WORKING PAPER

ROLE OF FARMERS' RISK AND AMBIGUITY PREFERENCES ON FERTILIZATION DECISIONS: AN EXPERIMENT

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In a context of climate change, the agricultural sector offers a potential of mitigation. However, most of the farmers do not adopt the mitigation practices recommended, among them the reduction of nitrogen fertilization. In parallel, various uncertainties characterize agricultural production, so that farmer's risk and ambiguity preferences may be potential determinants to the adoption (or not) of mitigation practices. This is precisely the objective of this paper to explore this way. For that purpose, we realize a questionnaire submitted to French farmers where we elicit risk and ambiguity preferences through simple lottery choices, and then we ask questions about the farmer's fertilization decisions. We show that risk aversion as well as ambiguity aversion impact fertilization practices, through diverse drivers and in an opposite direction. This result implies that fertilization practices are more complex than only classic risk-related behaviors. The incentive approaches associated with mitigation and fertilization have to take into account this complexity.

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1 Introduction

Reducing greenhouse gases (GHG) emissions in the agricultural sector is a major environmental policy challenge in France, where the sector was responsible in 2017 for 20.4% of the total GHG emissions (CITEPA, 2019). The agricultural sector, associated to the forest one, is the main sector able to sequester atmospheric carbon, so that it represents a great potential of mitigation. Mitigation practices that are proposed to farmers in the context of the European Common Agricultural Policy (CAP) encourage farmers to diversify their activities, integrate leguminous crop, improve land rotation, develop better link between a good feeding for the livestock and vegetal protein production, and especially limit the use of pollutant inputs. In this context, reducing synthetic nitrogenous fertilization or improving fertilization efficiency is an important mitigation strategy. A seminal study on French farmers' practices and economic characteristics show that reducing the total fertilizers application on the parcels, and reducing the first application in case of fertilization splitting, which are two important mitigation practices associated to synthetic nitrogen fertilization, can be associated to negative abatement costs (Pellerin et al., 2013).

However, farmers poorly adopt such practices, even when they are associated to benefits from adoption such as these specific mitigation practices (Pellerin et al., 2013). Several determinants of the non-adoption have been identified in the literature. For example, the level of education and the farm size were the most reliable variables that seem to significantly positively impact adoption. Our idea is that hidden costs linked to the existence of uncertainty may explain (almost partly) the non-adoption of fertilization reduction to mitigate climate change. Indeed, adoption of new practices generate production uncertainty on the farmer's profits[1]. The farmers are not certain of the efficiency of the practices, and the resulting outcome is uncertain. Changing the farmer's habits may be difficult, in particular because the reduction of fertilization is associated to uncertain effect on the profit. As a consequence, the farmer's preferences toward risk and ambiguity should also play a role in this adoption process. In this context, the question that we address is the following : What is the impact of farmer's preferences towards risk and ambiguity on fertilization choices ?

This research question refers to two different literatures aiming at the elicitation of farmer's risk and ambiguity preferences. The first literature gathers studies based on revealed preferences method, which provides an estimate based on real farmer's choices (production, input). The second literature is composed with articles using stated preferences methodologies. This method provides a quantification of the risk attitude through experiment based on simple decisions taken in a controlled environment to provide a pure measurement. In this paper, we propose to elicit risk and ambiguity aversion parameters through simple lottery choices, and then, to use these parameters as potential explanatory variables for farmer's fertilization choices. We then combine experimental data on risk and ambiguity aversion with real data on the fertilization decisions[2].

The rest of the paper is organized as follows. In Section 2 we precisely position our research as regard to the two literatures briefly evoked above, the one using revealed preferences method and the other based on stated preferences method. Section 3 presents the questionnaire. The results are presented in Section 4, and Section 5 provides the discussion and conclusion of the paper.

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[1]In addition to production uncertainty, a price uncertainty may also appeared. However, as the mitigation practice considered (fertilization) does not imply a change of the agricultural product or a change of market, we only focused on production uncertainty.

[2]A similar approach has been proposed in Brunette et al. (2017) where risk preferences parameter has been estimated through lottery choices and then used to explain the foresters' probability to harvest.

2 Literature review

Following the modeling approaches of Pope and Kramer (1979), Moschini and Hennessy (2001) and Roosen and Hennessy (2003), *inter alia*, the use of an input by a producer can be impacted by risk if the input is risk-increasing or decreasing (in yields), depending on the producer's risk preferences: a risk averse agent will use less of a risk-increasing input than a risk neutral one, and reciprocally. This result has been specifically extended in the case of input use and agricultural policies by Leathers and Quiggin (1991) who show that a policy can be partly inefficient if the risks associated to the input and producer's preferences toward risk are not taken into account. For instance, taxing a risk-increasing polluting input in order to disincentive its use by farmers can lead to disappointing results because risk averse farmers can try to maintain a sufficiently high level of its use to avoid risk. This phenomenon can explain why yields risk and risk preferences are hidden costs of pollution policies, especially for agricultural policies, and low level of participation can be observed.

The relationships between nitrogenous fertilization and risk is well-documented in empirical studies, that especially use revealed preferences methods or agronomic simulations. Stuart et al. (2014) show that applying more nitrogenous fertilizer is a risk-decreasing activity, and depends on farmers' perception about risk and their trust in the information provided about fertilization reduction. Financial insertion and background risks, as well as the level of competition and the dependency toward contractors, create risks that prevent farmers from reducing their use of nitrogenous fertilizer to maintain a sufficient level of yields. Sheriff (2005) shows that all farmers put a nitrogenous fertilizer rate according to the yields expectation independently of risk preferences, thus uncertainty impacts this rate. Moreover, risk aversion and risk perception impact fertilizer use by farmers, in the same way than in the Pope and Kramer (1979) rationale: it depends on the risk-decreasing or risk-increasing nature of the input. Bontems and Thomas (2000) study the role of risk aversion and additional information on nitrogenous fertilizer applications, and found that a large proportion of their sample of farmers was risk averse, and risk aversion led to an over-fertilization accounting for 7.1% of total fertilizer costs per hectare on average. The value of information, associated to the practice of fertilization splittings and observation of nitrogen availability between splits, account for 23.53% of fertilizer costs per hectare. Dequiedt and Servonnat (2016) developed the mathematical conditions for risk aversion to lead to higher rate of fertilization. They tested empirically their results and found that an important proportion of French farmers was risk averse and that these preferences led to 29.4% more nitrogenous applications by hectare. This account for approximately €75.8/ha, and increases the marginal abatement costs of fertilization reduction. The gains that farmers can receive if the application recommendations by extension agents would take into account risk and risk aversion have been studied by Gandorfer et al. (2011). Through different measures of risk, they compute the optimal level of nitrogenous rate in different scenarii in order to reach certainty equivalents in the same perspective as objective yields. Among their results, they found that fertilization decreases especially the probability of negative profits and, for the scenarii of high risk aversion, the consideration of risk premia leads to an average gain per hectare for the farmers. Monjardino et al. (2015) also show that the risk and risk preferences significantly modify the level of optimal nitrogenous fertilization to apply in order to close the gap between certain yields goals and actual yields. Globally, the theoretical results of the modeling approaches are often validated by empirical studies, showing that risk perception, risk preferences and arbitrage between yields mean and variance, impact the level of nitrogenous fertilization. This relationship depends on natural conditions, but is relatively robust in one direction: risk aversion seems to incentive farmers to apply more fertilizer rate on their crops, and consequently increases the cost of reducing

applications.

More recently, another literature emerged based on experimental economics and proposed to elicit risk and ambiguity aversion parameters through simple lottery choices. Measuring directly risk and ambiguity preferences through experiments allows for the isolation of these attitudes from other behavioral parameters in a controlled environment. It thus prevents some endogeneity biases related to the simultaneous contribution of perceptions, context and individual preferences to the final decision. Binswanger (1980) was the first to submit lotteries to a sample of farmers in order to elicit their risk preferences. The experiment presents a comparison of lotteries from the less to the riskier, and ask farmers to choose their preferred lotteries. The more they like risky lotteries, the more risk loving they are, and reciprocally[3]. The author found that Indians farmers were on average risk averse, and that it can have an influence on a lot of phenomenon (investment, credit, innovation adoption, etc.). These initial researches served as an impulse in the literature, so that several elicitation procedures appeared. One of the famous procedure, the Multiple Price List (MPL) method, was popularized by Holt and Laury (2002). The idea is to submit to the subjects ten paired-lottery choices, and to observe the switching point, i.e. the choice for which they switch from the safe option to the risky one. This switching point allows then to infer a coefficient of relative risk aversion according to the specification of the utility function adopted. This MPL method has already been used to elicit the farmer's risk preferences. Reynaud and Couture (2012) implemented an experiment with 30 French farmers aiming to compare three different elicitation procedures among which the MPL one. They show that the estimate of risk aversion is dependent on the procedure and the context. Bocquého et al. (2014) conducted an experiment on a sample of 100 French farmers, and show that they exhibited attitudes in accordance to expected utility preferences assumption, and that they were risk averse. Chakravarty and Roy (2009) extended this MPL procedure to ambiguity aversion elicitation. Their respondents were risk averse but ambiguity neutral in the gain domain, but risk seeking and ambiguity seeking in the loss domain. Bougherara et al. (2017) elicited the risk and ambiguity preferences of 197 French farmers, and show that they are, on average, risk and ambiguity averse. The same result is obtained for farmers from other countries like Ethiopia for example (Akay et al., 2012).

