Crop Yield Risks and Nitrogen Fertilisation in French Agriculture: Implications for Insurance

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Abstract

The links between nitrogen uses and insurance are explored in this paper, comparing two insurance mechanisms: the Multi-Peril Crop Insurance currently offered in France, and an index insurance based on area yields. A simulation of the two insurance systems on a data set at plot scale for two crops (maize and grassland) in the French department Deux-Sèvres over the period 2010-2013 allows us to define the most advantageous system in terms of yields losses coverage. From that, we then model the relationship between nitrogen fertilisation and insurance eligibility for each of the two schemes based on a production function linking nitrogen to the yields. We find a mixed effect of nitrogen on insurance eligibility in both schemes for the two crops considered. Suggesting that the effects of policies aimed at reducing nitrogen fertilizers use would differ depending on the insurance system and the crop type. These results highlight the usefulness of crop-specific insurance contracts and bring insights to the current debates about crop insurance reform in various European countries.

Keywords: Crop Insurance; Nitrogen fertilizer; Risk; French Agriculture

1 Introduction

The notion of risk in agriculture takes on a particular meaning inherent to this sector, which is particularly exposed to natural hazards. Particularly dependant on biological processes, agriculture is very exposed to weather-related hazards (Abler and Shortle [2000]), the frequency and intensity of which increasing with climate change, directly and negatively affecting production. The question of risk management in agriculture remains a major issue in agricultural economics as most production decisions have risk implications. The risks faced by farmers have a number of specific characteristics that limit their ability to control them completely, hence the need to use risk management tools in order to control the possible adverse consequences of uncertain production framework.

The effectiveness of the risk managements tools available for the farmers depends on the risk level. When the level of risk is low or normal, risk management is the responsibility of the farmer. The tools at his or her disposal to do so are savings, diversification, inputs combination, production contracts and membership of a cooperative. For intermediate levels of risks, farmers can transfer their risks to other agents by taking out insurance policies against payment of a premium. And for the last level of risks, the catastrophic risks, they are covered by the public funds.

Given the susceptibility of crop yields to weather conditions and climate change threat, crop insurance, by mitigating weather-related risks, can play an important role in securing farmers

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income and is receiving growing interest from the public authorities. Even though crop insurance have had a long experience throughout developed countries in the world, its survival strongly depends on government support (Kramer [1983]; Smith et al. [2010]; Garrido and Zilberman [2008]). Three features associated to traditional crop insurance have undermined its success : high costs, moral hazard and adverse selection. It follows that it is unattractive to producers and have been financially unsustainable (the premium collected do not cover the indemnities) for the agencies offering this insurance. Moreover, private insurance is effective when dealing with idiosyncratic risks, but unfortunately when it comes to crop production risks, they tend to be systemic, hence the poor success of the traditional crop insurance.

Crop insurance may interact with other risk management tools and affect production practices. The typical example is the insurance effect on input use such as pesticides and fertilizers, that is linked to the existence of moral hazard which arises when insurance contracts are based upon hard-to-measure facts. The implications are, being relieved of some of the consequences of low inputs the producer may reduce inputs intensity. Or on the other hand, if the producer is in a lower-risk environment, insurance may encourage input use. This has been the case with pesticides, the use of which has increased on insured farms in France and Switzerland (Möhring et al. [2020]). With regard to fertilizer use, the effect of insurance is still debated in the literature.

Nitrogen fertilizer has played a major role in modern agricultural practices, as the use of nitrogen-based fertilizers has strongly contributed to the increase of crop growth and yields (Lawlor et al. [2001]). But many evidence in the literature conclude to negative effect of agriculture fertilization on water pollution and climate change (Zhang et al. [1996]; Kumazawa [2002]; Nielsen and Lee [1987]; Paudel and Crago [2021]), mainly because of over-application or misapplication that results in losses to the environment (Lassaletta et al. [2014]). Thus it can safely be assumed that the reduction of nitrogen levels and the support of nitrogen best management practices could be done without significant yield losses (Ren et al. [2022]). As production and risk management are linked, pollution arising from agriculture can be reduced by directly targeting the production practices (Dequiedt et al. [2023]). But some concerns arise with the effects of standard crop insurance on the environment given the changes that it may induce to the farmers behaviour. The question of the relationship between insurance and nitrogen is all the more important as policies aiming to reduce nitrate pollution by reducing nitrogen fertilizers level may have consequences on yields in the context of crop insurance. Moreover, the risks and uncertainty associated with climate conditions may lead farmers to use more chemical inputs, which are currently widely used in agricultural systems of developed countries.

Considering agriculture contribution to climate change and biodiversity loss (Seguin and Soussana [2008]; Pal et al. [2019]; Husnain et al. [2018]), through the (over)use of fertilizers and pesticides, the role of insurance in mitigating chemical inputs is being considered. This also raises the question of the ability of insurance to support a transition toward low chemical inputs use. In this paper we focus on nitrogen fertilizer effects on yields risks and the induced effects on yield based crop insurance.

In what follows, we seek to contribute to the literature over the relationship between crop insurance and nitrogen fertilizer by studying the sensitivity of crop insurance to nitrogen fertilizer through crop yields. We focus on quantity production risk. We propose a comparative analysis of two insurance mechanisms, the Multi-peril crop insurance (MPCI) and an index insurance based on area yield. The Multi-peril Crop Insurance as an indemnity-based scheme, based on producer's individual yields, it seeks to tailor coverage to individual yield losses. At the opposite the Area-Yield index Crop insurance (AYI) provides coverage for yield losses based on the aggregate yield of a surrounding area. As an index insurance, it actually erases moral hazard, adverse selection and reduce administrative costs but may induce what is called basis risk which according the World Bank, arises when the index measurements do not match an individual insured's actual losses.

The paper is organised as follows. In section 2, we present how the connection between risk, insurance and nitrogen fertilisation is addressed in the literature. Then in section 3, we describe the two insurance types considered in this paper. The following sections outline the methodology of the analysis: In section 4 we perform a simulation of MPCI and AYI on a data set at plot scale for two crops (maize and grassland) in the French department of Deux-Sèvres, over the period 2010-2013. This allows us to study which system offers the best yields losses coverage. In section 5 we present the estimation methods leading us to estimate the relationship between insurance and nitrogen fertilizer. We start by looking at the yields response to nitrogen fertilizer on our sample, then we model the econometric relationship between nitrogen fertilisation and insurance based on both simulated insurance schemes, using a random effect logit model. Afterwards we present the main results of the analysis. Finally in the last section 7, we give the principal conclusion of our analysis and we discuss to what extent our results are representative of the French insurance market, which factors must be considered in agriculture policies about fertilisation, yield risks and crop insurance, and the conditions for France to welcome index insurance such as Area-Yield Insurance. We also briefly touch on the implications for climate change mitigation in agriculture.

2 Literature Review

In this section, we review the literature on the relationship between nitrogen, yields and insurance, and relate this to risk considerations. This topic is part of the literature about crop insurance and inputs use. Most papers studying the relationship between insurance and fertilization are related to the moral hazard implication of insurance and the consequences on inputs use and a big part of this literature concerns pesticides use. We actually find few papers on nitrogen fertilisation and crop insurance and the relevant ones we find focus on whether they are substitutes or complements.

There is a very important proof in the literature of agriculture fertilization effect on water pollution and climate change (Zhang et al. [1996]; Bacon [1995]; Kumazawa [2002]; Nielsen and Lee [1987]). To address the urgent problem of mitigating polluting emissions, many papers based on the assumption of profit maximization or costs minimization, argue that the most effective instrument is emissions pricing (Ellerman et al. [2010]; Cara and Jayet [2011]; Dequiedt and Moran [2015]; Bourgeois et al. [2014]).

Although, integrating risk attitude and risk management can bring more insights on the pollution issue. And considering risks (Tevenart et al. [2017];) and uncertainty (Bontems and Thomas [2000]; Babcock [1992]; Tevenart and Brunette [2021]) justifies the interest for insurance as it can provide an incentive to limit agricultural pollution by reducing the use of polluting chemical inputs, which are used as risk management tools by the farmers. Related to nitrogen fertilizer, Dequiedt et al. [2023] find that risk aversion is associated with an additional application of nitrogen fertiliser and for these risk adverse farmers, an insurance program can help in mitigating the pollution resulting from nitrogen fertilizer. These results obtained in a French context, support those of DeVuyst and C. [1999] on an American application in which they propose an insurance scheme aimed at avoiding nitrogen over-fertilization. The idea is that for risk adverse farmers, excessive input application is a mean to prevent themselves against risks. Thus an insurance group incentive contract by insuring the losses that may happen in case of a cut in the nitrogen rates, can help reduce agriculture non-point source pollution. But this paper does not include whether insurance and fertilization are complement or substitute as that is the nature of the relationship that determines if an insurance contract would actually reduce or not the excess of fertilizer.

