in the past on new crops or new practices on their field, supervised by cooperatives or researchers.

Results of the *logit* model

The *logit* regression (model 1) was used to analyze the dichotomous choices of adoption or rejection of the diversification crop. As a starting point, the basic specification of utility function U_{ij} was a linear function of the attributes and the *constant* (6).

$$U_{ij} = \beta_j X_{ij} = \beta_1 \text{Margin} + \beta_2 \text{Nitro} + \beta_3 \text{Tech} + \beta_4 \text{Pest} + \beta_5 \text{Season} + \text{Constant} \tag{6}$$

In Eq. (6), i represents the respondents $i = 1, \ldots 71$ and j represents the choice card, $j = 1, \ldots 15$. β_j is the vector of coefficients of the different attributes of the choice cards.

Table 2 Descriptive statistics of the sample

	Description	Mean	*Std. Dev.*
Farmer characteristics			
Age	Farmer's age in years	50.1	*11.8*
Education	= 1 if the farmer has baccalaureate and 0 otherwise	0.3	–
Experience	Farming experience of the farmer in years	22.1	*11.9*
Household size	Number of household dependent members	2.6	*0.8*
Off-farm work	= 1 if the farmer works off-farm and 0 otherwise	0.4	*0.4*
Farm characteristics			
Total land	Total land size of the farmer in hectare	151.4	*81.2*
Working unit	Number of workers on the farm (farmer included)	1.8	*1.7*
Agronomic difficulties	Number of recurrent agronomic difficulties	1.5	*1.9*
Slope	= 1 if sloping plot 0 otherwise	0.5	–
Gathered field	=1 if fields are gathered 0 otherwise	0.8	–
Contract	% of the production sales with a forward contract	29.7	*25.9*
Wheat gross margin	Farmer current gross margin in durum wheat (€/ha)	769.7	*237.9*
Other production workload	% of workload required to other productions	40.1	*25.4*
Other production income	% of income represented by other productions	34.9	*20.8*
Information			
Coop member	= 1 if the farmer is a coop member 0 otherwise	0.9	–
Experiments	= 1 if the farmer does or has done experiment	0.6	–
Change	= 1 if the farmer has already major changes	0.8	–
Project	= 1 if the farmer has a major project in the future	0.5	–

Source: Authors' survey, 2014

The model displayed a rather high fit with a Mac Fadden R^2 of 0.19 (Hensher & Johnson, 1981), and the model correctly predicts 72% of choices (Table 3). The hypothesis of all coefficients equal to zero was rejected at 1%. Most of the coefficients were significant, and all the signs were as expected. The constant coefficient was negative and significant (p values below 10^{-4}), which means that the rejection of a diversification crop was weighted negatively, on average, in the sample. The cropping season (*Season*) was the only non-significant attribute estimate. The gross margin (*Margin*) and pest management (*Pest*) attribute coefficients were highly significant (p values below 10^{-4}). As expected, the *Margin* attribute estimate was positive; the choice of diversification is encouraged if diversification crops are more profitable. Conversely, the requirement of an additional pest treatment negatively affected farmers' adoption; farmers avoid crops that call for the number of treatments to be raised. The technicality of cropping management (*Tech*) was also highly significant in the farmer's adoption behavior (p value of 0.004). High crop management technicality implies a larger workload and many technical operations. Therefore, farmers prefer crops with a lower level of technicality. Results also showed that nitrogen restitution (*Nitro*) positively affected the adoption of a diversification crop. Nitrogen is a limiting factor for grain production, especially for durum wheat in short rotation. An increase in nitrogen restitution can reduce fertilization costs for farmers or increase the yield of the subsequent rotation crop. This result was also consistent with the previous result of the gross margin attribute.

Willingness to pay for the attributes of the diversification crop

The marginal WTP was computed from the results of the *logit* model (Table 3). The results showed that the mean marginal WTP of a unit of nitrogen restitution to the subsequent crop was €1.21/unit (Table 4). This is comparable to the current market value of a nitrogen unit. The marginal WTP of avoided additional pest treatment per hectare was valued at €93 by the respondents. Considering the total cost of a pest treatment, including product, fuel, and machinery costs, this WTP is close to the current market cost of an herbicide treatment in south-western France (about €80/ha based on extension services data). Both results backed up our experiment, since estimates were close to the market prices. The WTP also assigns a monetary value to non-market attributes. The willingness to accept to grow a diversification crop with a high level of technicality (which is the opposite of the WTP) was valued at €52. It is non-symmetric with the willingness to pay to reduce the technicality from a medium to low level of technicality that was valued at €47. A higher technicality is linked to higher risk level and higher profit, compared with a lower technicality that means lower risk level and lower profit. This asymmetry in WTP may reflect the asymmetry of preferences towards choices involving risky gains and losses.