The estimates provided by experimental economics are often used to explain real agricultural decisions. The studies that did this provided divergent results. Ghadim et al. (2005) showed that Australian farmers adopt new crops depending on their risk aversion, risk perceptions and the perceived covariance between the yields of the different crops. Le Cotty et al. (2018) found that impatient farmers tend to secure their current consumption by fertilizing more if they are risk averse, while patient farmers do the reverse if they are risk averse because they need to smooth their consumption over time. Hellerstein et al. (2013), through a Holt and Laury's experiment, found that more risk aversion led to less diversification and less likelihood to adopt an insurance contract. Liu (2013) showed that risk aversion can lead to significant delay in adoption of new varieties of crops. Engle-Warnick et al. (2007) and Barham et al. (2014) both observed with experiments (respectively in Peru and in the US) that ambiguity aversion decreases the probability to adopt a new crop variety if farmers are not sure of the associated distribution of yields or if the new variety increases the level of ambiguity about yields. In the latter, the authors even show that risk aversion has no impact on adoption of risk-decreasing crop, suggesting that ambiguity alone can sometimes has an effect *per se*.

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[3]This Ordered Lottery Selection (OLS) procedure was diffused later on by Eckel and Grossman (2008).

3 Questionnaire

The questionnaire was in three parts (see Appendix B). The first one was composed of lottery choices to elicit risk aversion and ambiguity aversion parameters. The second part is related to the farmers' practices in terms of fertilization and also contains some information about their property. The last part is dedicated to socio-demographic characteristics.

3.1 Part 1 of the questionnaire: Elicitation of preferences

The preferences are elicited through a MPL method, as proposed by Holt and Laury (2002) for risk, and Chakravarty and Roy (2009) for ambiguity. Appendix A presents the lottery choices under risk and ambiguity. For each task, individuals are presented with ten decisions between two lotteries (Option A and Option B). For each decision, the subject has to choose between a safe option (Option A) and a risky one (Option B) for risk (Table 7), and between a risky decision (Option A) and an ambiguous one (Option B) for ambiguity (Table 8). The number of safe choices allows to infer a coefficient for the relative risk aversion coefficient assuming a power utility function as: $U(x) = x^r$ with r the relative risk aversion coefficient and x the wealth. The expected utility is given by $Eu(x) = pU(x)$ with p the objective probability associated to a set of risky outcomes. Table 1 presents this classification. Under the same assumption, Table 2 presents the classification for ambiguity aversion following Chakravarty and Roy (2009). We use the KMM model (Klibanoff et al., 2005) to represent ambiguity preferences through a ϕ function representing the distorsion of the value function according to ambiguity preferences. Given s the subjective probability belief over a set of ambiguous outcomes, the total expected value function over outcomes can be written as $V(x) = s\phi[Eu(x)]$, with $\phi(z) = z^a$. The concavity of U gives the level of risk aversion, while the concavity of ϕ gives the level of ambiguity aversion.

Table 1: Risk aversion classification based on lottery choices

Number of safe choices	Bounds for relative risk aversion	Classification
0 and 1	$r < -0.95$	Highly risk-loving
2	$-0.95 < r < -0.49$	Very risk-loving
3	$-0.49 < r < -0.15$	Risk-loving
4	$-0.15 < r < 0.15$	Risk-neutral
5	$0.15 < r < 0.41$	Slightly risk averse
6	$0.41 < r < 0.68$	Risk averse
7	$0.68 < r < 0.97$	Very risk averse
8	$0.97 < r < 1.37$	Highly risk averse
9 and 10	$1.37 < r$	Stay in bed

From these tables two indicators may be extracted. The first one is the number of safe choices to represent risk aversion and the number of risky choices to represent ambiguity aversion. In both cases, the higher the number is, the higher the strength of the aversion will be. The second indicator that may be computed is an individual's average risk and ambiguity coefficient. Indeed, using the center of the interval, we can attribute to each subject their corresponding coefficient. These two indicators are then used as a farmer's characteristic and considered as a potential explanatory variable for fertilization choices.

Table 2: Ambiguity aversion classification based on lottery choices

Number of risky choices	Bounds for relative ambiguity aversion	Classification
0	$s > 1.92$	Extremely ambiguity-loving
1	$1.92 < s < 1.59$	Highly ambiguity-loving
2	$1.59 < s < 1.35$	Very ambiguity-loving
3	$1.35 < s < 1.15$	Ambiguity-loving
4	$1.15 < s < 1$	Slightly ambiguity-loving
5	$1 < s < 0.86$	Ambiguity neutral
6	$0.86 < s < 0.75$	Slightly ambiguity averse
7	$0.75 < s < 0.66$	Ambiguity averse
8	$0.66 < s < 0.43$	Very ambiguity averse
9	$0.43 < s < 0.30$	Highly ambiguity averse
10	$s \geq 0.30$	Extremely ambiguity averse

3.2 Participants, order effect and incentives

The questionnaire was submitted to a sample of 45 French farmers from four French agricultural cooperatives[4]. The questionnaire was realized during meetings organized by the cooperatives, between November 2018 and March 2019. The researchers were present during the meeting to present the questionnaire and answer to any potential questions from the farmers.

The first part of the questionnaire used methodology from experimental economics to elicit farmer's preferences. In this part, we are not allowed to use financial incentives as traditionally done in such tasks in experimental economics, especially in lab experiment. However, the farmers were informed that they will receive the results of the study. In the literature, Beattie and Loomes (1997) and Camerer and Hogarth (1999) showed that, since questions are related to simple lottery choices, monetary incentives do not seem to significantly affect the decisions. In the same vein, some papers show the absence of difference in terms of decisions between lottery choices using hypothetical or real payoffs (Battalio et al., 1990; Wik et al., 2004). Finally, as indicated by Dohmen et al. (2011), hypothetical choices still represent good predictors of risk preferences. In this context, we do not expect a bias resulting from not using financial incentives.

Another concern when using elicitation task from experimental economics is the order effect, i.e. the order in which the subjects answer to the various tasks. In order to control for order effect, half of the distributed questionnaire begun with the elicitation of preferences towards risk first and then, the elicitation of ambiguity preferences, and the opposite occurs for the other half.

3.3 Parts 2 and 3 of the questionnaire: fertilization and socio-demographic characteristics

The survey specifically focuses on the bigger parcel of the farmer's exploitation (except grasslands). The bigger parcel is more likely to host the main crop of the exploitation during the agricultural campaign and the crop for which the farmer expects to grow most of her profits (scale effect, intensity effect). Specific questions associated to parameters that can explain the nitrogenous needs,

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[4]The size of the sample is often small when dealing with "real subjects". It may be compared with the sample of 30 French farmers of Reynaud and Couture (2012) and to the sample of 42 French private forest owners of Brunette et al. (2013).

and the nitrogenous fertilization decisions are asked in order to provide relevant control variables: spreadable area on the parcel, type of precedent crop, soil type, potential organic fertilizer use and fertilizer tillage. Parcel locations (department, municipalities) as well as the status of the farmer with this parcel (owner, tenant) and the potential cropping contract are asked too.

The actual and expected yields are crucial for the farmers since the risk the farmer would face relative to fertilization is related to how she seeks to reach this yields objective. Since actual yields give us vague general information about the level of efficiency of fertilization decisions, the yields goal before the end of the campaign is a proxy of what yields could have be expected at the beginning and the difference between both is a proxy of the actual shocks that farmer faces on the crop. We expect to use this proxy as a potential explanatory variable of the fertilization's level, in interaction with risk and ambiguity preferences.

The synthetic nitrogen fertilization and its potential N2O emission depends on multiple parameters: the dose of fertilizer, the spreading method type, the splitting of spreading according to the plant needs, all those elements being related to the current regulation on nitrogen fertilization. We thus explore all these elements in order to have a complete view of how can synthetic nitrogen be used. We also associated these elements to the advices farmers received about them from their cooperative agent. This last part was of particular importance for our cooperatives partners, in a perspective of monitoring and evaluation of their activities. To sum-up the fertilization part, as we want to test the way risk and ambiguity preferences can impact N2O emission from synthetic nitrogen fertilization and the capacity to follow the official advices about fertilization, we seek quantity and quality variables about actual fertilization, and also quantity and quality variables about advices in order to construct difference variables. In order to gather more control variables, we asked farmers the amount they receive from CAP subsidies (and the specific part associated to "green" behaviors), if they contracted an optional yields insurance, the total area of their farm and their possible participation in a farmers union.

In a last part we asked classical questions about socio-demographic variables that can impact risk and ambiguity preferences as well as global economic behaviors of the farmers. Age, marital status, education as well as revenues (*inter alia*) were asked. The survey is totally anonymous, in order to ensure farmers that their response concerning fertilization (a sensitive topic) will not be associated to them.

4   Results

4.1   Elicitation of risk and ambiguity preferences

These three graphs show the results for risk and ambiguity preferences (N = 35). Figures 1 and 2 show the distribution of preferences in our sample. The average Number of Safe Choices (NSC - risk) is 6, while the average Number of Risky Choices (NRC - ambiguity) is around 5. The major part of respondents is risk averse (70.27%) while 14.86% of farmers are risk neutral and the remaining 14.86% are risk loving. The major part of respondents is ambiguity neutral (38.24%) and ambiguity loving (38.24) and 23.5% are ambiguity averse (34 non empty answers). Each number of safe (risky) choices corresponds to a range of coefficients of risk (ambiguity) aversion. We attribute a coefficient to each number of safe (risky) choices by taking the midpoint of each class, so that each respondent

has a coefficient[5]. The average coefficient of risk aversion is 0.615 (prevalence of risk aversion) and the average coefficient of ambiguity aversion is 0.91 (close to ambiguity neutrality).
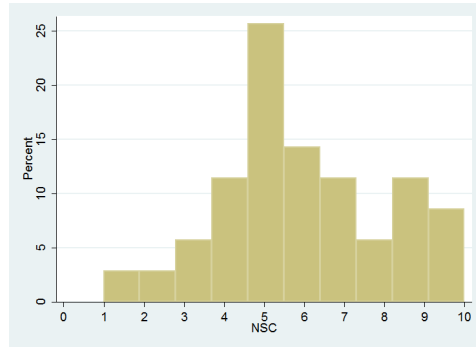