Ehrlich and Becker [1972] theoretically showed that market insurance and self-insurance are substitutes and market insurance and self-protection can be considered complements, in the existence of moral hazard. As fertilization is considered as a self-protection tool by reducing the probability of a loss, it is therefore complement to market insurance. But fertilization can also reduce the magnitude of a loss and be considered as a self-insurance tool and be a substitute to market insurance. Huang et al. [2001], using an expected value analysis show that an insurance program can actually reduce the adoption cost of some sustainable agricultural practices, by transferring the risk and therefore sharing risk among the participants in the program. Their analysis focus on the mitigating method which consists in applying nitrogen to the crop during the growing-season only. Lu et al. [2023] in an econometric analysis based on the United States, conclude that counties with higher crop insurance participation tend to have lower nitrogen concentrations in its water bodies, although the effects are small. The results of these studies tend to support the idea that insurance could be a substitute to fertilization although in the literature, there is no consensus. Supporting that hypothesis, Babcock and Hennessy [1996] find for different nitrogen fertilizer rates and for reasonable levels of risk aversion, that nitrogen fertilizer and insurance are substitutes, suggesting that those who purchase insurance are likely to decrease nitrogen fertilizer applications. Smith and Goodwin [1996] in an econometric analysis considered insurance participation decisions to be endogenous and, found that Kansas wheat farms who participated in the crop insurance program spent less on fertilizer expenditures. At the opposite, other evidences in the literature support that standard crop insurance tends to negatively affect the environment given the farmers behaviour change that it induces. And that form of moral hazard arises if insurance is used as a complement to other management practices like fertilization. From an econometric analysis, this result is supported by Horowitz and Lichtenberg [1993] paper in which they estimated that the purchase of crop insurance had induced Midwestern farmers to increase their nitrogen fertilizer applications by approximately 19%. Working on Chinese data, Niu et al. [2022] using an econometric method, also found a positive effect of agricultural insurance on fertilizer related pollution.

In this paper, by comparing the Multi-Peril crop insurance to an Area-Yield index insurance we study the relationship that ties insurance to nitrogen fertilisation. We perform a hypothetical analysis which consists into explaining the effect of nitrogen rates on the probability of observing insurable losses based on the yields response to nitrogen fertilizer of the plots in our data set. Behaviour toward risk or insurance is not considered here and we assume all the plots of our data as insured. Thus subvention is not taken into account.

3 Insurance schemes description

The two types of crop insurance programs considered in this paper include individual farm-level insurance: the Multi-peril crop insurance (MPCI) and area-yield index insurance (AYI).

3.1 Multi-peril Crop Insurance

There are three types of MPCI: revenue protection, revenue protection with crop price exclusion and yield protection. In this article, MPCI will refer to the yield protection type. MPCI offers coverage to farm's crop losses from many climatic perils [1]. It insures the yield as a percentage of the actual production history (APH), with benefits based on the spring projected value or price. Under this insurance program an indemnity is paid when the actual yield on the farm falls below a certain percentage of the producer's individual APH. The payment is calculated as the shortfall in yield multiplied by a pre-determined price guarantee. Typically, MPCI requires farmers to use standard production techniques in order to receive compensation for crop losses, but physical assessment of the losses implies high costs. In addition to the monitoring costs, moral hazard and adverse selection are substantial problems. As a result, the private insurance market has failed to offer these products on a purely commercial basis. Historical evidence from

[1] According the countries and the crop, MPCI covers for the following events : drought, extreme heat, heat stroke, sunstroke, low temperatures, lack of sunshine, Cold wave, frost, excess water, heavy rain, torrential rain, excessive humidity, hail, heavy snow or ice, storm, whirlwind, sandstorm.

the United States and Spain, strongly suggests that markets for crop insurance would fail to raise participation rates and even to exist without substantial subsidies covering administrative costs and premium fees (Kramer [1983]; Smith et al. [2010]; Garrido and Zilberman [2008]).

The MPCI is based on the individual actual production history (APH) which is therefore used as the reference yield. For an insured farm in the MPCI system, the insurance is activated if for a given year, the yield falls below a certain threshold of the APH (Y_h_i). In France, the reference yield is either the mean yield of the previous three years or the yields olympic mean i.e the mean yields over the five preceding years, by removing the highest and the lowest values. When yields data for the last five years are not available, the reference yield is calculated replacing the missing data with the mean yield of the department.

3.2 Area-yield Index Insurance

An alternative to MPCI is AYI, where indemnities are based on shortfalls in the area mean yield, rather than the individual farmer yield.

The idea of an index insurance based on area yields was first theoretically formulated by Halcrow [1949]. Halcrow promoted an alternative crop insurance scheme in which both indemnities and premiums would be based not on a producer's individual yield but rather on the aggregate yield of a surrounding geographical area. Then, Miranda [1991] revisited the issue in 1991 and made recommendations on how to make it a very efficient risk reducing tool and to avoid most of the adverse selection and moral hazard problems that have historically plagued the actuarial performance of the MPCI. Area-yield insurance was first offered in the U.S. in 1993, and has since been encouraged over individual farm-level insurance, because area-yield products may help to reduce program losses and contribute to a more sustainable crop insurance program in the long-term. Instead of the farm actual production history, geographical-level yield, more often, county-level yield serves as the foundation for the program. Area-yield data are generally available and much more reliable than information regarding farm-level data, making premiums easy to be determined more accurately. Under index-based area yield insurance (AYI), the payment is calculated as the difference between the long-term mean historical area yield and the actual mean area yield multiplied by a predetermined guaranteed price. This long-term mean historical yield is called the normal yield and it corresponds to the most expected yield inside an area. The yield insured is determined as a percentage (usually 50 to 90-95 percent) of the normal yield for the area. Compensation is paid regardless of the actual losses suffered by the farm, if the mean yield on the farmer's area falls bellow a certain threshold of the normal area yield. The main concern with area-yield insurance like other index-based insurance, however, is basis risk (Skees et al. [1997]). This refers to the imperfect correlation between the county-level yields and farm-level yields, and this basis risk may make area-yield insurance unattractive to farmers and insurance company. In order to reduce the basis risk, Miranda [1991] suggests that for a given area, individual yields should be highly correlated with area yields, and there should be a more homogeneous crops and production conditions in the selected area. In addition to the United States, Sweden, Canada, India and Mexico, among others, have already introduced this type of insurance (Mahul and Stutley [2010]). In France, insurance programs do not yet include this type of mechanism.

4 Case Study and Data

France is a good example of the problem of nitrogen over-application due to the importance of its agricultural sector. The nitrogen fertilizers were responsible for 42% of the GHG emissions from agriculture in 2020 (French Ministry of Agriculture and Food, 2020). In response to these environmental consequences, important regulations on fertilization, such as the "nitrates" directive in Europe, have been established. In the case of France, Dequiedt et al. [2023] shows that insurance coupled with an incentive mechanism to reduce fertilisation can potentially lead to significant reductions in GHG emissions, particularly through fertilisation reduction, in the presence of risk-averse farmers. There is actually few studies addressing the subject of fertilizer reduction and insurance in France. This could be of great interest given the low take-up of crop insurance, with 30% of French farmland excluding grasslands being insured, and the limited insurance on offer, with MPCI being the only insurance available excluding grasslands and limited to yield losses resulting from climatic hazards. Since the 2023 reform of the crop insurance, the subsidized insured yield must be between 90% and 100% of the APH, with the exception of farms converting to organic farming, for which the insured yield may fall below 90%. The standard policy provides for a minimum threshold and subsidised deductible for insurance of 20% and a subsidy rate of the premium 70% for all crops. The question of insurance and pollution in agriculture is therefore very important in the French context, where nitrogen pollution is causing serious environmental problems. And as fertilizer reduction may increase yield risks (in terms of yields reduction), combined with increasing weather risks (IPCC [2022]), insurance profit could be affected, as the pressure on yield based insurance would increase. These considerations are important insofar as, since the introduction of the MPCI contract in France in 2005, premiums collected by insurers have been unable to cover claims paid out and insurance companies have experienced difficulties in achieving their solvency ratio of 70%. In 2016, the general insurance loss ratio reached a record 231% (France assureurs, 2021). Doing so, for crop insurance to be an effective and attractive tool, both the benefits and risks for farmers and insurers need to be considered.

4.1 Data

The dataset used for the analysis comes from Epicles, a database developed by InVivo-Agrosolution, a French union of agricultural cooperatives. It includes data covering the period 2010-2013 on the fertilisation practices of the cooperative's farmer members, the amount prescribed by the cooperative, the amount applied, the crop yield, the plot area, the soil type and the previous crop in the rotation. This information is available at plot level. We are mainly interested in two variables: Nitrogen (mineral and from manure) and Yields. In order to isolate the effect of nitrogen on yield, plots that have received mineral fertilizer other than nitrogen were eliminated from the data set. In addition, plots with zero nitrogen values are also eliminated from the study as they correspond to unreported or erroneous information. Subsequently, the data were filtered, to only keep the plots for which data for all the 4 years were available.