Results of the RPL model

The previous *logit* model (model 1) assumed fixed effects of preferences between individuals. A random parameter *logit* (RPL) was estimated to account for unobserved heterogeneity (model 2). The attributes were random (except for the *Margin* attribute), and the error terms were assumed to be independent and normally distributed (IID). In order to capture the

Table 3 Results of the basic specification *logit* estimates (model 1)

Attributes	Modality	Basic specification model		
		Coef.	***Std. Err.***	***P* > |*z*|**
Margin (hundred €)	Continuous	0.948	*0.072*	0.000***
Nitro	Continuous	0.011	*0.004*	0.005**
Tech = high technicality		−0.542	*0.188*	0.004**
Tech = low technicality		0.395	*0.178*	0.027*
Pest = +1 treatment		−0.839	*0.195*	0.000***
Pest = -1 treatment		0.089	*0.189*	0.637
Season = summer		−0.053	*0.152*	0.726
Constant		−4.289	*0.396*	0.000***
N		1065		
LL		−592		
Mac Fadden adjusted R^2		0.19		

*α = 0.1, **α = 0.05, and ***α = 0.01—significance levels

observed heterogeneity, several farmer and farm-specific characteristics were integrated into the model (Z_i vector). Some interactions were also tested to evaluate how farm characteristics can affect farmers' preferences for the crop attributes (Eq. 7).

$$U_{ij} = \text{Margin}\left(\beta_{1i_1} + \beta_{1i_2}{*}\mathbf{Z_i}\right) + \text{Nitro}\left(\beta_{2i_1} + \beta_{2i_2}{*}\mathbf{Z_i}\right) + \text{Tech}\left(\beta_{3i_1} + \beta_{3i_2}{*}\mathbf{Z_i}\right) + \text{Pest}\left(\beta_{4i_1} + \beta_{4i_2}{*}\mathbf{Z_i}\right) + \text{Season}\left(\beta_{5i_1} + \beta_{5i_2}{*}\mathbf{Z_i}\right) + \beta_{6i}\mathbf{Z_i} + \text{Constant} \quad (7)$$

Attribute estimates of the RPL model

The introduction of new variables, interactions, and random parameters improved the model's overall fit, with an increase in the log-likelihood ratio compared to the *logit* model from −592 up to −508 (Table 5). Considering the farmers' preferences for the diversification crop attributes, with respect to the mean parameter estimates, the results

Table 4 Mean marginal willingness to pay (in €) for crop traits (model 1)

Attribute	Estimate	95% interval	
		Lower bound	Upper bound
Nitro	1.21 (€/U)	0.32	2.11
Tech = highly technical	−52.2 (€/ha)	−89.4	−15.1
Tech = slightly technical	47.2 (€/ha)	12.2	82.1
Pest = +1 IFT	−93.3 (€/ha)	−131.2	−55.4
Pest = −1 IFT	12.4 (€/ha)	−27.6	52.4
Season = summer	−2.2 (€/ha)	−35.7	31.2

Table 5 Results of the random parameter *logit* estimates (model 2)

	Coef.	*E-type*	*P > z*
Attributes			
Margin	1.660	*0.179*	0.000***
Nitro	0.005	*0.007*	0.417
Pest= −1 treatment	0.070	*0.217*	0.748
Pest = +1 treatment	−1.168	*0.227*	0.000***
Tech= low technicality	0.657	*0.213*	0.002**
Tech = high technicality	−0.489	*0.222*	0.028*
Season	−0.022	*0.176*	0.901
Interactions			
Nitro × slope	0.018	*0.009*	0.031*
Margin × contract	−0.003	*0.001*	0.001***
Margin × wheat GM^	−0.001	*0.000*	0.001***
Farm and farmer characteristics			
Education	0.587	*0.289*	0.042*
Other production workload	−0.047	*0.017*	0.006**
Gathered field	−0.676	*0.349*	0.050*
Other production income	0.053	*0.021*	0.011*
Project	−0.758	*0.279*	0.007**
Change	0.917	*0.400*	0.022*
Constant	−5.052	*0.706*	0.000***
Standard error			
Nitro	*0.019****	*0.006*	–
Constant	*0.742*	*0.153*	–
N	1020		
LL	−508.296		