Figure 1: Number of safe choices (NSC) selected by the farmers
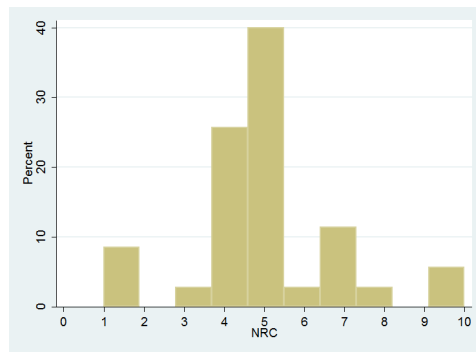

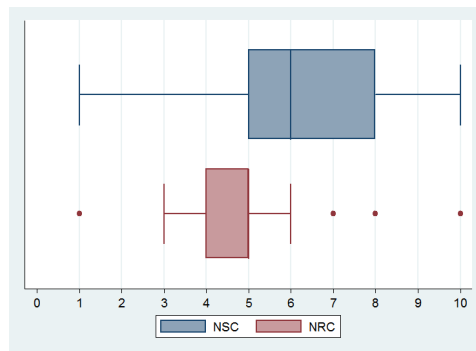Figure 2: Number of risky choices (NRC) selected by the farmers

Figure 3: Number of safe and risky choices selected by the farmers

These results are in line with the findings of Bougherara et al. (2017) for the French farmers' risk aversion (0.614), but not for the ambiguity aversion (0.722), where the respondents were more ambiguity averse. The results are very close from those of Barham et al. (2014), finding a prevalence of risk aversion preferences in terms of population proportion, and 38% of ambiguity neutrality, 38%

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[5]For the extreme categories we assume 2 and -2 under risk, as Reynaud and Couture (2012), which correspond to 2.55 and -0.75 under ambiguity if we assume the same computation method.

of ambiguity loving and 24% of ambiguity aversion on a sample of Midwestern (US) farmers. More generally, risk aversion and ambiguity neutrality is in line with the results of Chakravarty and Roy (2009) on a sample of Indian students. The good fit of our measures with some results from these previous researches is an important outcome, in terms of replicability and external validity of the elicitation methodology.

The Figure 3 presents box plots of the dispersion of preferences for risk and ambiguity in our sample. We can see that the risk lottery's responses are more spread than for the ambiguity lottery's responses, but the later present some outliers.

We constructed a categorical variable with three modalities: if the respondent is risk (ambiguity) loving it takes the value 1, if the respondent is risk (ambiguity) neutral it takes the value 2, if the respondent is risk (ambiguity) averse it takes the value 3. The modality 2 is attributed if the farmer made 4 safe choices in the risk experiment and 5 risky choices in the ambiguity experiment. If the answer is below this neutrality number, the farmer is assumed to be risk (ambiguity) loving, and the farmer is assumed to be risk (ambiguity) averse if the answer is above this neutrality number. We produced the cross Table 3 of risk and ambiguity preferences according to these categories (N = 45).

Table 3: Cross table function of the modality

	Ambiguity			
Risk	Inclination	Neutrality	Aversion	Total
Inclination	2	1	1	4
% row	50	25	25	100
% column	15.38	7.69	12.50	11.76
Neutrality	2	2	0	4
% row	50	50	0	100
% column	15.38	15.38	0	11.76
Aversion	9	10	7	26
% row	34.62	38.46	26.92	100
% column	69.23	76.92	87.50	76.47
Total	13	13	8	34
% row	38.24	38.24	23.53	100
% column	100	100	100	100

We can see the proportion (frequencies and percent) in each crossed modality. It seems that the fact to be risk averse and ambiguity averse is linked. We performed independence tests that all failed to reject the independence hypothesis: both variables cannot be considered as significantly dependent. In order to reinforce our conclusions about correlation between risk and ambiguity measures, we proposed pairwise Pearson correlations estimations. We will link three variables of preferences: the previously mentioned categorical variable, the initial variable of NSC and NRC, and the coefficients associated to the midpoint of each class. Associated results are presented in Table 4.

The positive significant correlations in the case of risk are not surprising because they always correspond to variables that covariate by construction. The interesting thing to note is the significant and strong negative correlation between the Midpoint variable for ambiguity and all the variables related to risk. The coefficient of ambiguity aversion being a descending variable, this result shows that more risk aversion is correlated with more ambiguity aversion. This result is in line with previous ones indicating a significant and positive correlation between risk and ambiguity preferences (Lauriola and Levin, 2001; Chakravarty and Roy, 2009; Brunette et al., 2015).

Table 4: Pearson correlation coefficients (*p<0.1)

	Categ. (risk)	Categ. (amb.)	Midpoint (risk)	Midpoint (amb.)	NSC	NRC
Categ. (risk)	1.000					
Categ. (amb)	0.236	1.000				
Midpoint (risk)	0.679*	0.047	1.000			
Midpoint (amb.)	−0.753*	-0.033	−0.989*	1.000		
NSC	0.711*	0.048	0.977*	−0.989*	1.000	
NRC	0.100	0.851*	0.089	-0.085	0.134	1.000

4.2 Descriptive statistics

4.2.1 Crops and yields

Our sample is constituted by farmers cropping mainly cereals for at least 75.72%, more than 10% by oilseed and the remaining part in other crops (vineyards, chestnut, etc.). In France, arable lands are constituted by 2% in vineyards, 34.56% of cereals (together with seeds productions), 1.1% of oilseeds, 0.73% of fruit trees, 5.47% of annual forages (especially ensilage maize) (MAA, 2019). We have a special crop composition that deviates from the national figures and is widely represented by cereals. This is directly associated to the cooperatives we had access to. The BANCO report (Pellerin et al., 2013), that is at the origin of the MACC estimation, was focused on annual crops, that in France is essentially represented by cereals. The work of Dequiedt and Servonnat (2016) about risk and fertilization reduction was only treating cereals and oilseed, on a sample of farmers coming from the same group of cooperatives than ours (the advantage relies in the replication potential of the sample selection). The composition bias is thus limited in the fact that the perimeter of the abatement potential and costs estimation study corresponds a lot to these crops, and do not apply to all the crops that can be found in France. We still have to take it into account in our regressions if it leads to estimation bias.

We only show the descriptive statistics about yields for the main crops of our sample, wheat (15 answers) and maize (7 answers). The average level of actual harvested yields for wheat is 61.16 qt/ha (std 15.12 qt/ha) and the average level of yields objective is 67.16 qt/ha (std 14 qt/ha). The average level of actual harvested yields for maize is 118.7 qt/ha (std 35.5 qt/ha) and the average level of yields objective is 123.43 qt/ha (std 30.24 qt/ha). The rate of difference between actual yields and objectives is -5% for wheat and -4% for maize. We asked farmers the reason of the difference according to their perception. They said that meteorological conditions were the main explanation especially the quantity of rain that was too low or too high (71% of cases for maize and wheat farmers).

Figure 4 plots the relationship between actual yields and what was the objective at the beginning of the agricultural campaign. The bisectrix (green line) shows a hypothetical situation where there would be a perfect matching between the *ex ante* objective and the actual realization of yields. We can observe a positive and slightly convex relationship between both (red line), which is a sign that in our sample the higher the goals, the harder they are achieved, with a better matching for the highest goals.
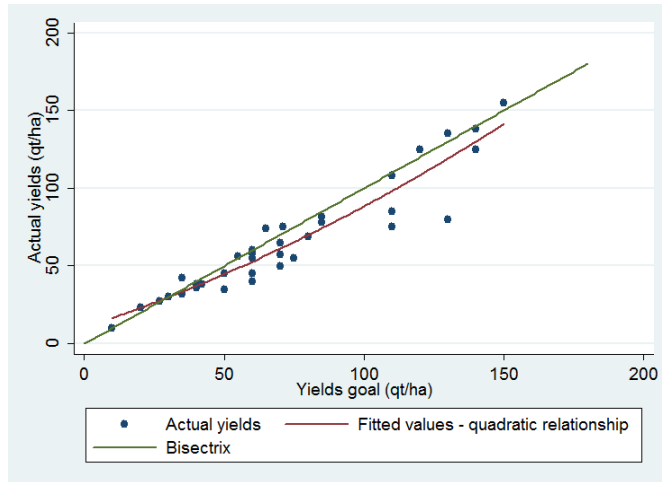
Figure 4: Relationship between actual and objective yields

We constructed a rate of deviation on the form $\frac{actualyields - goals}{goals}$ in order to observe the level of deviation on a normalized basis, which allows volume comparisons. Results are presented in Figure 5. The average rate is -8.24% (std 0.14%, 37 answers). We can observe that the average rate of yields objective achievement by crops is most of the time negative, strong for some crops (ensilage maize especially), and positive for two crops (maize seeds and sunflower).
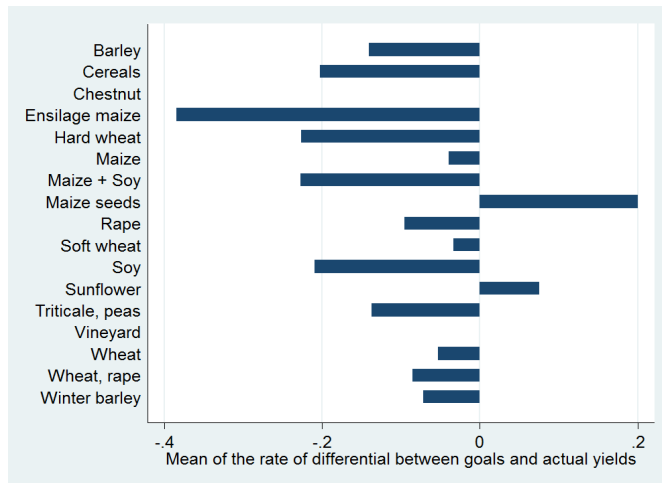

Figure 5: Deviation rate between actual and objective yields

4.2.2 Synthetic nitrogen fertilization

95.6% of the respondents applied synthetic nitrogen fertilizers on their parcel. The share of operational costs associated to synthetic nitrogen fertilizers use on the declared parcels is 26% on average. This is important if we set that in general, labor (wage), mechanical soil work (fuel, etc.), seeds, other fertilizers, phytosanitary products and potentially irrigation might be contingent operational costs on the same parcel.