We then chose to focus on the Deux-sèvres department as it contains the most important numbers of data, the other departments containing low numbers of plot which does not allow us to do significant analysis. Moreover the importance of agriculture in this department makes it a good study case. Agriculture plays an essential role in Deux-Sèvres with 75% of the departmental territory, representing 450,591 hectares used for agricultural production. In the agricultural census of 2020, Deux-Sèvres had 4,585 farms with mean usable agricultural area (UAA) of 89 hectares. The north of the department is devoted to livestock while the southeast is concerned with field crops of which 55% are cereals, oil seeds and other grains. 28% of the total agricultural land is dedicated to annual pasture lands and temporary grasslands (Deux-Sèvres Agricultural Chamber, 2020).

The selected data set finally contains 78 maize plots and 258 grassland plots over 4 years. The analysis is conducted for each crop separately.

4.2 Implementation: Multi-peril Crop Insurance

The MPCI is based on the individual yields history of farms. The simulations made are based on the current scheme in France where the individual yields history is that of the preceding five years and the loss threshold to trigger insurance covering is currently fixed at 20%. In our analysis, our data set covering 2010-2013, the first year of insurance subscription is 2010, and thus the APH (Y_h_i) to be used as the reference yield is the variable "objective yield". This objective yield is the mean yield over the past 5 years from which the highest and the lowest value have been removed. The yield loss ratio (LR) for each plot i in year t is calculated as:

$$LR_{it} = Max\left(\frac{Y\_h_i - Y_{it}}{Y\_h_i}; 0\right) * 100 \tag{1}$$

We deduce whether the plot meets the criteria for receiving indemnification or not. The insured farmer receives a compensation if LR is superior to 20%. This information is stocked in a binary variable (I_{it}^{MPCI}) taking the value 1 when the yield loss ratio is bigger than 20%, and 0 otherwise.

$$I_{it}^{MPCI} = \begin{cases} 0 \iff LR_{it} \leq 20 \\ 1 \iff LR_{it} > 20 \end{cases} \tag{2}$$

The MPCI contract includes a 20% deductible borne by the farmer, the compensation is given for the supplementary percentages of loss ratio above the 20% losses. The expression of the insured losses (IL_{it}) in quintals per hectare $q.ha^{-1}$ is given by:

$$IL_{it}^{MPCI} = I_{it}^{MPCI} * (LR_{it} - 20) * Y\_h_i \tag{3}$$

It represents what the insured can expect to receive as compensation under this insurance scheme in the event of a claim.

The part of the losses that is not subject to compensation, the deductible (DED_{it}), depends on the yield losses and the insured losses. The yield losses (Y_loss_{it}) in this context, correspond to the amount in $q.ha^{-1}$ of the crop yield losses relative to the APH. It is calculated as :

$$Y\_loss_{it} = (Y\_h_i * LR_{it})/100 \tag{4}$$

And the deductible in $q.ha^{-1}$ is equal to the difference between the total yield losses and the insured losses ($DED_{it} = Y\_loss_{it} - IL_{it}^{MPCI}$).

Finally, from what we've done in the simulation, we can see how insurance changes the distribution of the yields. We determine the total gains from insurance (IG_{it}) as the sum of the actual annual yield (Y_{it}) and the insured loss ($IG_{it} = Y_{it} + IL_{it}^{MPCI}$).

4.3 Implementation: Area-yield Index Insurance

The AYI uses an index which is the reference yield (for example the mean, median, minimum, or maximum yield) in an area (department, county, etc.). The reference yield corresponds to the normal yield (Y_n) of the area. In our simulation, we choose as normal yield, the mean of the objective yields of all the plots in the data set for the year 2010 (beginning of the period). [2]. When the contract is being established, the farmer chooses to insure a certain percentage of the normal departmental yield depending on their (knowledge of their) own yields. This insured yield is called the critical yield (cY_i), and is calculated according the following principle: if the objective yield in 2010 for a plot is 10 $q.ha^{-1}$, and the normal departmental yield is 8 $q.ha^{-1}$, then we assume that the critical yield corresponds to 120% of the normal yield. In this case, the farmer will receive compensation whenever the annual mean yield drops below 120% of the normal area yield. There is no constraint about the coverage value, it simply corresponds to the

[2]We choose a quite simple value for the normal yield as we only have data from 2010 to 2013. Indeed, more elaborate calculations involve studying the time series of yields over the relevant period and determining the trend in order to identify normal or irregular variations and thus determine what will be considered as the normal yield. Then it can be necessary to assign weights to years if a long-time period is considered.

2010's individual objective yield although in real life the critical yield is restrained to a certain range of the normal area yield.

As recommended by Halcrow [1949], to avoid adverse selectivity[3], and for practical purposes, we consider a four-year contract from 2010 to 2013 and it is not possible to change the critical yield during this period. Since we only have 4 years of observations, the critical yield over the whole period (2010-2013) does not change and is that calculated based on the objective yields of the year 2010. And the normal yield remains the same during the 4 years.

In this scheme, insurance compensation is due when the annual mean yield $\bar{Y}_t$ is, for each plot, below its cY_i. Formally,

$$I_{it}^{AYI} = \begin{cases} 1 & \iff \bar{Y}_t < (Y_n * cY_i)/100 \\ 0 & \iff \text{otherwise} \end{cases} \tag{5}$$

Following Miranda [1991] and Smith et al. [1994], if for each of the next 4 years available in our data set, the mean yield over all plots in the department on a given year ($\bar{Y}_t$) is lower than cY_i, the eligible plots therefore receive the compensation $\tilde{m}$ in quintals per hectare expressed as :

$$\tilde{m}_{it} = max((cY_i * Y_n) - \bar{Y}_t; 0) \tag{6}$$

It corresponds to the difference between the critical yield and the annual mean yield.

As AYI is not directly based upon the individual plot yields, it may lead to basis risks, i.e. the situations where the mean yield for year t falls below the critical yield without necessarily implying that the farmer has experienced yield loss or the opposite, the farmer has experienced yield loss but as the mean yield for year t is not below the critical yield, they do not receive compensation. We highlighted the situations generating basis risks and created a binary variable which takes the value 1 when there is basis risk and 0 otherwise.

Finally, there as well, it is possible to determine the total insurance gain (IG_{it}) according to the same principle as in MPCI. The total gains from insurance (IG_{it}) corresponds to the sum of the actual annual yield (Y_{it}) and the insurance compensation ($IG_{it} = Y_{it} + \tilde{m}_{it}$) received by the eligible plots.

For each crop, maize and grass, we compared the performance of the insurance by studying its effects on the yields distribution.

5 Estimations

5.1 Yields response to nitrogen fertilizer

Prior analysing the relationship between nitrogen and insurance, it is important to describe the yield response to nitrogen. As we are interested in yield-based crop insurances, we can assume that the effect of an input on the insurance will depend on the effect of that input on the yields. If an input does not affect the yields (expected values and/or variance), then we can expect no effect on the insurance mechanism. This step, actually allows us to determine the inputs combination of our data set that affect the yields mean and variability. We applied a production function based on Just and Pope [1978]; and Just and Pope [1979] production function in which inputs influence the mean but also the variability of crop yields :

$$y = \mu(X, \beta) + \sigma(X, \alpha)\varepsilon \tag{7}$$

where y is the crop (maize or grass) yield. The functions $\mu(X, \beta)$ and $\sigma(X, \alpha)$ respectively denote the expected yield and the yield variability, conditional of X a set of independent variables (N,

[3] Halcrow [1949] explains that adverse selectivity may exist due to intermittent participation based on the fact that farmers might be able to estimate area yields one or two years in advance with greater accuracy than could an insurer. Thus, he suggests charging of an initial entry fee and a re-entry fee, and long-term contracts of more than two years.

Area, Soil type, and the inter-cropping type). β and α are the corresponding vectors of the estimated parameters. Finally, we assume that ε have the following characteristics $E(\varepsilon) = 0$ and $\sigma(\varepsilon) = 1$.

From Eq. (7), the expected yield can be represented as:

$$\mu(X, \beta) = \beta_0 + X\beta \tag{8}$$

And the yield variance function as:

$$\hat{\sigma}^2(X, \alpha) = [y - \mu(X, \beta)]^2 = \alpha_0 + X\alpha \tag{9}$$

To describe the crop yield response to Nitrogen fertilizer considering the plots characteristics, a square root functional form was fitted to the data. Most papers studying yield response to nitrogen use a non linear functional form, mostly a quadratic equation accounting for the yields decreasing after achieving the maximum yield. For this study, we rely on a square root functional form following Finger [2012] as the square root specification leads to the smallest cost of misspecification. The use of this functional form imply not only certain effects on yield mean but also on yield variance. The nitrogen applied on the plots comes from two sources: mineral nitrogen and nitrogen from manure. Doing so, in the estimations described below, we used in one case the two types and in another case, we use the total nitrogen as the sum of mineral and manure nitrogen.

