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

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Abstract

The links between nitrogen uses and insurance are explored in this paper via the comparison of two insurance mechanisms: 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, allowed us to define the most advantageous system in terms of yield loss coverage. Using the simulation result, we then modelled the relationship between nitrogen fertilisation and insurance eligibility for each of the two schemes based on a production function that links nitrogen to the yields. We found 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 fertiliser use 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, including France.

Keywords: Crop Insurance; Nitrogen fertiliser; Risk; French Agriculture.

JEL classifications: Q14; G22; Q50

1 Introduction

The notion of risk in agriculture takes on a specific meaning inherent to this sector, which is particularly exposed to natural hazards. Extremely dependent on biological processes, agriculture is highly exposed to weather-related hazards (Abler and Shortle, 2000), the frequency and intensity of which increase with climate change, directly and negatively affecting production. The question of risk management in agriculture remains a major issue in agricultural economics since 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 frameworks. In addition to production decisions (input mix, farm organisation, etc.) that can provide risk management support, farmers have access to a number of market-based risk management tools, including forward sales, diversification and insurance contracts.

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Given the susceptibility of crop yields to weather conditions and climate change, crop insurance, by mitigating weather-related risks, can play an important role in securing farmers' incomes and is receiving growing interest from the public authorities. The COP23 identified crop insurance as a major tool to adapt to climate change (Drieux et al., 2019). Even though crop insurance have been existing for a long time in developed countries throughout the world, its livelihood strongly depends on government support (Garrido and Zilberman, 2008; Kramer, 1983; Smith et al., 2010). Three features associated with traditional crop insurance have undermined its success: high costs, moral hazard and adverse selection. It follows that it is unattractive to producers and has been financially unsustainable (the premiums collected do not cover the indemnities) for the agencies offering this insurance (Moschini and Hennessy, 2001). 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 limited success of traditional crop insurance in most countries.

Crop insurance may interact with other risk management tools and affect production practices. The typical example is the insurance effect on the use of inputs such as pesticides and fertilisers, which is linked to the existence of moral hazard that arises when insurance contracts are based on hard-to-measure facts. The implication is that since producers are able to eliminate some of the consequences of low inputs, they may reduce input intensity. 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 fertiliser use, the effect of insurance is still debated in the literature.

Nitrogen fertiliser has played a major role in modern agricultural practices, given that the use of nitrogen-based fertilisers has strongly contributed to the increase in crop growth and yields (Lawlor et al., 2001). However, there is ample evidence in the literature pointing to the negative effect of fertilisation in agriculture on water pollution and climate change (Kumazawa, 2002; Nielsen and Lee, 1987; Paudel and Crago, 2021; Zhang et al., 1996), 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). Since production and risk management are linked, pollution arising from agriculture can be reduced by directly targeting production practices (Dequiedt et al., 2023). Considering the contribution of agriculture to climate change and biodiversity loss (Husnain et al., 2018; Pal et al., 2019; Seguin and Soussana, 2008), through the (over)use of fertilisers and pesticides, the role of insurance in mitigating chemical inputs is being considered.

Nevertheless, some concerns arise concerning the effects of standard crop insurance on the environment, given the changes that it may induce on farmers' behaviours. The question of the relationship between insurance and nitrogen is all the more important since policies aimed at reducing nitrate pollution by reducing nitrogen fertiliser levels 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 in developed countries. This also raises the question of the ability of insurance to support a transition toward low chemical input use. In this paper, we focus on the effects of nitrogen fertiliser on yield risks and the effects it induces on yield-based crop insurance.