The nitrogen balance sheets give the total nitrogen fertilizers application on the parcel during the agricultural campaign (in kgN/ha). It does not make a lot of sense to observe the general statistics for this variable because it highly depends on the crop, and inter-crop comparisons have no actual interest in our topic. We still can say that the average level of fertilization is around 151 kgN/ha (std 72.5 kgN/ha, 37 answers) as indicated on Figure 6. This graph shows how farmers tend to follow advices from their cooperative agent in terms of fertilization for the annual cropping. We can observe that farmers relatively apply as much fertilizers as the advice, except some outliers. We still can say that there are more deviations when the advice is higher.
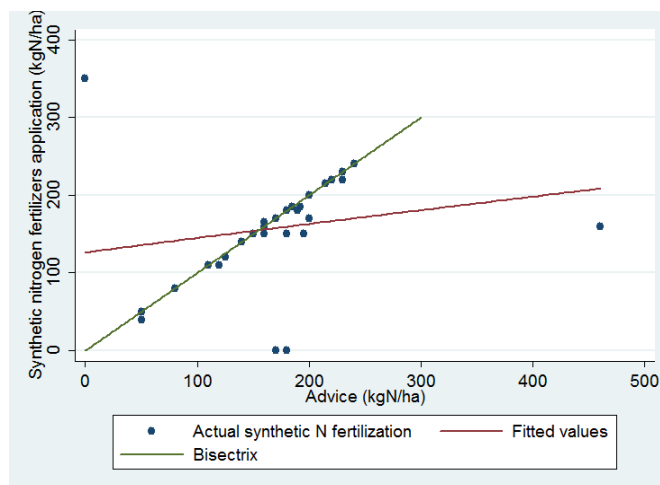

Figure 6: Relationship between actual and advised fertilization

Reducing the global synthetic nitrogen application balance sheet is an important mitigation practice. But it relies on the actual nitrogen rates in the soils, and depends on the alternative practice in case of insufficient nitrogen rate. While alternatives (like legume crop in intermediary cropping) are not always applicable or efficient enough, another approach is to split the applications and to modulate each application in order to optimize the leaching by crops according to their needs over time, and thus to reduce the loss by non-absorption and the emission of N2O by volatilization. This is especially the first application at the beginning of the campaign (during the crop growth cycle) that can be source of modulation, and advisers try to push farmers to put less nitrogen fertilizers at the beginning and if needed, to compensate with more fertilizer at the next application (sidedressing). Moreover, the first application is associated to much more emissions (Sheriff, 2005). Technically, the reduction of fertilization at the first splitting relies on the fact that it can still be nitrogenous from the last campaign and the precedent crop if soils are correctly managed between campaigns. In another vein, the first application is crucial and source of uncertainty if badly implemented: the beginning of the growth cycle is very important for the remaining of the campaign and for the yields goals to be reached (as well as quality goals). Moreover, it can be impossible to make sidedressing applications of nitrogen in the advanced stages of the growing-blooming cycle depending on uncertain water access and field work conditions, so that risk averse farmers would tend to apply more nitrogen than risk neutral farmers at the first application (Feinerman et al., 1990; Bontems and Thomas, 2000; Sheriff, 2005). However, the assumption that farmers attribute clear objective profits distribution to the fertilization practices is weak, since the issue may fairly be that the uncertainty can be deeper about the future states-of-the-nature, due to the embeddedness of several uncertain bio-physical factors in the forecasts related to sidedressing possibilities. We seek

to see how splitting is implemented by the farmers from our sample, and also if it deviates from the advices coming from the cooperative agents, in relationship with risk and ambiguity preferences. The average level of fertilization at the first application is around 50.5 kgN/ha (std 24.7 kgN/ha, 37 answers). Once again, it depends a lot on crops and inter-crop comparisons are not our interest. We compute the same graph than Figure 6 for the first application of fertilizer. Results are presented in Figure 7 and we observe the same kind of behaviors.
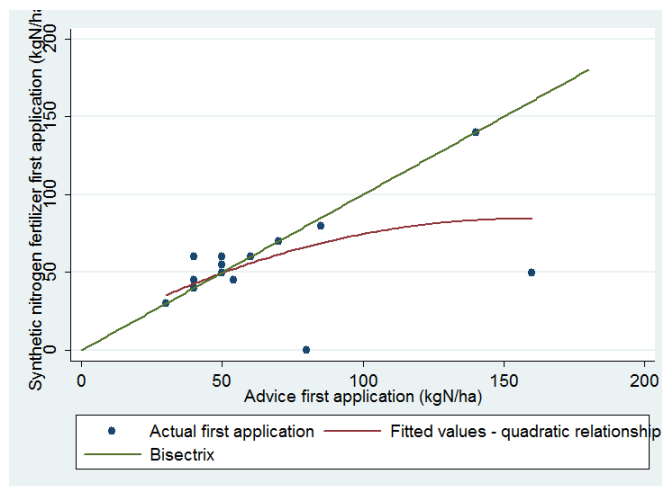

Figure 7: Relationship between actual and advised first application

We developed indicators about the degree to which farmers tend to follow advices in terms of total synthetic nitrogen fertilizers application, of fertilizer application for the first application, and for the number of splitting. Farmers' preferences under uncertainty may impact the willingness to follow advices, if the assumption of uncertainty associated to their consequences is valid. The two first indicators share the same structure: $\frac{actual practice - advice}{advice}$. They are a normalized rate of matching, that is negative if farmers put less than advised, positive if they put more, null if they perfectly match the advice. The more they go far from 0, the more the farmer deviated from the advice. The average rate of matching for the total fertilization is -0.08 (std 0.21, 33 answers), and for the first application it is -0.043 (std 0.28, 23 answers). For the number of splitting and the related advice, that is a relative integer, the indicator is just a difference between the actual number and the advised number. 0.5 means a semi-split: it is a situation where two different splittings were possible for the adviser (2 or 3, 4 or 5 for instance), and the farmer had the choice. The average number of difference between advices and actual practices is 0.1 (std 0.5, 29 answers). 79% of farmers applied exactly what they were told to in terms of splitting.

17 respondents have been placed in a "vulnerable zone" for the questioned parcel, a specific recognition of environmental quality on the parcel and the risk in terms of ecological destruction if certain farming practices are used (around 37% but there are a lot of missing answers). This official zoning implies obligation and forbidden practices, especially in terms of nitrogen fertilization. In our sample, the average maximum authorized quantity of nitrogen fertilization is 154.6 kgN/ha (16 answers). 20.6% declared having a mandatory fertilization method, such as using only organic fertilizer, liquid product, ovine manure (34 answers). These statistics give an idea of the weight of regulation on respondents, despite the regular lack of answers to these questions.

4.2.3 Other practices and characteristics

We asked farmers who applied organic fertilizer (manure for instance) on the parcel how they did take into account the amount of nitrogen contained in this product. Among the 34 answers we collected, 35.56% only used the reference table (very generalist in terms of information), 20% only used an analysis of the product (the most precise source of information), and 4.4% both, while 15.56% did not take the amount of nitrogen into account. This application of organic-based nitrogen was taken into account for the synthetic nitrogen application by 90.32% of respondents (31 answers). Thus, we can see that the precise level of nitrogen that is applied is not always known by farmers before they apply fertilizer on their parcels. 59.38% of farmers that applied organic fertilizer buried it through tillage (32 answers). Only 4.9% of farmers did not apply any nitrogen fertilizer. 56% applied both on their parcel, while 39% applied only synthetic fertilizer and none of the farmers applied only organic fertilizers (41 answers).

Respondents come from Drôme (31.71%), Meuse (21.95%), Tarn (21.95%), Charente Maritime (12.20%), Isère (7.32%), and Meurthe (4.88%). We can see that we have a wide geographic dispersion with a non-homogeneous composition. This presents the advantage of getting us a control for some fixed local characteristics that can be catched through the department membership (or the town, that we know too). The disadvantage is that we can't control for crucial heterogeneous unobservable variables that impacted diversely the locations and can explain individual farming choices. 43.9% of respondents own the parcel and 66.1% are tenant. 36.59% of farmers were cropping their parcel under a contract, mainly about seed production, product quality and industry-related sales. This characteristic can be important, especially for the case of quality contracts, because in some cases a good quality in terms of protein of the product (especially for wheat) requires specific amount of nitrogen level (less than for the "quantity-focused" cases). 32.5% of respondents had a crop insurance during the campaign (40 answers), which is closed to the national level. The average size of the parcel is 15.34ha. The average total area of the farms is 149.7ha, which is more than twice of the national average of around 58ha in 2013 according to Eurostat. The composition in terms of crop, as well as location specificities, and selection effects associated to the cooperative (InVivo group and its affiliations) may partly explain this difference. The average perceived CAP annual subsidy was 34 276 euros in our sample, and the average subsidy specifically related to environment was 3524 euros (10.3% of the total).