*α = 0.1; **α = 0.05; ***α = 0.01—significance levels

^*GM*, gross margin

were also close to the fixed-parameter models. However, they confirmed farmers' heterogeneous preferences with respect to some attributes. Thus, the standard error of the RPL model estimates exhibited significant heterogeneity in taste for the nitrogen attribute (*Nitro*). The standard error of the *Nitro* attribute estimate was greater than the mean estimate (0.019 versus 0.005). Within the sample, farmers' valuation of the nitrogen restitution attribute was highly heterogeneous. The introduction of interactions showed that soil condition and sloping fields affect farmers' sensitivity to this attribute.

Results on individual characteristics

Turning to the role of individual characteristics, results showed that farmer's higher level of education increased the adoption of a diversification crop in the rotation (Table 5). With regard to working time, not surprisingly, a high workload for other production than crops (livestock, etc.) reduced the probability of adoption of a diversification crop. However, the more significant the share of this production in the farmer's income, the higher the probability of adopting a diversification crop. Plot structure also affected adoption, whereby farmers with gathered plots were less likely to diversify their rotation. Lastly, variables associated with the farm's past and future development partly explained farmers' adoption behavior. Having already made major changes on the farm since settling had a positive effect on adoption: ending or setting up a new farming activity, change of farming practices such as conversion to organic farming. Conversely, farmers who planned to make changes in the next 5 years were less likely to introduce a new diversification crop.

Results on interactions between crop attributes and farmers' characteristics

After testing a number of possible interactions, three interactions were selected based on their significance (Table 5). These significant interactions revealed that individual characteristics affect farmers' sensitivity to the diversification crop attributes. Firstly, the nitrogen restitution attribute (*Nitro*) positively interacted with soil characteristics such as sloping plots (*Slope*). This is consistent with the fact that fertilizer efficiency is highly dependent on soil-climate conditions and nitrogen leaks are considerable on sloping plots. Secondly, the gross margin attribute interacted with two farm characteristics. The gross margin effect significantly decreased with the farmer's current level of durum wheat gross margin (*margin* × *wheat GM*). Thus, farmers with a high current profitability of wheat could probably afford to adopt less profitable crops. Furthermore, farmers who partially insure their income with forward contracts placed a lower value on the gross margin of the diversification crop (*margin* × *contract*), suggesting cross-effects between production strategies and marketing strategies.

Both specifications of the *logit* model (basic *logit* and RPL *logit*) finally pointed up the role of different attributes, in addition to the monetary attribute, which could strongly affect a farmer's choice of a diversification crop. Agronomic attributes such as the level of nitrogen restitution of the diversification crop on the subsequent rotation crop, depending on soil conditions, played a significant role. Also, farm characteristics such as main crop performance (gross margin), other production workload, other production income, and marketing strategy significantly influenced diversification adoption.

Discussion and conclusion

Crop diversification is getting a major concern for specialized crop grain farms that face more and more agronomic difficulties like pest and pathogen resistance or crop yield stagnancy. The design of cropping systems with longer rotations is a lever to overcome these difficulties. Lengthening crop rotation was here considered a new technology that requires new skills, brings up uncertainties, and refers to the adoption of an innovation. The preferences for crop diversification attributes were evaluated with a CM.

Tradeoffs between monetary and non-monetary determinants

The key role played by monetary determinants in adoption behavior of an innovative technology is widely acknowledged in the agricultural economics literature. However, short-term profit maximization appears to be a restrictive view of farmers' adoption behavior (Just, 2000). Based on a CM, our work highlights the role played by non-monetary attributes in farmers' adoption of a diversification crop. Less than half of the farmers surveyed said they would adopt a diversification crop, and the majority of those ones would do so on more than 10% of their total agricultural area. Not surprisingly, we show a positive and significant weight of the monetary attributes. Agronomic attributes such as the level of nitrogen restitution and the possibility to avoid pest treatments are highly valued by farmers. This confirms that the nitrogen intake of a nitrogen-catching crop inside a rotation reduces the cost of mineral fertilizers and probably helps in overcoming the recurrent problem of winter nitrogen leaching in this regional production system (Preissel et al., 2015). We estimated a marginal willingness to pay for one unit of nitrogen restituted to the subsequent crop of €1.21/unit. This value is comparable to the current market value of a mineral nitrogen unit. The opportunity cost of crop diversification over mineral nitrogen applications could even be negative if, as expected, the price of energy and chemical inputs increased in long term. Our results also show that high crop management technicality is rejected by farmers. They exhibit asymmetric preferences, negative preferences for increasing technicality being higher, in absolute value, than positive preferences for decreasing technicality, probably due to asymmetric preferences towards risk in the gains and in the losses.