In this article, we seek to contribute to the literature on the relationship between crop insurance and nitrogen fertiliser by studying the sensitivity of crop insurance to nitrogen fertiliser through crop yields. We focus on quantity production risks. We propose a comparative analysis of two insurance mechanisms, multi-peril crop insurance (MPCI) and an index insurance based on area yield. Multi-peril crop insurance is an indemnity-based scheme based on the individual yields of producers. It seeks to tailor coverage to individual yield losses. On the other hand, 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 eliminates moral hazard, adverse selection and reduces administrative costs, but may induce what is referred to as basis risk, which, according to the World Bank, arises when the index measurements do not match an insured individual'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 types of insurance considered in this paper. The following sections outline the methodology of the analysis. In section 4, we describe the simulation method 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 yield loss coverage. In section 5, we present the estimation methods that allow us to estimate the relationship between insurance and nitrogen fertiliser. We start by looking at the yield response to nitrogen fertiliser on our sample. We then 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 in section 6.1. Finally, in 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 risk and crop insurance, and the conditions necessary 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 link this to risk considerations. This topic is part of the literature about crop insurance and input use. Most papers that focus on the relationship between insurance and fertilisation are related to the moral hazard implication of insurance and the consequences on input use, and a big part of this literature concerns pesticide use. We actually found few papers on nitrogen fertilisation and crop insurance, and the relevant ones we found focus on whether they are substitutes or complements.

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

However, integrating risk attitude and risk management can provide more insights into the pollution issue. Moreover, considering risks (Tevenart et al., 2017) and uncertainty (Babcock, 1992; Bontems and Thomas, 2000; Tevenart and Brunette, 2021) justifies the interest for insurance since 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.

Concerning nitrogen fertiliser, Dequiedt et al. (2023) found that risk aversion is associated with an additional application of nitrogen fertiliser and for these risk-averse farmers, an insurance programme can help to mitigate the pollution resulting from nitrogen fertiliser. These results obtained in a French context, support those of DeVuyst and Ipe (1999) on an American application in which they propose an insurance scheme aimed at avoiding nitrogen over-fertilisation. The idea is that for risk-averse farmers, excessive input application is a mean to protect themselves against risks. Thus, an insurance group incentive contract that insures losses that may occur in the case of a reduction in nitrogen rates can help reduce agriculture non-point source pollution.

However, this paper does not specify whether insurance and fertilisation are complements or substitutes since that is the nature of the relationship that determines if an insurance contract would actually reduce or not the excess of fertiliser.

Ehrlich and Becker (1972) theoretically showed that market insurance and self-insurance are substitutes and market insurance and self-protection can be considered as complements, in the existence of moral hazard. Since fertilisation is considered as a self-protection tool by reducing the probability of a loss, it is therefore complement to market insurance. However, fertilisation can also reduce the magnitude of a loss and be considered as a self-insurance tool and a substitute for market insurance. Huang et al. (2001), using an expected value analysis showed that an insurance programme can actually reduce the adoption cost of some sustainable agricultural practices by transferring the risk and therefore sharing risk among the participants in the programme. Their analysis focuses on the mitigating method that consists in applying nitrogen to the crop during the growing-season only.

Lu et al. (2023) in a study on the United States, concluded, using an econometric method, that counties with higher crop insurance participation tend to have lower nitrogen concentrations in their water bodies, although the effects are small. The results of these studies tend to support the idea that insurance could be a substitute for fertilisation, although there is no consensus in the literature. Supporting that hypothesis, Babcock and Hennessy (1996) found that, for different nitrogen fertiliser rates and for reasonable levels of risk aversion, nitrogen fertiliser and insurance are substitutes, suggesting that those who purchase insurance are likely to decrease nitrogen fertiliser applications.

Smith and Goodwin (1996) in an econometric analysis, considered insurance participation decisions to be endogenous and found that Kansas wheat farmers who participated in the crop insurance programme spent less on fertiliser expenditures. In contrast, there is evidence in the literature to support the fact that standard crop insurance tends to negatively affect the environment, given the change in farmers' behaviours that it induces. Moreover, a form of moral hazard arises if insurance is used as a complement to other management practices like fertilisation. On the basis of an econometric analysis, this result is supported by Horowitz and Lichtenberg (1993) in a paper in which they estimated that the purchase of crop insurance had induced Midwestern farmers to increase their nitrogen fertiliser 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 fertiliser-related pollution.