4.2.4 Socio-demographic statistics

97.6% of our sample is composed by males (41 answers). The average age is 45.3 years old, in a range from 16 to 66 years old. In France, the average age of male farmers is 49 years old (53 years old for females) and 61% of farmers are aged between 40 and 60 years old (INSEE, 2018). According to our data, 82% of our respondents are between 40 and 60 years old. Our sample is more concentrated in terms of age, and it may be related to the fact that being a part of the cooperative and being motivated about meetings create a selection of farmers. 45% of the respondents are married, 42.5% are single, 10% are in Civil Solidarity Pact and 2.5% are divorced (40 answers). In terms of education level, 77% of the respondents own a Baccalaureate (39 answers). At least 41% are Bac+2 and not beyond, which may correspond to a Agricultural post-bac technical diploma. 23% stopped school after the Bac. 18% only have a middle school certificate. In France, farmers who went above the Baccalaureate are 17%. 44% of French farmers stopped after middle school (MAA, 2019). It shows our sample is constituted of farmers better educated than the general population of farmers at a country level. This is partly due to the composition in terms of age of our sample (32% are less than 40 years old against 23% for France), because younger farmers access a better

education that the former generations (MAA, 2019). 41% of the households in our sample are constituted of at least four people, 30.8% are constituted by the farmer alone, the remaining part is two or three people in the household (39 answers). 52% of respondents have two childrens, 20% have no childrens, 12% have three childrens and the rest have one, or more than three childrens (25 answers). The statistics concerning the farmer's revenues show that 8.11% of farmers have less than €1000/month, while 24.32% have more than €3000. The other ranges are characterized as follows: [1000-1500[€/month (24.32% of the sample), [1500-2000] €/month (10.81%), [2000-2500[€/month (21.62%), and [2500-3000[€/month (10.81%).

4.3 Pairwise correlations and marginal impact estimations

4.3.1 Correlations

We performed pairwise correlations estimations (Pearson or Spearman) between all our measures of risk and ambiguity attitudes with interest variables: the total level of nitrogen fertilization, the level of fertilization at the first application, the number of splitting in fertilizers application, the rate of differential between the total advised application and what has been actually applied, the rate of differential between the actual and advised first application, and the rate of differential between the number of advised and actual splitting. We found no significant correlations with the Pearson coefficient applied on continuous variables. The Pearson coefficient fails at estimating correlation coefficient for ordinal or categorical variables. The Spearman rank-order coefficient is suited to estimate correlation coefficients with categorical variables. We found only one almost significant (p-value = 0.13) positive Spearman correlations between the NRC (ambiguity) and the level of fertilization at the first application (Spearman = 0.28). This would be the sign that farmer applies more nitrogen at the first fertilization splitting when they are ambiguity averse. Bontems and Thomas (2000) and Sheriff (2005) show that sidedressing nitrogen fertilization can be cost-efficient (better use of input) but depends on the propensity of farmers to take the risk that future natural conditions can prevent them from doing other applications after the first splitting. We find a negative relationship between our categorical variable of risk aversion and the number of fertilization splitting, but the coefficient is not significant. The main result with the Spearman rank-order coefficient shows a new relationship: ambiguity aversion leads farmers who agreed to split applications to apply more at the first stage in a situation where they are totally uncertain about what the future conditions will be. This may be the sign that when the risk of splitting is taken, ambiguity aversion encourages farmers to hedge against the probabilistic uncertainty that they are exposed to. However, lot of other factors can explain that phenomenon, that we can't test since we are not *ceteris paribus*.

4.3.2 Taking into account sampling design in regressions

The observations of our sample were not individually selected: we performed our experiment randomly on the farmers that we had at our disposal in usual meetings that occured in the cooperatives. However, the probability of being "selected" in our sample directly depends on individual characteristics of the respondents (crop, soil, etc.) that lead them to be a part of these experiment groups and can simultaneously impact individuals' decisions. Those characteristics are heterogeneously repeated in the sample, so that the composition of the sample is not the same as for the total population. Any regression that would be runned without correcting for these sampling selections would attribute false phenomenons to the whole population of farmers, while the results would be only accurate for the sample at stake. Ignoring selection weight can thus lead to biases in estimation, and it is possible to fix this issue by attributing probability weight to each observation. Finding

the proper variables that can be used to make good sampling weights depends on the available data and on the assumption we can make about the probability of selection. The crop the farmers choose on their parcel seems to us a good weighting variable, since the composition of our sample is widely determined by crops and targeting cooperative that work with annual non-perennial crop was one of our selection criteria. The composition bias can be important, since two main crops compose our sample and wear specific agronomic and economic characteristics (wheat and maize). Moreover, this question has been generally well-filled by respondents. Adding probability weighting is feasible with Stata: the dependent and independent variables of each row is multiplied by a weight that corresponds to the inverse of the probability of having put each crop on the parcel and the variance-covariance matrix is estimated through a robust sandwich estimator. The more a crop represents a big proportion in the sample, the smallest will be the multiplied factor.

Our observations were collected by group (local cooperatives) so that there can be correlation between error terms between observations in a same group, leading to a failure of the homoskedasticity assumption. These clustering can be taken into account in the regressions by applying adjustment weighting coefficients to subgroups standard errors covariance matrix in order to correct heteroskedasticity. We can assume that the local cooperative groups from which the farmers come are natural clusters among which respondents are concentrated, and some unobservable phenomena can affect the group uniformly. This subgroup catches correlation between behaviors as well as a part of exogenous natural hazards. We can also use a White (1980) heteroskedasticity consistent standard errors estimation in order to fix for heteroskedasticity issues, but it does not allow for clustered variability to be corrected, and the adjustment is at the individual level. We will compare both.

4.3.3 Regressions results

We realized 12 OLS regressions to try to explain the total fertilization (Table 5) and the fertilization at the first splitting (Table 6). These regressions differ in several ways. They take into account weighting and/or clustering and they consider either the categorical variable (risk lover/averse, ambiguity lover/averse) or the number of safe (NSC) and risky (NRC) choice.

We will only comment regression with significant coefficients. Given the limited number of observations, most of the relevant regressions were the ones with at least thirty observations. This is the higher average number of observations we obtained. Given the low number of degrees of freedom, we limited our regressions to one independent variable.

We can see in Table 5 that in the most robust regressions that we have (third column), the fact to be in the risk averse category leads to a significant lower level of total fertilization compared to the reference category of risk neutral farmers (coeff. = -48.84 significant at the 1% level). Reversely, Table 6 shows that being more ambiguity averse (NRC) has a positive marginal impact on the quantity of nitrogen fertilizers applied at the first split (coeff. = 1.422 significant at the 10% level). These results have to be interpreted simultaneously.

The first one indicates a phenomenon that is symmetric to numerous common assumptions about the positive impact of risk aversion on nitrogenous fertilization. While the role of risk aversion on fertilization, as we saw in the literature review, is not clear-cut and depends on the risk-increasing or decreasing nature of the input (and thus depends on the natural states-of-the-nature in terms of meteorological conditions, and complementarity with water and pesticide uses), nitrogen fertilizers seem to be not considered as a risk-decreasing input in our sample. This lowers the assumption that risk aversion can be a barrier to adoption of practices that reduces the total quantity of fertilizers

Table 5: Total fertilization

VARIABLES												
Risk lover	-28.25	-50.60	-50.60									
	(54.07)	(41.58)	(49.03)									
Risk averse	-58.16	-48.84**	-48.84***									
	(41.43)	(19.57)	(5.471)									
Ambiguity lover				-12.25	18.80	18.80						
				(32.17)	(28.91)	(14.96)						
Ambiguity averse				-30.70	-14.52	-14.52						
				(37.48)	(40.08)	(21.10)						
NSC							3.754	6.827	6.827			
							(6.278)	(4.775)	(5.393)			
NRC										-3.424	-6.235	-6.235
										(6.794)	(6.461)	(4.430)
Constant	191.2***	186.9***	186.9***	157.4***	142.4***	142.4***	122.7***	103.5***	103.5*	162.6***	177.0***	177.0***
	(38.24)	(8.863)	(4.501)	(22.75)	(25.72)	(8.803)	(39.03)	(34.51)	(35.30)	(36.34)	(33.83)	(22.89)
Weighting (crop)	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Clustering (cooperative)	No	No	Yes	No	No	Yes	No	No	Yes	No	No	Yes
Observations	31	31	31	31	31	31	31	31	31	31	31	31
R-squared	0.074	0.047	0.047	0.023	0.031	0.031	0.012	0.042	0.042	0.009	0.030	0.030
F	1.121	3.595	117.5	0.336	0.610	1.590	0.357	2.045	1.603	0.254	0.931	1.982
p-Fisher	0.340	0.0408	0.00142	0.717	0.550	0.338	0.555	0.163	0.295	0.618	0.342	0.254

Standard errors in parentheses
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 6: Fertilization at the first splitting

VARIABLES												
Risk lover	1.750	1.825	1.825									
	(19.35)	(6.614)	(7.242)									
Risk averse	-0.207	-4.310	-4.310									
	(14.82)	(6.873)	(5.037)									
Ambiguity lover				-3.667	6.471	6.471						
				(8.682)	(8.172)	(6.882)						
Ambiguity averse				3.762	4.886	4.886						
				(10.11)	(12.61)	(2.738)						
NSC							0.732	1.529	1.529			
							(2.171)	(1.567)	(1.198)			
NRC										2.094	1.422	1.422*
										(1.796)	(2.005)	(0.527)
Constant	51.25***	53.14***	53.14***	48.67***	45.44***	45.44***	47.07***	41.02***	41.02***	37.76***	41.08***	41.08***
	(13.68)	(3.747)	(4.580)	(6.139)	(6.655)	(2.332)	(13.50)	(10.77)	(6.668)	(9.606)	(10.03)	(4.301)
Weighting (crop)	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Clustering (cooperative)	No	No	Yes	No	No	Yes	No	No	Yes	No	No	Yes
Observations	31	31	31	31	31	31	31	31	31	31	31	31
R-squared	0.001	0.009	0.009	0.019	0.019	0.019	0.004	0.020	0.020	0.045	0.018	0.018
F	0.00873	0.318	0.537	0.277	0.315	8.685	0.114	0.953	1.628	1.360	0.503	7.282
p-Fisher	0.991	0.730	0.632	0.760	0.732	0.0565	0.738	0.337	0.292	0.253	0.484	0.0739

Standard errors in parentheses
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

use, because it reversely looks like a driver of reduction. However, it is notable that the risk aversion variable at stake is the categorical one: the reference category that we choose for comparison is the category 2, for risk neutrality. The coefficient is thus the average level of fertilizers of risk averse farmers in general compared to risk neutral farmers in general.