Role of local soil-climate conditions in adoption

We showed that the positive effect of crop rotation on soil nitrogen intake was valued even stronger when farmers already faced difficulties with their current cropping system or had restrictive soil-climate conditions that increase the risk of nitrogen leaching (higher plot slopes for instance). In semi-arid agricultural systems, Mac Cord et al. also showed that favorable growing conditions increase the adoption of crop diversification (McCord et al., 2015). Our results confirm that it remains true in temperate areas where soil-climate conditions also play a significant role in farmers' diversification adoption decision.

Managing several productions on a farm

The adoption of a diversification crop is reinforced when farm performance is high in its main crop and when farmers work with forward contracts. This suggests that crop diversification decisions probably interfere with income risk management strategies at farm scale, suggesting also cross-effects between production and marketing decisions (Ricome et al., 2016).

A well-known determinant of diversification is the role played by marketing chains and possible outlets for the diversification crops. If market opportunities do not exist, it is very risky for a farmer to develop a diversification crop at large scale (Meynard et al., 2018). This was not investigated in the present CM where market channels were assumed to be controlled, but it could be relevant to test this attribute in future research.

Finally, if choice modelling is an already published and widespread method, most of the existing studies concerned the adoption of a technology trait or of a crop variety and very few of them concern the adoption of a diversification crop. Our study adds to the scientific corpus on choice-modelling methods by proposing a referendum-choice experiment to explore farmers' preferences for increasing cultivated biodiversity in Western countries (Birol et al., 2006; Waldman et al., 2017). This contributes to the analysis of tradeoffs between monetary and non-monetary determinants in crop diversification decisions (Useche et al., 2013). It also makes for a better understanding of the complementary levers able to drive technological change towards sustainable farming systems (Asrat et al., 2010; Blazy et al., 2011).

Understanding the heterogeneity of adoption of a diversification crop could finally help both public and private stakeholders, especially farmers' cooperatives and extension services, design appropriate policy and advice towards farmers. Passing on local information to farmers on crop agronomic performances could probably enhance crop diversification adoption. A significant share of farmers' heterogeneity in preferences nevertheless remains unobservable and difficult to explain. It probably relates to farmers' knowledge, experience, and perceptions.

Appendix

Table 6 Overview of the choice set

	Nitrogen restitution (*units of nitrogen*)	Pest treatment avoided (*per hectare*)	Level of technicality	Season	Gross margin
Card 1	50	1	Medium	Winter	€300/ha
Card 2	25	−1	High	Winter	€300/ha
Card 3	0	0	Low	Summer	€300/ha
Card 4	25	−1	Medium	Winter	€375/ha
Card 5	50	0	Low	Summer	€375/ha
Card 6	0	1	High	Summer	€375/ha
Card 7	50	−1	Low	Winter	€450/ha
Card 8	0	0	High	Winter	€450/ha
Card 9	25	1	Medium	Summer	€450/ha
Card 10	0	1	Low	Winter	€525/ha
Card 11	25	0	Medium	Summer	€525/ha
Card 12	50	−1	High	Summer	€525/ha
Card 13	50	0	High	Winter	€600/ha
Card 14	25	1	Low	Summer	€600/ha
Card 15	0	−1	Medium	Summer	€600/ha

Author contribution Aude Ridier: conceptualization, methodology, writing (review and editing), resources, supervision, funding acquisition, and project administration. Caroline Roussy: conceptualization, methodology, formal analysis and investigation, and writing (original draft). Karim Chaib: conceptualization, methodology, validation, resources, supervision, and writing (review and editing).

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Declarations

Conflict of interest The authors declare no conflict of interest.

References

Adamowicz, W., Boxall, P., Williams, M., & Louviere, J. (1998). Stated preference approaches for measuring passive use values: Choice experiments and contingent valuation. *American Journal of Agricultural Economics, 80*, 64–75.