The model is estimated using the following empirical specification for the expected yield:

$$y_{it}(X, \beta) = \beta_0 + \beta_1 N_{it}^{0.5} + \beta_2 N_{it} + \beta_3 Area_{it} + \beta_4 Soil\_typ_{it} + \beta_5 INT_{it} + \omega_{it} \tag{10}$$

with $\omega_i = e_i + \mu_{it}$.

In the above function, N represents the nitrogen variable, this is either mineral nitrogen and manure nitrogen, or the sum of the two, i.e. total nitrogen. Area, Soil and INT are the variables for plot area, soil type and inter-crop type respectively [4].

The square root coefficient shows decreasing marginal productivity of nitrogen if $\beta_1 > 0$ and $\beta_2 < 0$. If this is fulfilled, yields are monotonically increasing up to some point of nitrogen use and then monotonically decreasing.

Evaluating the risks implications of the inputs, in a second step, squared residuals of Eq. (10) are used to estimate the yield variance function below:

$$(\hat{\omega}_{it})^2 = \alpha_0 + \alpha_1 N_{it}^{0.5} + \alpha_2 N_{it} + \alpha_3 Area_{it} + \alpha_4 Soil\_typ_{it} + \alpha_5 INT_{it} + \nu_{it} \tag{11}$$

From this equation, a positive (negative) estimated parameter indicates that the corresponding variable increases (decreases) yield variability and is either risk increasing or risk decreasing.

The functions are generally estimated using the feasible generalized least squares (FGLS) method. Considering our small panel data set where $N > T$, the FGLS estimator is not the most appropriate, we choose a random effect panel estimator. As equations (10) and (11) exhibit heteroscedasticity, heteroscedasticity robust standard errors are used for the estimations.

In the next section, this specification is used to estimate the models in which I_{it}^{AYI} and I_{it}^{MPCI} are the dependent variables.

5.2 Nitrogen effect on insurance probability

Our objective is to highlight the variables that might play a role in whether or not a plot experiences losses that qualify it for insurance compensation in a given year using a set of explanatory variables relative to the plot. We used a binary-choice econometric model in which the variables I_{it}^{AYI} from 5 and I_{it}^{MPCI} from 2 are the dependent variables. This study being

[4]For grasslands the specification does not include INT variable as this variable does not change for all the grass plots in the sample and for all years.

in line with the literature on the relationship between insurance and fertilisation, we sought to explain the extent to which nitrogen fertilisation is associated with the probability of being qualified to receive insurance indemnity. We are controlling with variables relative to the plot size, the soil type and the inter-cropping type. A likelihood ratio test performed comparing the panel estimator to the logit estimator concluded that the panel-level variance component is important, thus the logit estimator and the panel estimator are significantly different and the panel estimator tend to be more appropriate. We then, estimated a random effect (RE) logit model taking into account the panel dimension of our data set. There too, heteroscedasticity robust standard errors are estimated. The RE model allows us to get the probability of a positive outcome for each plot:

$$Pr(Y_{it} \neq 0 \mid X_{it}) = P(X_{it}\beta + \nu_i) \tag{12}$$

expressing the probability for each plot i in year t to being qualified to receive insurance compensation depending on X, a set of explanatory variables (N, Area, Soil and INT). β represents the vector of the estimated parameters. And finally, the random effects ν_i are assumed i.i.d., $N(0; \sigma_\nu^2)$.

The model was applied with 312 plots-years for maize and 1032 plots-years for grassland. The econometric model and the explanatory variables are identical for maize and grass but estimations for the two crops are conducted separately. And as with the production function estimation, there too the estimations are made using in one case the total nitrogen used on the plot and in another case the two different sources of nitrogen.

6 Results

6.1 Descriptive Results

Tables 1 and 2 report for maize and grass plots, the mean and standard deviation for nitrogen, yields and loss ratio, as well as their corresponding insurance variable status and we use these tables to compare the characteristics of the plots (mean values). We have by insurance scheme the plots that would receive compensation in only one type, in both types at the same year and the plots that would never be eligible at any year.

The plots being eligible in only AYI have the highest mean values for the yields, N_min, N_man and *Area*. Moreover a most important number of plots are eligible to AYI only than to MPCI only. These plots have the biggest area, and yields. They spread more mineral nitrogen than other plots except for the year 2011 were the mineral nitrogen rate for non eligible plots were superior to all the others. With a small mean LR, these plots yields actually vary less compared to their individual yields history. They are considered eligible to receive insurance although they have not suffer yield losses. Revealing some sort of basis risk favoring big plots and reducing the efficiency of this type of insurance. Considering the small size of the sample (78) strong individual values may affect in an important way the mean. But these observations regarding AYI are the same for grass crops for which we have a more important sample. Thus, we can suppose that AYI tend to favor bigger farms. But in reality this raises two important questions: the likeliness of bigger farms to subscribe insurance and specially this type of insurance, and the samples to be used to calculate the mean yield to determine whether a plot should receive compensation or not.

No plots were found eligible only to MPCI in 2013. And in total, few plots out of the 78 plots in our sample are eligible to MPCI. Their yields mean values are the smallest even though for mineral and manure nitrogen their mean values are comparable to the other groups and sometimes slightly higher. The MPCI being based on LR, their LR are the highest of the sample. Actually few plots would have received compensation in the same year in both AYI and MPCI. There is only 1 plot in 2010, 2 in 2011 and 2012 and 1 in 2013.

Table 1: Descriptive statistics and distribution by insurance type for maize plots

				Yield		N_min		N_man		Area		LR	
Year	I^{AYI}	I^{MPCI}	n	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
2010	0	0	41	103.20	18.62	93.44	28.64	120.02	54.37	2.03	2.28	0.01	0.05
2011	0	0	9	78.36	11.74	127.44	24.95	120.11	36.04	2.72	2.83	0.09	0.08
2012	0	0	18	81.65	13.14	119.44	38.01	136.33	39.56	2.93	3.89	0.04	0.07
2013	0	0	56	111.94	18.33	128.91	35.23	112.55	52.88	2.65	3.39	0.00	0.02
2010	0	1	2	37.5	24.75	117.5	3.54	95.5	4.95	2.7	1.32	0.50	0.40
2011	0	1	16	55.63	15.01	128.5	47.00	96.19	26.89	1.42	0.92	0.36	0.14
2012	0	1	7	58.71	6.63	88.57	33.05	120.43	29.76	1.55	1.22	0.33	0.05
2010	1	0	34	116.55	12.81	122.12	37.04	156.24	35.23	5.66	5.82	0.03	0.06
2011	1	0	51	109.43	13.19	124.41	30.75	111.43	35.98	4.28	5.20	0.03	0.05
2012	1	0	51	100.62	14.32	124.35	33.25	125.43	31.52	4.34	5.20	0.07	0.06
2013	1	0	21	120.67	13.03	132.19	19.79	100.90	52.59	6.99	6.35	0.02	0.03
2010	1	1	1	89	.	96	.	140	.	2.46	.	0.23	.
2011	1	1	2	79.5	3.54	112.5	86.97	121	118.79	3.39	2.64	0.28	0.03
2012	1	1	2	73.25	18.03	83	52.33	83	45.25	2.98	2.06	0.31	0.03
2013	1	1	1	90	.	133	.	188	.	5.25	.	.25	.

For grasslands, like with maize crops, the most important number of crops to be eligible to insurance are with the AYI with a total of 155 plots out of 258 in 2010, 2011 and 2013 and 128 in 2012. For those only eligible in AYI, the mean yields are the highest with a difference of more than 20 $q.ha^{-1}$ compared to the other groups. Mineral and manure nitrogen as for area, their mean values are comparable to the other groups. There too, basis risk is to be considered. In MPCI there is fewer plots to be compensated: 26 plots in 2010, 25 in 2011, 15 in 2012 and 22 in 2013. The plots only to be compensate in MPCI have the smallest mean yields and the smallest area. The same 2 plots are eligible only in MPCI in 2011 and 2012. For them, the mineral nitrogen mean in 2012 have been divided by more than 2.5 while the manure nitrogen mean have been multiplied by more than 5. 10 plots eligible in 2013 have suffered a 100% losses although nitrogen inputs have been spread on the plots. The data set does not reveal whether this corresponds to no harvest at all for some reason. For the plots eligible at the same time in AYI and MPCI, for most of the years, regarding their yields, their mean values are superior to those only eligible in MPCI and not eligible in the both schemes. Regarding the area, or nitrogen rates, for some years their mean values and nitrogen rates are superior to the plots not eligible in both schemes, for other years they are not.