The second result is the most original. Ambiguity aversion leads to put more fertilizers at the first application split (see Table 6), which is equivalent to say that having an aversion for making bets on outcome whose probabilistic distribution is uncertain encourages farmers to hedge against future possible nitrogen lacks. We interpret this result as follows: if cooperative agents ask farmers to split their application, the first application is the most crucial, not only because it happens at the

beginning of the growing stage for the crop, but especially because the farmer does not know if it will be possible for her to fertilize again at the future stages, because future states-of-the-nature are deeply uncertain. The possibility to make future splittings is dependent on this inability to make complete forecasts about entangled natural conditions. If we want to connect more the interpretation to the lotteries experiment, we can say that the ambiguity averse farmers insure themselves by putting more fertilizers at the first splitting, which is exactly the thing cooperative agents do not want them to do, because they prefer to bet on a risky practice than on an ambiguous one. However, this impact is much smaller than the negative impact of risk aversion on total fertilization. Moreover, splitting practices induce dynamic evaluation of profits and optimal input uses, as shown in Bontems and Thomas (2000), which implies other potential explanations, like information value. We do not test for that in this study. The benefits from splitting is, according to Bontems and Thomas (2000), to allow the farmers to gather information about the true nitrogen needs of the crops and to be more efficient in their first and sidedressing application, thus reducing the production costs. We show in this study that ambiguity aversion may impact the total benefits from information value, and is a complementary driver of fertilization decisions.

The low number of observation for each regression (31) nuances our results. Adding control variables for crops (17 modalities), soil quality (21 modalities), precedent crops (22 modalities), interactions between risk and ambiguity preferences, differences between actual yields and yields goals and the perception of experienced risks at the last campaign by farmers, and several controls for agricultural practices and socioeconomic and demographic variables would produce more robust results and limit the biases that we may experience. Because each modality of the categorical variables represents a covariate, the necessary number of observations would have to be significantly higher. The dependent variables related to fertilization being directly explained by obvious variables like the crop that has been put on the parcel by the farmers or the soil quality, which are information that we asked in the questionnaire, it would be crucial to make our regression with these controls. This is an important caveat of our econometric analysis.

The indicators about the degree to which farmers tend to follow advices in terms of total synthetic nitrogen fertilizers application, of fertilizer application for the first application, and for the number of splitting were not sufficiently matched with answer about risk and ambiguity preferences, so that a too limited number of observations were gatherable. This makes impossible to make proper regressions with these variables.

5   Conclusion

We implemented an experiment on farmers in collaboration with their cooperative group (InVivo group) in order to test on real data our main assumption: uncertainty may be a barrier to nitrogen fertilization reduction. We test two levels of preferences toward uncertainty, risk attitudes (known probability) and ambiguity attitudes (unknown probability). In the scope of our goal to estimate the interactions between those measures and the mitigation potential associated to fertilizer reduction, we seeked to test the role of these individual behavioral attitudes on diverse practices related to fertilization, about the fertilization practices directly (global level of fertilizer, level of fertilization at the first splitting, number of splittings) and the farmers' willingness to follow advices from their cooperative agents who try to lead them toward less emitting production practices. We also planned to estimate the role of several agricultural, regulatory and socioeconomic characteristics, and their embedded with uncertainty preferences, on fertilization practices and propensity to follow advices.

We found that our respondents were mostly risk averse and ambiguity neutral. Our measures are closed to some previous studies on farmers. The representativeness of our sample in terms of crops is low (with comparison to French farmers) but is closed from the previous studies about nitrogen fertilization reduction, which often test the same kind of crops, cereals and oilseeds. The last campaign were globally not a good year for our respondents, who slightly failed on average to reach their yields goals. Our respondents did not follow perfectly what was advised in terms of fertilization, and an important part of them has to be in compliance with fertilization regulatory rules on their parcel. They present some important statistical differences with the national farmers population, in terms of size of farm (bigger), age (younger) and education (more educated).

We performed OLS regressions with considerations of sampling design in order to produce the most robust estimations as possible. We found significant marginal impacts only for two dependent variables (when sample weights and clustering are introduced), the total quantity of nitrogen fertilizer use, and the quantity of fertilizer use at the first splitting.

Being risk averse is associated to a lower level of total fertilization (-48.8 kgN/ha on average) with respect to the reference category (risk neutrality). This result is interesting but difficult to analyze, because it can be the sign that nitrogen fertilizers are perceived as risk-increasing by farmers, or risk-decreasing (or neutral) but the global level of risk were perceived as very low by farmers who self-insure with fertilizers. It could be the sign of diverse water and fertilizer use characteristics (Feinerman et al., 1990) and interaction between pest invasion risk with good growing conditions and crops growth level related to fertilizer use (Horowitz and Lichtenberg, 1994). However, we can say that the total level of fertilization may be always associated to yields goals and agricultural knowledge of farmers for which they might have an objective probabilistic "mapping", and a clear *ex ante* stochastic production plan for the whole campaign.

The second main result is the positive marginal impact of ambiguity aversion (NRC variable) on the level of fertilization at the first splitting (+1.42kg/ha for each higher level of risky choice). While this result is unique to our knowledge, it echoes some previous researches that highlighted the deep uncertainty that lay behind the splitting practice. Indeed, splitting fertilization is a good way to adapt the fertilizer application to the crops' needs, but it relies on technical feasibility of postponed applications, which itself directly depends on unpredictable pedo-meteorological conditions, and their short-term deeply uncertain fluctuations. Uncertain evolution of states-of-the-nature can't be *ex ante* forecasted at the time of the first application, but the farmer can have subjective priors and be more or less pessimistic about what can be expected. In this scope, ambiguity aversion impacts positively the level of fertilization at the first application. However, the marginal impact is low, implying that even the global effect is negligible compared to the first result. The net total estimated impact of our preferences measures on the total fertilization is negative. Moreover, the first result is significant because of sampling weight, while the second is significant because of clustered heterosckedastic-robust standard errors. The first case is not surprising. On the other hand, the second fact indicates that the significance of the result depends on the consideration of specific cluster-dependent unobservable variables, like very local fluctuations and characteristics. It is interesting because it can echo our interpretation about the NRC result, that ambiguity associated to the first splitting is embedded in the individual deep uncertainty about technical and natural feasibility of postponed splittings, which may be essentially local-specific and thus, partly shared by farmers from a given cooperative. In another vein, it is possible that the cluster-corrected standard errors fixes unobserved shocks on group-variations that are directly related to the differences that could have appear in the measurement processes between cooperative. While we tried to make exactly the same experiment on each farmers, it may have had slight differences which provoked group-specific measurement errors (day, time in the day, context etc.). This is specific to field ex-

periments compared to laboratory experiments.

We have several external and internal validity issues. We are limited by the number of respondents and the subsequent number of valid answers in our estimations. This limits the external validity of our results. Our experiment may be seen as a pilot for a wider experiment, in order to observe if our current results are robust or not to all the necessary controls. In terms of internal validity, it would be an interesting extension associated to the fact that we do not test for time preferences impact in this study. Time preferences explain choices at each step of the production, as well as decisions in terms of practices and production goals. Secondly, the use of the MPL procedure entails advantages and caveats. The specific versions of the lotteries that we use rely on calibrations associated to the widely accepted assumption of a CRRA (power) utility function and its form (chained lotteries with switching point) allows for the precise measurement of the level of risk aversion on the continuous distribution of gains. Moreover, its wide use in the literature allows for a good level of comparativeness of our results. The main caveats entangle the limit in identification of the actual preferences of the respondent. First, if the preferences of the agent do not follow a CRRA utility function, or more generally, if the individual has preferences not in line with expected utility framework, then the method is not relevant. This would lead to the risk that our subsequent regressions would have a limited internal invalidity and thus, limited results. Second, as we mentioned in the literature review, some critics have been developed by Drichoutis and Lusk (2016). However, these caveats did not prevent several studies to produce creditable results (see literature review).

There are two main implications in terms of public policies. First, this study partly shows that risk and ambiguity attitudes impact abatement costs associated to nitrogen fertilization reduction. While ambiguity aversion is a hidden costs of innovative fertilization practices like splitting, risk aversion can be a "hidden abatement benefit" for global reduction of nitrogen application. We can conclude that these phenomena question the optimality of flat rate subsidies. Fluctuations in production conditions can make fluctuate the abatement costs mechanically, and subsidies aiming at offsetting potential losses from reduction can become a windfall for farmers that would, in their majority, adjust their use of fertilizer by themselves. This feature induces a questioning of usual recommendations under risk consideration, like subsidized crop insurance that would cover yields risk and by this mean, encourages farmers to lower their fertilization: it depends on the interaction between nitrogen fertilizers and the environment they are applied in, and the crop, thus it can even have counter-productive effects on N2O mitigation (Sheriff, 2005). If we get back to the work of Bontems and Thomas (2000), we can say that fertilization splitting wears a huge benefit in terms of information value. This explains why farmers would be not so reluctant to adopt this practice. However, if ambiguity aversion increases the level of application at the first splitting and thus, increases emissions, it could be good to rather reducing uncertainty through generalized soil testing in order to secure information while developing new methods to ensure that sidedressing will be certainly makable later in the campaign. Trials can also be offered under diverse forms in order to improve farmers knowledge about the reaction of crops to these new forms of nitrogen management over the growing period.

Acknowledgments

References

Akay, A., Martinsson, P., Medhin, H., and Trautmann, S. (2012). Attitudes toward uncertainty among the poor: An experiment in rural Ethiopia. Theory and Decision, 73:453–464.

Barham, B., Chavas, J., Fitz, D., Salas, V., and Schechter, L. (2014). The roles of risk and ambiguity in technology adoption. Journal of Economic Behavior & Organization, 97:204–218.

Battalio, R., Kagel, J., and Jiranyakul, K. (1990). Testing between alternative models of choice under uncertainty: Some initial results. Journal of Risk and Uncertainty, 3(1):25–50.

Beattie, J. and Loomes, G. (1997). The impact of incentives upon risky choice experiments. Journal of Risk and Uncertainty, 14:155–168.