Adesina, A. A., & Baidu-Forson, J. (1995). Farmers' perceptions and adoption of new agricultural technology: evidence from analysis in Burkina Faso and Guinea, West Africa. *Agricultural Economics, 13*, 1–9.

Agreste (2014). mémento édition 2014, Direction régionale de l'alimentation, de l'agriculture et de la forêt de Midi-Pyrénées. https://draaf.occitanie.agriculture.gouv.fr.

Asrat, S., Yesuf, M., Carlsson, F., & Wale, E. (2010). Farmers' preferences for crop variety traits: Lessons for on-farm conservation and technology adoption. *Ecological Economics, 69*, 2394–2401.

Baffoe-Asare, R., Danquah, J. A., & Annor-Frempong, F. (2013). Socioeconomic factors influencing adoption of codapec and cocoa high-tech technologies among small holder farmers in Central Region of Ghana. *American Journal of Experimental Agriculture, 3*(2), 277.

Baumgart-Getz, A., Prokopy, L. S., & Floress, K. (2012). Why farmers adopt best management practice in the United States: A meta-analysis of the adoption literature. *Journal of environmental management, 96*(1), 17–25.

Beharry-Borg, N., Smart, J. C., Termansen, M., & Hubacek, K. (2013). Evaluating farmers' likely participation in a payment programme for water quality protection in the UK uplands. *Regional Environmental Change, 13*(3), 633–647.

Birol, E., Karousakis, K., & Koundouri, P. (2006). Using a choice experiment to account for preference heterogeneity in wetland attributes: The case of Cheimaditida wetland in Greece. *Ecological Economics, 60*, 145–156.

Blazy, J.-M., Carpentier, A., & Thomas, A. (2011). The willingness to adopt agro-ecological innovations: Application of choice modelling to Caribbean banana planters. *Ecological Economics, 72*, 140–150.

Breffle, W. S., & Rowe, R. D. (2002). Comparing choice question formats for evaluating natural resource tradeoffs. *Land Economics, 78*(2), 298–314.

Broch, S. W., & Vedel, S. E. (2012). Using choice experiments to investigate the policy relevance of heterogeneity in farmer agri-environmental contract preferences. *Environmental and Resource Economics, 51*(4), 561–581.

Davis, A. S., Hill, J. D., Chase, C. A., Johanns, A. M., & Liebman, M. (2012). Increasing cropping system diversity balances productivity, profitability and environmental health. *PloS One, 7*(10), e47149. https://doi.org/10.1371/journal.pone.0047149.

Espinosa Goded, M., Barreiro Hurlé, J., & Ruto, E. (2010). What do farmers want from agri-environmental scheme design? A choice experiment approach. *Journal of Agricultural Economics, 61*(2), 259–273.

Feder, G., & Umali, D. L. (1993). The adoption of agricultural innovations: A review. *Technological Forecasting and Social Change, 43*, 215–239.

Feder, G., Just, R. E., & Zilberman, D. (1985). Adoption of agricultural innovations in developing countries: A survey. *Economic Development and Cultural Change, 33*, 255–298.

Fernandez-Cornejo, J., Beach, E. D., & Huang, W.-Y. (1994). The adoption of IPM techniques by vegetable growers in Florida, Michigan and Texas. *Journal of Agricultural and Applied Economics, 26*, 158–172.

Greiner, R. (2015). Motivations and attitudes influence farmers' willingness to participate in biodiversity conservation contracts. *Agricultural Systems, 137*, 154–165.

Hanemann, W. M. (1984). Valuing the environment through contingent valuation. *The Journal of Economic Perspectives*, 19–43.

Hanley, N., Wright, R., & Adamowicz, V. (1998). Using choice experiments to value the environment. *Environmental and Resource Economics, 11*, 413–428.

Hanley, N., Mourato, S., & Wright, R. E. (2001). Choice modelling approaches: A superior alternative for environmental valuatioin? *Journal of Economic Surveys, 15*, 435–462.

Hensher, D. A., & Johnson, L. W. (1981). *Applied discrete choice modelling*. Wiley.

Johnson, R. J., Doye, D., Lalman, D. L., Peel, D. S., Raper, K. C., & Chung, C. (2010). Factors affecting adoption of recommended management practices in stocker cattle production. *Journal of Agricultural and Applied Economics, 42*, 15–30.

Just, R. E. (2000). Some guiding principles for empirical production research in agriculture. *Agricultural and Resource Economics Review, 29*, 138–158.