Table 2: Descriptive statistics and distribution by insurance type for grass plots

				Yield		N_min		N_man		Area		LR	
Year	I^{AYI}	I^{MPCI}	n	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
2010	0	0	97	44.64	9.69	54.55	24.38	54.78	28.01	2.64	2.57	0.01	0.04
2011	0	0	101	45.35	11.80	64.58	28.39	57.95	23.90	2.60	2.53	0.01	0.04
2012	0	0	128	49.07	10.69	59.46	26.14	61.16	27.78	2.68	2.63	0.00	0.02
2013	0	0	93	46.13	12.51	52.52	20.07	54.40	32.12	2.47	2.49	0.01	0.03
2010	0	1	6	23.67	7.09	41.83	31.07	41.67	42.88	1.32	0.79	0.44	0.04
2011	0	1	2	20	0	133	0	26	0	.54	0.16	0.33	0
2012	0	1	2	20	0	51	0	133	0	.54	0.16	0.33	0
2013	0	1	10	0	0	59.30	24.23	78.5	11.62	3.21	2.54	1	0
2010	1	0	135	72.52	14.80	65.47	26.72	56.07	39.11	2.59	2.29	0.02	0.05
2011	1	0	132	72.69	9.07	63.36	32.74	53.08	25.30	2.50	2.39	0.00	0.02
2012	1	0	115	75.57	6.66	78.53	42.47	69.71	31.48	2.56	2.31	0.01	0.05
2013	1	0	143	74.20	9.89	61.95	30.60	68.83	43.54	2.56	2.36	0.00	0.02
2010	1	1	20	52.85	13.59	42.70	30.38	34.45	31.92	2.30	3.14	0.34	0.17
2011	1	1	23	46.52	6.47	63.30	16.63	90.30	38.92	2.84	2.54	0.37	0.08
2012	1	1	13	60	0	30.77	3.63	30.77	3.63	1.76	1.88	0.26	0.04
2013	1	1	12	38.33	18.51	59.25	25.83	64.25	23.91	2.36	2.52	0.45	0.27

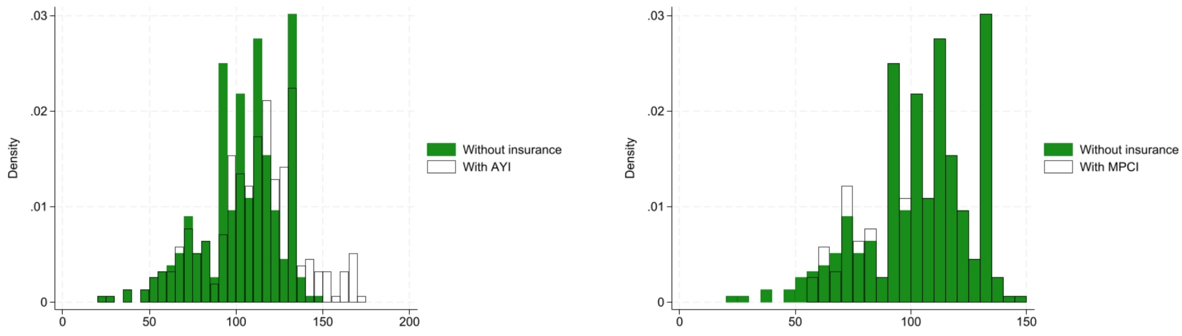
After having described which plots would receive insurance or not, we look at the effect of insurance on the yield distribution. This depends on the mechanism of compensation which include in the case of MPCI a deductible. Graphs 1 and 2 present respectively for maize and grassland plots, the distribution of the actual yields and the distribution of the yields after adding what each plots yields would be if they were involved in insurance[5]. The insurance gain as mentioned in this paper does not include the premium payment. There, it only refers to the yield coverage brought by the insurance. And, we acknowledge that the benefit from an insurance program accounts to the net gain, i.e. the payment received from the insurance minus the premium paid by the insured.

For both crops, AYI in comparison to MPCI strongly changes the yields distribution by increasing the right tail of the distribution. AYI increases the standard deviation of the total distribution but slightly reduces the skewness (improves the symmetry of the distribution) and reduces the kurtosis (heaviness of the tails) of the distribution.

For maize plots, the histograms confirm what we could observe with AYI on the previous tables. AYI, do not strongly affect the yields on the left side of the histogram as for most of them they are not eligible. The density of the plots with the smallest yields does not change strongly in AYI. What strongly changes is the density of the plots around 100 $q.ha^{-1}$. It seems like most of the plots around 100 $q.ha^{-1}$ are the ones who get more benefits from AYI. There is a transfer (of the earnings) to the right tail of the histogram, increasing the standard deviation of the yields. In MPCI, all the eligible plots yields are equal or inferior to 100 $q.ha^{-1}$. Few of them are actually eligible, and because of the deductible the compensation offered does not cover the total yield losses and so does not strongly change the yield distribution.

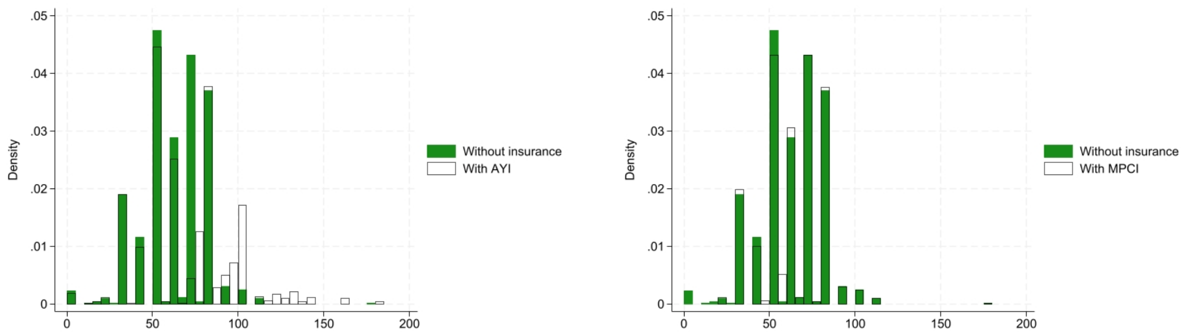
For grasslands, MPCI only affects the left tail of the histogram with like it is for maize plot, small effect on the yield distribution. For AYI the effect on the standard deviation is quite clear but with very small effect on the skewness and kurtosis of the distribution. The effect of AYI starts for plots yields around 50 $q.ha^{-1}$. The most important effect is for plots yields around 70 $q.ha^{-1}$.

[5] The details for each year can be found in Appendix B.



(a) AYI (b) MPCI

Figure 1: Yield distribution with and without insurance for maize plots



(a) AYI (b) MPCI

Figure 2: Yield distribution with and without insurance for grass plots

6.2 Yields response to nitrogen fertilizer

The estimations results of Eq. (8) and (9) are presented in Table 3 for maize and Table 4 for grasslands. The coefficient estimates for the production function show that manure nitrogen application decreases maize yield, however, with a saturating effect (i.e. manure nitrogen shows increasing marginal productivity). The estimates for the yield variation function show that yield variability (i.e. production risks) decreases with manure nitrogen application. The mineral nitrogen estimates are not significant. The total nitrogen estimates show that nitrogen decreases the yields till an inflexion point where it increases the yield. We have an U-shape function form at the opposite of what we used to find in the literature. There is no significant effect of total nitrogen on the yield variability. The plot area only has a significant effect on the production function.