Binswanger, H. (1980). Attitudes toward risk: Experimental measurement in rural India. American Journal of Agricultural Economics, 62:395–407.

Bocquého, G., Jacquet, F., and Reynaud, A. (2014). Expected utility or prospect theory maximisers? Assessing farmersâĂŹ risk behaviour from field-experiment data. European Review of Agricultural Economics, 41:135–172.

Bontems, P. and Thomas, A. (2000). Information value and risk premium in agricultural production: The case of split nitrogen application for corn. American Journal of Agricultural Economics, 82:59–70.

Bougherara, D., Gassmann, X., Piet, L., and Reynaud, A. (2017). Structural estimation of farmers' risk and ambiguity preferences: A field experiment. European Review of Agricultural Economics, 44(5):782–808.

Brunette, M., Cabantous, L., and Couture, S. (2015). Are individuals more risk and ambiguity averse in a group environment or alone? Results from an experimental study. Theory and Decision, 78(3):357–376.

Brunette, M., Cabantous, L., Couture, S., and Stenger, A. (2013). The impact of governmental assistance on insurance demand under ambiguity: A theoretical model and an experimental test. Theory and Decision, 75:153–174.

Brunette, M., Foncel, J., and Kéré, E. (2017). Attitude towards risk and production decision: An empirical analysis on French private forest owners. Environmental Modeling and Assessment, 22(6):563–576.

Camerer, C. and Hogarth, R. (1999). The effects of financial incentives in experiments: A review and capital-labor-production framework. Journal of Risk and Uncertainty, 1(19):7–42.

Chakravarty, S. and Roy, J. (2009). Recursive expected utility and the separation of attitudes towards risk and ambiguity: An experimental study. Theory and Decision, 66(3):199–228.

CITEPA (2019). Inventaire secten.

Cotty, T. L., d'Hôtel, E. M., Soubeyran, R., and Subervie, J. (2018). Linking risk aversion, time preference and fertiliser use in Burkina Faso. The Journal of Development Studies, 54(11):1991–2006.

Dequiedt, B. and Servonnat, E. (2016). Risk as a limit or an opportunity to mitigate ghg emissions? The case of fertilisation in agriculture. Working Papers Climate Economic Chair (CEC), 2016-06.

Dohmen, T., Falk, A., Huffman, D., Sunde, U., Schupp, J., and Wagner, G. (2011). Individual risk attitudes: measurement, determinants, and behavioral consequences. Journal of the European Economic Association, 9(3):522–550.

Drichoutis, A. and Lusk, J. (2016). What can multiple price lists really tell us about risk preferences? Journal of Risk and Uncertainty, 53(2-3):89–106.

Eckel, C. and Grossman, P. (2008). Forecasting risk attitudes: An experimental study using actual and forecast gamble choices. Journal of Economic Behavior & Organization, 68(1):1–7.

Engle-Warnick, J., Escobal, J., and Laszlo, S. (2007). Ambiguity aversion as a predictor of technology choice: Experimental evidence from Peru. CIRANO - Scientific Publications, 2007s-01.

Feinerman, E., Choi, E., and Johnson, S. (1990). Uncertainty and split nitrogen application in corn production. American Journal of Agricultural Economics, 72(4):975–985.

Gandorfer, M., Pannell, D., and Meyer-Aurich, A. (2011). Analyzing the effects of risk and uncertainty on optimal tillage and nitrogen fertilizer intensity for field crops in Germany. Agricultural Systems, 104(8):615–622.

Ghadim, A., Pannell, D., and Burton, M. (2005). Risk, uncertainty, and learning in adoption of a crop innovation. Agricultural Economics, 33(1):1–9.

Hellerstein, D., Higgins, N., and Horowitz, J. (2013). The predictive power of risk preference measures for farming decisions. European Review of Agricultural Economics, 40(5):807–833.

Holt, C. and Laury, S. (2002). Risk aversion and incentive effects. The American Economic Review, 92(5):1644–1655.

Horowitz, J. and Lichtenberg, E. (1994). Risk-reducing and risk-increasing effects of pesticides. Journal of Agricultural Economics, 45(1):82–89.

INSEE (2018). Tableaux de l'economie francaise.

Klibanoff, P., Marinaci, M., and Mukerji, S. (2005). A smooth model of decision making under ambiguity. Econometrica, 73:1849–1892.

Lauriola, M. and Levin, I. (2001). Relating individual differences in attitude toward ambiguity and risky choices. Journal of Behavioral Decision Making, 14(2):107–122.

Leathers, H. and Quiggin, J. (1991). Interactions between agricultural and resource policy: The importance of attitudes toward risk. American Journal of Agricultural Economics, 73(3):757–764.

Liu, E. (2013). Time to change what to sow: Risk preferences and technology adoption decisions of cotton farmers in China. The Review of Economics and Statistics, 95:1386–1403.

MAA (2019). Agreste, la statistique, l'evaluation et la prospective agricole.

Monjardino, M., McBeath, T., Ouzman, J., Llewellyn, R., and Jones, B. (2015). Farmer risk-aversion limits closure of yield and profit gaps: A study of nitrogen management in the southern Australian wheatbelt. Agricultural Systems, 137:108–118.

Moschini, G. and Hennessy, D. (2001). Uncertainty, risk aversion, and risk management for agricultural producers. Handbook of Agricultural Economics,in: B. L. Gardner & G. C. Rausser (ed.), Handbook of Agricultural Economics, edition 1, 1(2):88–153.

Pellerin, S., Bamière, L., Angers, D., Béline, F., Benoit, M., Butault, J., Chenu, C., Colnenne-David, C., de Cara, S., Delame, N., Doreau, M., Dupraz, P., Faverdin, P., Garcia-Launay, F., Hassouna, M., Hénault, C., Jeuffroy, M., Klumpp, K., Metay, A., Moran, D., Recous, S., Samson, E., Savini, I., and Pardon, L. (2013). Quelle contribution de l'agriculture française à la réduction des émissions de gaz à effet de serre? Potentiel d'atténuation et coût de dix actions techniques. Technical Report hal-01186943.

Pope, R. and Kramer, R. (1979). Production uncertainty and factor demands for the competitive firm. Southern Economic Journal, 46(2):489–502.

Reynaud, A. and Couture, S. (2012). Stability of risk preference measures: Results from a field experiment on French farmers. Theory and Decision, 73:203–221.

Roosen, J. and Hennessy, D. (2003). Tests for the role of risk aversion on input use. American Journal of Agricultural Economics, 85(1):30–43.

Sheriff, G. (2005). Efficient waste? Why farmers over-apply nutrients and the implications for policy design. Applied Economic Perspectives and Policy, 27(4):542–557.

Stuart, D., Schewe, R., and McDermott, M. (2014). Reducing nitrogen fertilizer application as a climate change mitigation strategy: Understanding farmer decision-making and potential barriers to change in the US. Land Use Policy, 36(1):210–218.

White, H. (1980). A heteroskedasticity-consistent covariance matrix estimator and a direct test for heteroskedasticity. Econometrica, 48(4):817–838.

Wik, M., Kebede, T., Bergland, O., and Holden, S. (2004). On the measurement of risk aversion from experimental data. Applied Economics, 36(21):2443–2451.

A The ten-paired lottery-choice

Table 7: The ten-paired lottery-choice decisions under risk

Decisions	Option A				Option B			
	Proba.	Payoff	Proba.	Payoff	Proba.	Payoff	Proba.	Payoff
1	10%	€ 7	90%	€ 5	10%	€ 13	90%	€ 0
2	20%	€ 7	80%	€ 5	20%	€ 13	80%	€ 0
3	30%	€ 7	70%	€ 5	30%	€ 13	70%	€ 0
4	40%	€ 7	60%	€ 5	40%	€ 13	60%	€ 0
5	50%	€ 7	50%	€ 5	50%	€ 13	50%	€ 0
6	60%	€ 7	40%	€ 5	60%	€ 13	40%	€ 0
7	70%	€ 7	30%	€ 5	70%	€ 13	30%	€ 0
8	80%	€ 7	20%	€ 5	80%	€ 13	20%	€ 0
9	90%	€ 7	10%	€ 5	90%	€ 13	10%	€ 0
10	100%	€ 7	0%	€ 5	100%	€ 13	0%	€ 0

Table 8: The ten-paired lottery-choice decisions under ambiguity

Decisions	Option A: urn A		Option B: urn B	
	In urn A, the distribution of balls is 5 black and 5 white		In urn B, the distribution of balls is not known	
	Chosen color obtained	Chosen color not obtained	Chosen color obtained	Chosen color not obtained
1	€ 13	€ 0	€ 9	€ 0
2	€ 12	€ 0	€ 9	€ 0
3	€ 11	€ 0	€ 9	€ 0
4	€ 10	€ 0	€ 9	€ 0
5	€ 9	€ 0	€ 9	€ 0
6	€ 8	€ 0	€ 9	€ 0
7	€ 7	€ 0	€ 9	€ 0
8	€ 6	€ 0	€ 9	€ 0
9	€ 4	€ 0	€ 9	€ 0
10	€ 2	€ 0	€ 9	€ 0

B Questionnaire

Survey on the use of synthetic nitrogen fertilizers

The survey you are going to participate aims at studying the climate change mitigation measures of the French agricultural sector. In particular, the survey focuses on farmers' fertilization decisions. Nitrogen fertilization is one of the main greenhouse gas emissions in the agricultural sector. The aim is to improve the understanding and determinants of fertilization decisions, particularly by focusing on an economic parameter reflecting individual preferences for risky choices.

This survey is conducted as part of a joint project between the INRA (National Institute for Agronomic Research), the Climate Economics Chair (CEC), and InVivo. More specifically, this work is part of a thesis in Economics, conducted within INRA.