Knowler, D., & Bradshaw, B. (2007). Farmers' adoption of conservation agriculture: A review and synthesis of recent research. *Food Policy, 32*, 25–48.

Lancaster, K. J. (1966). A new approach to consumer theory. *The Journal of Political Economy, 74*, 132–157.

Marra, M., Pannell, D. J., & Abadi Ghadim, A. (2003). The economics of risk, uncertainty and learning in the adoption of new agricultural technologies: where are we on the learning curve? *Agricultural Systems, 75*, 215–234.

McCord, P. F., Cox, M., Schmitt-Harsh, M., & Evans, T. (2015). Crop diversification as a smallholder livelihood strategy within semi-arid agricultural systems near Mount Kenya. *Land Use Policy, 42*, 738–750.

Mercer, D. E. (2004). Adoption of agroforestry innovations in the tropics: A review. *Agroforestry Systems, 61-62*, 311–328.

Meynard, J. M., Charrier, F., Le Bail, M., Magrini, M. B., Charlier, A., & Messéan, A. (2018). Socio-technical lock-in hinders crop diversification in France. *Agronomy for Sustainable Development, 38*(5), 54.

Paxton, K. W., Mishra, A. K., Chintawar, S., Roberts, R. K., Larson, J. A., English, B. C., Lambert, D. M., Marra, M. C., Larkin, S. L., & Reeves, J. M. (2011). Intensity of precision agriculture technology adoption by cotton producers. *Agricultural and Resource Economics Review, 40*, 133.

Preissel, S., Reckling, M., Schläfke, N., & Zander, P. (2015). Magnitude and farm-economic value of grain legume pre-crop benefits in Europe: A review. *Field Crops Research, 175*, 64–79.

Prokopy, L. S., Floress, K., Klotthor-Weinkauf, D., & Baumgart-Getz, A. (2008). Determinants of agricultural best management practice adoption: Evidence from the literature. *Journal of Soil and Water Conservation, 63*, 300–311.

Ricome, A., Chaïb, K., Ridier, A., Kephaliacos, C., & Carpy-Goulard, F. (2016). The role of marketing contracts in the adoption of low-input production practices in the presence of income supports: An application in Southwestern France. *Journal of Agricultural and Resource Economics, 41*.

Rolfe, J., & Bennett, J. (2009). The impact of offering two versus three alternatives in choice modelling experiments. *Ecological Economics, 68*(4), 1140–1148.

Roussy, C., Ridier, A., & Chaib, K. (2017). Farmers' innovation adoption behaviour: role of perceptions and preferences. *International Journal of Agricultural Resources, Governance and Ecology, 13*(2), 138–161.

Ruttan, V. W. (2002). Productivity growth in world agriculture: sources and constraints. *Journal of Economic Perspectives, 16*(4), 161–184.

Schott, C., Mignolet, C., & Meynard, J. M. (2010). Les oléoprotéagineux dans les systèmes de culture: évolution des assolements et des successions culturales depuis les années 1970 dans le bassin de la Seine. *Oil Seeds and fat Crop and Lipids, 17*, 276–291. https://doi.org/10.1051/ocl.2010.0334.

Smale, M., Just, R. E., & Leathers, H. D. (1994). Land allocation in HYV adoption models: An investigation of alternative explanations. *American Journal of Agricultural Economics, 76*, 535–546.

SSP Agreste. 2014. *Chiffres et données de l'agriculture*, Service de la statistique et de la prospective, French Ministery of Agriculture, http://agreste.agriculture.gouv.fr/donnees-de-synthese/

Tilman, D., Cassman, K. G., Matson, P. A., Naylor, R., & Polasky, S. (2002). Agricultural sustainability and intensive production practices. *Nature, 418*(6898), 671–677.

Train, K. (2009). *Discrete choice methods with simulation*. Cambridge University Press.
Useche, P., Barham, B. L., & Foltz, J. D. (2013). Trait-based adoption models using ex-ante and ex-post approaches. *American Journal of Agricultural Economics, 95*, 332–338.
Waldman, K. B., Ortega, D. L., Richardson, R. B., & Snapp, S. S. (2017). Estimating demand for perennial pigeon pea in Malawi using choice experiments. *Ecological economics, 131*, 222–230.
Walker, J., & Ben-Akiva, M. (2002). Generalized random utility model. *Mathematical Social Sciences, 43*, 303–343.

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