Table 3: Coefficient estimates of yields response to nitrogen fertilizer (maize)

	y_function1	var_function1	y_function2	var_function2
N_min$^{0.5}$	-6.84	-364.96		
	(8.81)	(339.18)		
N_min	0.39	17.23		
	(0.41)	(15.52)		
N_man$^{0.5}$	-3.65***	42.13		
	(1.05)	(31.17)		
N_man	0.29***	-3.60*		
	(0.07)	(1.99)		
Area	1.49***	-6.42	1.52***	-7.30
	(0.39)	(7.17)	(0.39)	(7.92)
Soil_typ=12	0.00	0.00	0.00	0.00
	(0.00)	(0.00)	(0.00)	(0.00)
Soil_typ=15	10.00	130.64	9.08	184.24
	(6.17)	(259.60)	(5.91)	(255.34)
Soil_typ=3	11.86**	118.96	11.26**	129.53
	(5.44)	(108.56)	(5.29)	(113.46)
Soil_typ=4	-17.10**	322.13**	-14.99*	340.30**
	(8.22)	(145.29)	(8.15)	(163.56)
Soil_typ=5	8.18	54.06	5.76	110.35
	(7.10)	(211.48)	(6.45)	(167.84)
Soil_typ=6	5.11*	-14.35	5.94**	-12.07
	(2.71)	(54.35)	(2.55)	(52.86)
Soil_typ=7	7.39**	-29.06	6.91**	-27.90
	(3.13)	(69.10)	(2.92)	(73.09)
Soil_typ=8	-10.50***	-157.00	-11.91***	-134.52
	(3.35)	(120.16)	(3.21)	(116.68)
INT=1	0.00	0.00	0.00	0.00
	(0.00)	(0.00)	(0.00)	(0.00)
INT=2	14.17**	-259.47	12.97**	-301.68
	(6.84)	(257.56)	(6.49)	(248.71)
INT=4	10.56**	42.16	10.07**	27.15
	(4.38)	(117.13)	(4.31)	(113.69)
INT=5	-3.09	-168.60	-4.09	-202.36
	(7.29)	(179.45)	(6.82)	(162.17)
INT=9	-14.64***	-308.05***	-16.77***	-307.04**
	(4.67)	(115.94)	(4.61)	(122.90)
INT=15	-16.83***	-388.51**	-14.83***	-439.04***
	(4.28)	(154.65)	(3.80)	(121.86)
INT=17	9.77*	-289.76***	10.21*	-347.66***
	(5.16)	(82.73)	(5.40)	(82.64)
INT=19	15.85***	-102.78	16.72***	-265.09**
	(4.23)	(148.60)	(3.59)	(114.08)
N_total$^{0.5}$			-9.23**	-104.95
			(4.14)	(130.68)
N_total			0.39***	2.88
			(0.14)	(4.43)
Intercept	115.51**	2206.76	132.91***	1265.17
	(47.79)	(1786.03)	(31.10)	(976.22)
N	312	312	312	312

Legend: * p<.1; ** p<.05; *** p<.01

For grasslands, we do not find a significant effect of manure and mineral nitrogen on the expected yields and the yields variation. The coefficient estimates for the production function show that total nitrogen decreases the yields up to a certain point where it starts increasing the yield. There too, we have an U-shape function. There is no significant effect of total nitrogen on the yield variability. The plot area is not significant.

Table 4: Coefficient estimates of yields response to nitrogen fertilizer (grass)

	y_function1	var_function1	y_function2	var_function2
N_min$^{0.5}$	-1.11	-18.47		
	(1.77)	(60.29)		
N_min	0.16	-1.08		
	(0.10)	(3.47)		
N_man$^{0.5}$	-0.43	-5.71		
	(0.49)	(20.56)		
N_man	0.06	0.28		
	(0.04)	(1.66)		
Area	0.14	-4.76	0.14	-4.46
	(0.36)	(7.90)	(0.36)	(7.95)
Soil_typ=2	0.00	0.00	0.00	0.00
	(0.00)	(0.00)	(0.00)	(0.00)
Soil_typ=3	-9.16***	150.01***	-9.29***	174.00***
	(3.46)	(51.14)	(3.38)	(51.03)
Soil_typ=4	-15.57***	296.66***	-15.11***	307.10***
	(4.17)	(79.18)	(4.06)	(79.53)
Soil_typ=5	-11.84***	40.55	-11.32***	61.79
	(3.45)	(54.72)	(3.40)	(54.27)
Soil_typ=6	-11.01***	140.59**	-10.61***	156.19**
	(3.71)	(65.06)	(3.65)	(66.83)
Soil_typ=7	-6.26*	184.04*	-5.57	196.77*
	(3.76)	(110.04)	(3.68)	(106.56)
Soil_typ=8	-1.19	76.11	-1.04	77.93
	(6.56)	(128.54)	(6.16)	(131.19)
Soil_typ=9	5.52*	-114.92***	4.67	-92.29**
	(3.16)	(38.97)	(2.99)	(38.27)
Soil_typ=10	-7.54	-79.78	-7.70	-59.31
	(5.04)	(49.05)	(4.95)	(49.86)
Soil_typ=11	14.24***	66.98	14.63***	66.71
	(4.41)	(66.84)	(4.36)	(67.25)
Soil_typ=12	4.41	-118.35***	5.31*	-114.91***
	(3.16)	(45.90)	(3.04)	(44.34)
Soil_typ=15	-3.67	256.31**	-5.62	298.30***
	(6.05)	(104.65)	(5.92)	(101.56)
Soil_typ=16	-11.73***	-56.93	-11.14***	-70.58*
	(4.04)	(38.42)	(3.65)	(37.95)
N_total$^{0.5}$			-4.79***	32.22
			(1.51)	(54.49)
N_total			0.26***	-2.46
			(0.06)	(2.23)
Intercept	63.77***	418.79	84.84***	124.74
	(8.08)	(256.75)	(8.63)	(311.40)
N	1032	1032	1032	1032

Legend: * p<.1; ** p<.05; *** p<.01

6.3 Insurance vs nitrogen estimations results

Tables 5 and 6 show respectively for maize and grassland, the random effect logistic regression estimated odds ratios, and the significance of each coefficient for AYI and MPCI.

For maize plots, the coefficient estimates for *N_min*, *N_man* and *N_total* are not significant. The coefficient associated to *Area* is positive (odds ratio > 1) and significant. It shows that the probability of receiving indemnification in AYI increases with the plot size. In the estimates using *N_total* for nitrogen variable and with MPCI, it is negative and significant. The probability of receiving insurance indemnification in MPCI decreases with the plot area.

When focusing on maize plots, the links between insurance indemnification and nitrogen depends on the type of insurance used. Indeed, nitrogen use (neither mineral, Man, total) is not correlated to indemnification in the area-yield index system; in contrast, the total nitrogen use is negatively and significantly correlated to MCPI indemnification.

We used the same functional form as the one used for the production function in order to study how the effect of nitrogen on the yields may affect yield based crop insurance. From that we can see that even in cases where the nitrogen estimates showed a significant effect on the yields, it did not result in a significant effect of nitrogen on the probability of indemnification.

Table 5: Estimated results of nitrogen effect on insurance probability for maize plots

	AYI1	AYI2	MPCI1	MPCI2
N_min$^{0.5}$	1.090		0.761	
N_min	0.993		1.014	
N_man$^{0.5}$	1.131		3.246	
N_man	0.997		0.935	
Area	1.383 ***	1.379 ***	0.852	0.857 **
Soil_typ				
15	1.387	1.437	0.620	0.728
3	0.069 ***	0.076 **	1.926	2.134
4	0.007 ***	0.007 ***	17.189	11.085 ***
5	0.328	0.414	3.445	4.492 *
6	0.375 *	0.435 *	1.629	1.304
INT				
2	113.206 ***	103.668 ***	0.628	0.675
4	4.490 *	4.503 *	0.520	0.550
5	56.069 **	52.348 **	1.796	1.980
17	18.988 ***	19.838 ***	0.326	0.241
N_total$^{0.5}$		1.691		1.964
N_total		0.983		0.975
Intercept	0.105	0.005	0.003	0.001
N	300	300	300	300
Log pseudolikelihood	-133.34	-133.47	-72.90	-76.91
χ^2	64.93	62.12	33.46	65.32

Legend: * p<.1; ** p<.05; *** p<.01

For grasslands the total nitrogen variable estimated coefficient is positive and significant (the square root term is significant and negative and indicates the threshold effect of the variable on the odds) in the estimation with AYI. For this variable, these results follow those obtained with the production function estimation. The manure nitrogen variable is significant (the square root term too). The odd of indemnification in AYI decreases with the manure nitrogen up to a point, then increases. The plot area is not significant for any insurance type.

6.4 Analysis of over-fertilisation

For the plot of our data set, the cooperative advises the nitrogen rate to be applied based on the level of manure nitrogen available and on the nitrogen that remains in the ground. The actual mineral nitrogen rates sometimes do not follow these recommendations[6]. Some apply more or less than recommended. We plotted the scale of the differential of fertilisation for each crop.

We can see on these histograms that over-fertilisation concerns more the grass plots. We have a longer right tail for grasslands than with maize plots. On Table 7 we have by over-fertilisation (0 and 1) some statistics regarding the nitrogen values. The maize plots manure and mineral mean values are quite close for the over-fertilised plots and those not. And these values are close to the total sample mean values. Concerning grasslands, the mean values for plots over-fertilizing are much more important than those non-over-fertilizing and they are also superior to the total mean values. For maize as for grass plots, the mean yields are not much different for the over-fertilising plots and those which do not over-fertilise.

[6]Regressions have been made by over-fertilisation. As a result, we do not find a significant difference between the plots over-fertilising and the others considering the insurance variables.