The questionnaire will consist of three parts. In the first part, it will be necessary to make hypothetical choices between two options. These choices will help measure your individual attitude

towards risk. This method is widely used in economics to reveal to individuals their preferences for more or less risky situations. The second part will be composed of questions relating to your management decisions and, more particularly, fertilization. The final part of the survey will focus on your socio-economic characteristics.

There are no good or bad answers during the survey, just different behaviors to observe. For the purposes of the survey, you must answer all the questions. The confidentiality of the information contained in this questionnaire is ensured by the anonymity of the respondent. Your answers will remain confidential. The results will be presented in synthetic form in scientific publications with scrupulous respect for the anonymity of the respondents. Once the data is processed, it will be returned to you individually and you can compare your results to the average of our sample and your cooperative.

The lack of communication between participants is a guarantee of success. We ask you not to discuss with other participants during the survey.

Part 1: Choice between two options

This first part is composed of two series of 10 decisions represented by two tables.

All questions correspond to fictitious situations for which we ask you to answer as if you were facing a real situation, taking the necessary time to choose the answers that best correspond to your preferences.

First table:
For each of the 10 decisions (lines) you must choose which of the two options (A or B) you prefer.
Let's take an example. Decision 1 of the table reads as follows:
- Option A: get €7 with 10% chance or €5 with 90% chance.
- Option B: get €13 with 10% chance or €0 with 90% chance.
This decision 1 can also be represented in the form of a circular graph as well:
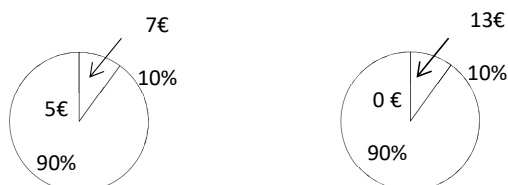
The following decisions read in the same way, only the probabilities associated with earnings change. Please complete the boxes below the table.

Decisions	Option A				Option B			
	Proba.	Payoff	Proba.	Payoff	Proba.	Payoff	Proba.	Payoff
1	10%	€ 7	90%	€ 5	10%	€ 13	90%	€ 0
2	20%	€ 7	80%	€ 5	20%	€ 13	80%	€ 0
3	30%	€ 7	70%	€ 5	30%	€ 13	70%	€ 0
4	40%	€ 7	60%	€ 5	40%	€ 13	60%	€ 0
5	50%	€ 7	50%	€ 5	50%	€ 13	50%	€ 0
6	60%	€ 7	40%	€ 5	60%	€ 13	40%	€ 0
7	70%	€ 7	30%	€ 5	70%	€ 13	30%	€ 0
8	80%	€ 7	20%	€ 5	80%	€ 13	20%	€ 0
9	90%	€ 7	10%	€ 5	90%	€ 13	10%	€ 0
10	100%	€ 7	0%	€ 5	100%	€ 13	0%	€ 0

- I choose option A for decisions 1 to ☐ .

You can answer with a number between 1 and 10. If you choose 3 it implies that option A is chosen for the first three lines, then B for the following ones. If you choose 1 it implies that you choose A only for the first line, and B for the others. If you do not put anything that implies that you choose B for all lines: you will have to answer 1 in the next question.

- I choose option B for decisions ☐ at 10.

<u>Second table</u>:

For each of the 10 decisions (lines) you must choose which of the two options (A or B) you prefer. This time, both options are likened to a draw in an urn composed of 10 balls of black or white colors. Option A corresponds to an urn composed of 5 black balls and 5 white balls. If you choose this option, you know that you have 5 chances out of 10 (or 1 chance out of 2) to win. In other words, the probability of winning is equal to 50%.

Option B corresponds to an urn whose exact composition is not known. If you choose this option you do not know exactly your chance to win. This varies between 0 chance out of 10 (for example, you choose the white ball, and the urn contains only black balls) and 10 chances out of 10 (for example, you choose the white ball and the urn contain only white balls). In other words, the probability of winning is between 0% and 100%.

Prior to the 10 decisions, you will have to choose the color that you consider as winning, black or white.

Choose a color: BLACK ☐ or WHITE ☐

Let's take an example. Decision 1 of the table reads as follows:
- Option A: get €13 with 1 chance out of 2 (50%) or €0 with 1 chance out of 2 (50%).
- Option B: get €9 or €0, but you do not know the chances of winning associated.
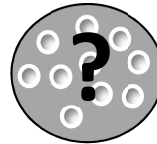
This decision 1 can also be represented in the form of an urn as here:
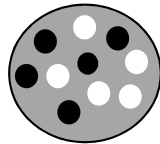
Urn A : 5 white balls and 5 black balls.

- Chosen color obtained : €13

- Chosen color not obtained: €0

Urn B : 10 balls, distribution not known.

- Chosen color obtained : €9

- Chosen color not obtained: €0

The following decisions read in the same way, only the potential gains for Option A change. Please complete the boxes below the table.

Decisions	Option A: urn A		Option B: urn B	
	In urn A, the distribution of balls is 5 black and 5 white		In urn B, the distribution of balls is not known	
	Chosen color obtained	Chosen color not obtained	Chosen color obtained	Chosen color not obtained
1	€ 13	€ 0	€ 9	€ 0
2	€ 12	€ 0	€ 9	€ 0
3	€ 11	€ 0	€ 9	€ 0
4	€ 10	€ 0	€ 9	€ 0
5	€ 9	€ 0	€ 9	€ 0
6	€ 8	€ 0	€ 9	€ 0
7	€ 7	€ 0	€ 9	€ 0
8	€ 6	€ 0	€ 9	€ 0
9	€ 4	€ 0	€ 9	€ 0
10	€ 2	€ 0	€ 9	€ 0

- I choose option A for decisions 1 to ☐ .

You can answer with a number between 1 and 10. If you choose 3 it implies that option A is chosen for the first three lines, then B for the following ones. If you choose 1 it implies that you choose A only for the first line, and B for the others. If you do not put anything that implies that you choose B for all lines: you will have to answer 1 in the next question.

- I choose option B for decisions ☐ at 10.

Part 2: Management decisions on the largest plot of your farm, excluding pasture

We wish to remind you that all the answers to this questionnaire will be totally anonymous and will not be treated in any way outside the scientific publication for which they are intended.

For this part of the questionnaire, we will refer to the largest plot of your farm, excluding pasture. We would like to know more about your farming practices on this plot during the last crop year.

• Location:
→ Which department?
→ On which commune is your parcel located?

• What is your status vis-à-vis the parcel in question? ☐ Owner ☐ Tenant

• What is the main crop?

• Is it a contract crop? ☐ No ☐ Yes
→ If yes, what kind of contract?

• What is the smallest area spread on the plot (in hectares)?

• What is the type of precedent (previous crop on the plot)?

• What is the type of soil on the plot?

• What was your target for early returns (in qt/ha)?

- What were your real yields after harvest (in qt/ha)?

    → If objective and real returns have been different, please explain why:

- Have you applied one (or more) organic nitrogen fertilizer on this plot? □ No □ Yes
→ If yes, how much (in kg/ha)?
→ How was the amount of nitrogen contained in this (these) intake (s) taken into account? □ Analysis □ Reference table □ It was not taken into account
→ Does mineral nitrogen fertilizer advice take into account this quantity? □ No □ Yes

- Have you buried the fertilizer? □ No □ Yes

In terms of mineral nitrogen fertilization:
- Please indicate the amount of mineral nitrogen recommended by your nitrogen advisory agency on this plot (in kgN/ha)?

- Was there any advice on the first nitrogen intake? □ No □ Yes
→ If yes, how much (in kg/ha)?

- Have you been advised to split contributions? □ No □ Yes
→ If yes, how much ?

- Did you split the contributions? □ No □ Yes
→ If yes, how much ?

    Regulatory Doses:
- Is there a maximum that you should not exceed on this parcel? □ No □ Yes.
→ If yes, how much (in kg/ha)?

- Is there a type of spreading that you must follow? □ No □ Yes
→ If yes, which one?
→ If yes, what is this regulatory constraint related to? □ Vulnerable area □ MAE □ Other

    Actual decisions of mineral nitrogen fertilization:
- How much did you actually apply to this parcel in total (in kgN/ha)?

- And at the first intake (in kgN/ha)?
→ Explain the reasons for your choice:

- What is the share of synthetic nitrogen fertilizer costs in your total expenses for this parcel (in %)?

Some additional questions on your farm:

- How much PAC assistance do you receive in total (in €/year)?
→ Of this total amount, which amount corresponds to specific environmental aids and the reduction of the chemical spreading do you perceive (MAE or other) (in €/year)?

• Have you signed this year a voluntary agricultural yield insurance? ☐ No ☐ Yes

• What is the total area of your farm (in hectares)?

• Are you part of an operator's union? ☐ No ☐ Yes
→ If yes which?

Part 3: Socio-economic characteristics
　　Answers to these questions are essential to properly analyze your decisions. We remind you that your answers will be treated anonymously.

• What is your age in years ?

• Sex: ☐ Man ☐ Woman

• Marital status: ☐ Single ☐ Married ☐ Civil Solidarity Pact

• Level of studies :
☐ Without diploma ☐ Brevet ☐ Bac
☐ Baccalaureate + (specify the number of years of study after baccalaureate:....)

• Number of people in the household: ☐ 1 ☐ 2 ☐ 3 ☐ 4 and more
Among them, how much children ?

• In what interval are the total monthly incomes of your household (net of taxes)?
☐ < €1000/net/month ☐ from 1000 to €1500/net/month
☐ from 1500 to €2000/net/month ☐ from 2000 to €2500/net/month
☐ from 2500 to €3000/net/month ☐ > €3000/net/month

• Here you can express your opinion on synthetic nitrogen fertilizers and policies to regulate their use:

• Here you can give us your opinion on the survey (strengths, possible difficulties encountered, etc.):

Email address for the return of the results:

THANKS FOR YOUR HELP
WE WILL TRANSMIT YOUR INDIVIDUAL RESULTS WHEN THEY WILL BE PROCESSED

WORKING PAPER

PREVIOUS ISSUES