Table 6: Estimated results of nitrogen effect on insurance probability for grass plots

	AYI1	AYI2	MPCI1	MPCI2
N_man$^{0.5}$	0.429		0.406	
N_min	1.072		1.032	
N_man$^{0.5}$	0.450***		0.838	
N_man	1.064**		1.023 **	
Area	0.967	0.976	0.998	0.996
Soil_typ				
3	0.001	0.001	0.400 *	0.383 **
4	0.000**	0.000**	0.739	0.755
5	0.000	0.000	0.257 *	0.242 **
6	0.000**	0.000*	0.883	0.817
7	0.001	0.001	0.342 *	0.307 **
8	0.100	0.115	0.696	0.614
9	0.010	0.006	1.468	1.494
10	0.014	0.013	0.545	0.482
11	236.144	300.211	0.216	0.175 *
12	18997.701	21793.140	3.580 **	3.346 *
16	0.001	0.001	3.125	2.163
N_total$^{0.5}$		0.097***		0.682
N_total		1.118***		1.014
Intercept	1.72e+05**	2.01e+08***	13.225	1.504
N	1019	1019	972	972
Log pseudolikelihood	-284.65	-286.31	-265.61	-273.30
χ^2	54.32	42.34	64.41	35.33

Legend: *** p<.01, ** p<.05, * p<.1

Table 7: Descriptive statistics by over-fertilisation

(a) maize

	OVER_FERT		
	0	1	Total
Mean			
N_MIN	120.3523	119.8739	120.1699
N_MAN	121.2073	119.2101	120.4455
Yield	104.2699	97.64958	101.7449
SD			
N_MIN	30.67182	41.82319	35.27777
N_MAN	38.66885	54.3131	45.20326
Yield	22.50519	23.02759	22.8966

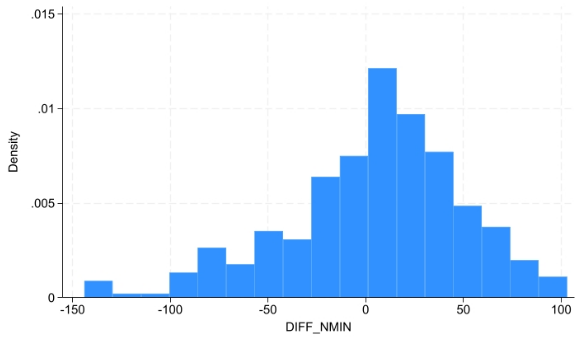
(b) Grass

	OVER_FERT		
	0	1	Total
Mean			
N_MIN	53.93158	107.9677	62.04748
N_MAN	56.84721	76.93548	59.86434
Yield	60.05895	58.59613	59.83924
SD			
N_MIN	21.36554	33.65725	30.49772
N_MAN	31.32215	40.59088	33.63395
Yield	18.54705	19.01924	18.61672

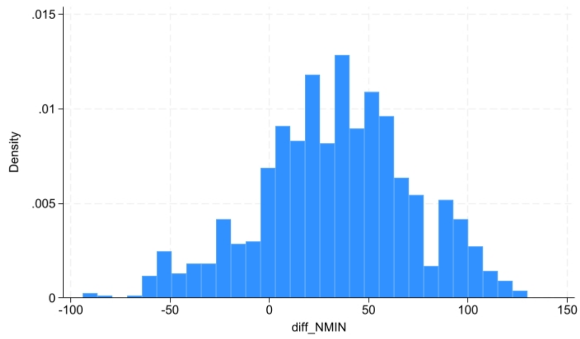
7 Discussion and Conclusion

Our study presents results from the simulation of two yield-based insurance schemes and estimates the effect of nitrogen fertilizer on both insurance schemes using plots data of the French Department of Deux-Sèvres for maize and grass production. After having simulated the two insurance schemes, we performed a binary-choice model estimations using a random-effect logit regression to assess the relationship between insurance and nitrogen. Overall, we find that AYI brings larger coverage for both crops compared to MPCI. One curious fact observed in our analysis concerned the fact that AYI tends to increase the standard deviation of the total yields. The larger plots in this system benefit more from insurance because their critical yields are usually above the mean yields and are often determined as eligible for insurance. From a practical point of view, this raises the question of which plots to consider for the annual mean yield calculation and index setting under AYI. That is an important point to solve in order to reduce basis risk. One of the most important elements in the modulation of the AYI is the determination of the normal yield and the size of the geographical area concerned.

Here, due to the short time horizon of the data available, it is clear that the normal yield



(a) Maize



(b) Grass

Figure 3: Distribution of the difference between nitrogen advice and effectively applied mineral nitrogen

may not be representative of the department. The time horizon to be used for the calculation of the normal yield is also an important point to avoid basis risk. A too long or too short time horizon may not be accurate and lead to an imprecise index.

The MPCI offers a lower coverage of yields losses in comparison to AYI, specially for maize. This is due to the existence of a franchise. In real life, in MPCI, the farms making up the insurance portfolio are geographically dispersed, reducing the risk for the insurer. But in our case, since our simulation only covered plots located in the same department, we can obviously assume a strong correlation of risks and a systemic risk. For both insurance schemes, we could notice that the mean nitrogen values were not necessary smaller for the plots eligible to insurance than to the non eligible plots. Moreover, indemnity insurance is not offered for grasslands in France. For the latter, index insurance is more spread and used in most European countries [Vroege et al., 2019]. But we wanted to submit this crop to the MPCI for comparison purposes.

Concerning the effect of nitrogen on insurance indemnification probability, the general conclusion emerging from the regression analysis is that the effect of nitrogen in the both insurance schemes is mixed.

We can not clearly established whether nitrogen rate reduction might affect the efficiency of current insurance scheme. It is counter-intuitive to find a positive significant effect between nitrogen and insurance. But a negative significant effect would mean that, policies aiming at reducing nitrogen use in farming practices for insured farms could induce higher coverage costs to insurers ceteris paribus. One possible implication of the results is that in general, some crops may be more suitable for a certain type of insurance than others and that it can be interesting to propose insurance according the crop specificity.

The main environmental problem with nitrogen fertilizer concerns the over-application, but the time of application is also of interest. Meaning that these considerations should complete the quantitative ones.

Of course, it is understood that our results are not intended to serve as an inference, as this is not a purely empirical study and have some limits. But they do raise the issue of crop insurance and the need to propose one that is effective to face weather and environmental risks. However, these results highlight the need to study alternative insurance schemes and the elements that need to be taken into account in developing them. The risk attitude of farmers is not considered in this study even though it could explain the use of nitrogen and consequently the eligibility for insurance.

As it is important for European countries as France to achieve SDGs and transform food systems along sustainable pathways, agricultural insurance could play an important role in risk management. The questions highlighted in this paper can help stakeholders including policymakers and insurance companies in the development of new policies.

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Appendices

Appendix A Variables

Table 8: Variables definition

Variable	**Definition**
Yield	Yield in quintals per ha
N_min	Mineral nitrogen in kg per ha
N_man	Farm (manure) nitrogen in kg per ha
Area	Plot area in ha
Soil_typ	1 Not specified 2 Silt 3 Clay loam 4 Clay 5 Clay-loam 6 Deep clay-limestone 7 Superficial clay-limestone 8 Clay-sandy 9 Sandy 10 Sandy loam 11 Sand-clayey 12 Groia 13 Gray Rendzin 14 Chalk land 15 Organic soil 16 Pounding silt
INT	1 Not specified 2 Cereal regrowth 4 Residues maintained 5 Weak cruciferous 9 Medium grass 15 Medium leguminous 17 Other intermediate nitrate trap 19 Grass mixture

Appendix B Insurance effect on yield distribution by year

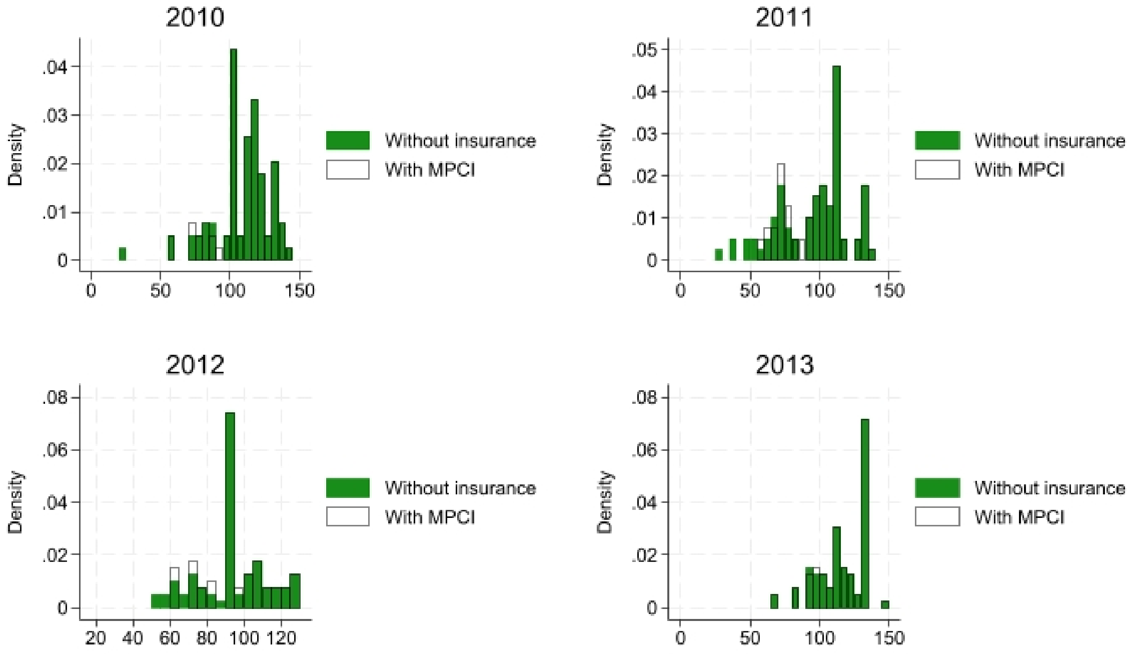

Figure 4: Yield distribution with and without MPCI (maize)

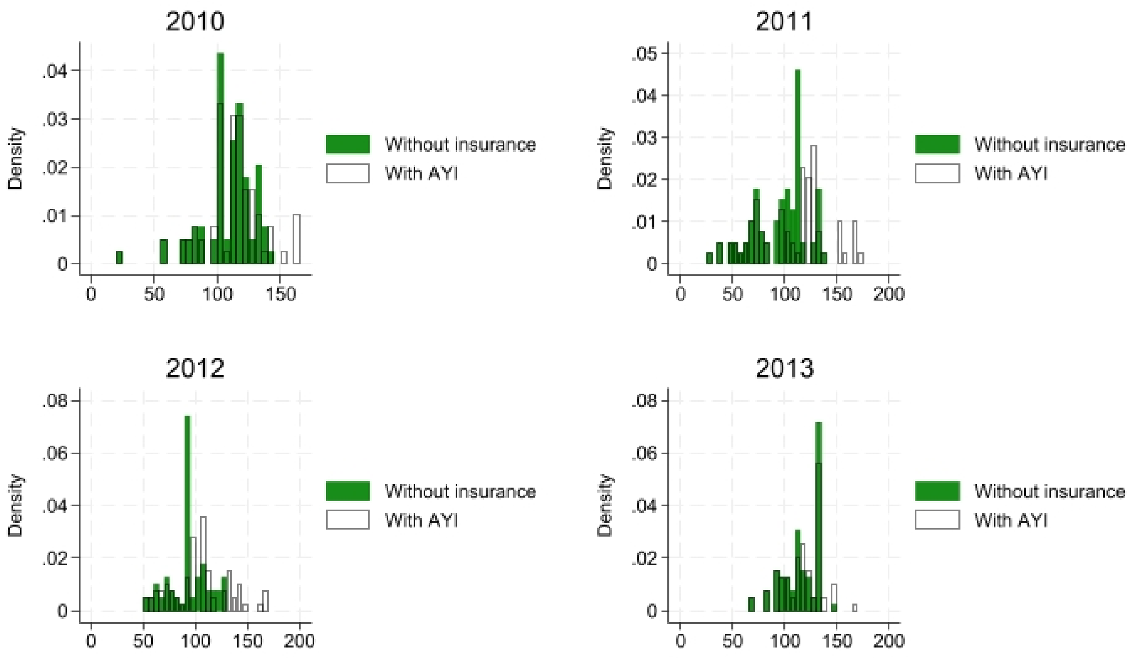

Figure 5: Yield distribution with and without AYI (maize)

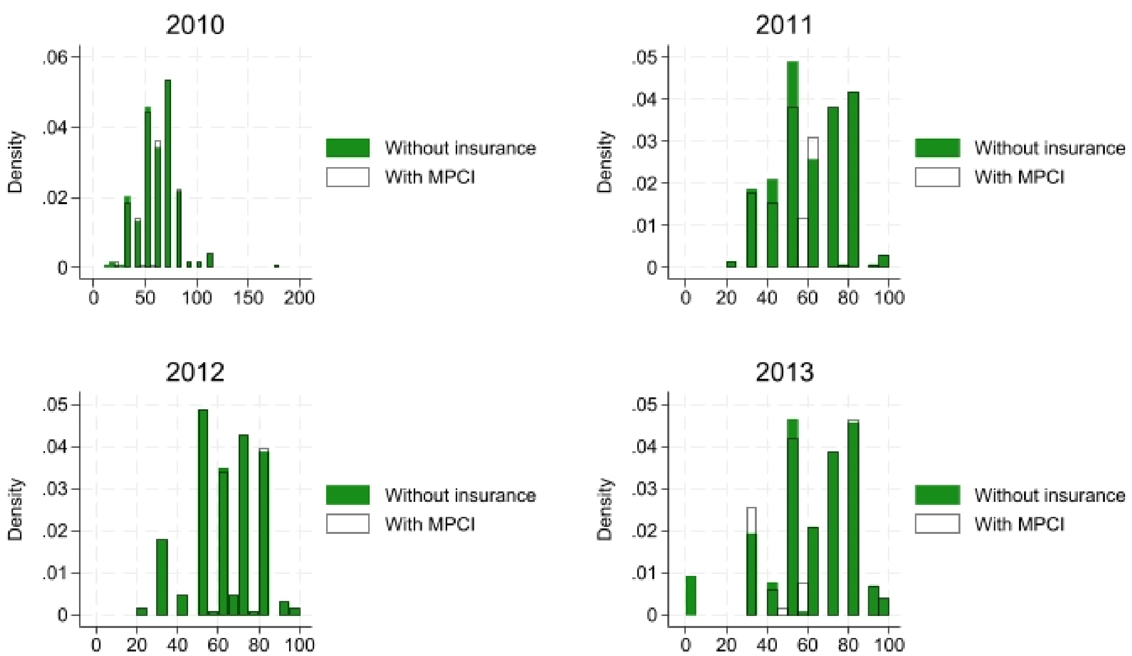

Figure 6: Yield distribution with and without MPCI (Grass)

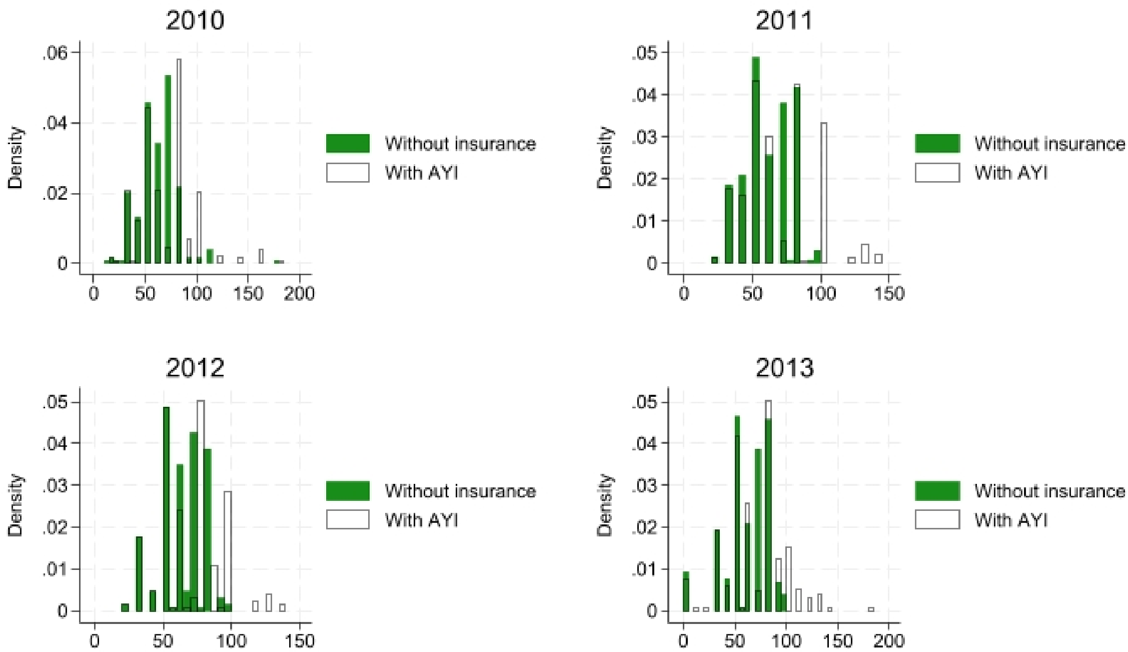

Figure 7: Yield distribution with and without AYI (Grass)