In this paper, by comparing multi-peril crop insurance to an area-yield index insurance, we study the relationship that links insurance to nitrogen fertilisation. We perform a hypothetical analysis that consists in explaining the effect of nitrogen rates on the probability of observing insurable losses based on the yield response to nitrogen fertiliser of the plots in our data set. Attitude toward risk is not considered here and we assume that all the plots of our data are insured. Thus government subsidies are not taken into account.

3 Insurance schemes description

The two types of crop insurance programmes 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 (Olsen and Stockton, 2021). In this article, MPCI will refer to the yield protection type. MPCI offers coverage for farm crop losses due to many different types of 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 programme, 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 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 that cover administrative costs and premium fees (Garrido and Zilberman, 2008; Kramer, 1983; Smith et al., 2010).

MPCI is based on the actual individual production history, 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 olympic yield mean, i.e., the mean yield over the five preceding years, removing the highest and the lowest values. When yield data for the last five or three years are not available, the reference yield is calculated by 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 on the individual farmer's yield.

The idea of an index insurance based on area yields was first theoretically formulated by Halcrow (1949). Halcrow (1949) promoted an alternative crop insurance scheme in which both indemnities and premiums would be based not on a producer's individual yield but, instead, on the aggregate yield of a surrounding geographical area. Miranda (1991) then 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 programme losses and contribute to a more sustainable crop insurance programme in the long-term. Instead of the actual farm production history, geographical-level yield and, more often, county-level yield serve as the foundation for the programme. Area-yield data are generally available and much more reliable than information regarding farm-level data, making it easy to accurately determine premiums.

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 referred to as the normal yield and corresponds to the most expected yield inside an area. The insured yield 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 below 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 companies. 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 more homogeneous crop and

[1] According to the country and the crop, MPCI covers 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.

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 programmes 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. Nitrogen fertilisers were responsible for 42% of the greenhouse gases (GHG) emissions from agriculture in 2020.[2] In response to these environmental consequences, important regulations on fertilisation, such as the "nitrates" directive in Europe, have been established. In the case of France, Dequiedt et al. (2023) show 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 case of risk-averse farmers. Few studies actually address the subject of fertiliser reduction and insurance in France. This could be of great interest given the low adoption rate 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 crop insurance, the subsidised 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 a subsidised deductible for insurance of 20% and a subsidy rate of the premium of 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. Moreover, since fertiliser reduction may increase yield risks (in terms of yield reduction), combined with increasing weather risks (IPCC, 2022), insurance profit could be affected, since 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 for the MPCI reached a record 231%.[3] Consequently, 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 data set used for the analysis was taken 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 recommended 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 had received mineral fertiliser other than nitrogen were eliminated from the data set. In addition, plots with zero nitrogen values were also eliminated from the study since they corresponded to unreported or erroneous information. Subsequently, the data were filtered and only the plots for which data for all 4 years were available were kept.

We then chose to focus on the Deux-sèvres department since it contains the largest amount of data, whereas the other departments have a small number of plots, which did not allow us to make a significant analysis. Moreover the importance of agriculture in this department makes it a good case study. Agriculture plays an essential role in Deux-Sèvres, with 75% of

[2]French Ministry of Agriculture and Food, 2020.

[3]France Assureurs, 2023, L'ASSURANCE FRANCAISE: Données clés 2022.

the departmental territory representing 450,591 hectares used for agricultural production. In the agricultural census of 2020, Deux-Sèvres had 4,585 farms with a mean usable agricultural area (UAA) of 89 hectares. The north of the department is devoted to livestock, whereas the southeast is focused on field crops of which 55% are cereals, oil seeds and other grains. A total of 28% of the total agricultural area is dedicated to annual pasturelands and temporary grasslands (Deux-Sèvres Agricultural Chamber, 2020).

In the end, the selected data set contained 78 maize plots and 258 grassland plots over 4 years. The analysis was conducted for each crop separately. The details about the variables used for the analysis are presented in Appendix A.

4.2 Implementation: multi-peril crop insurance

The MPCI is based on the individual yield history of farms. The simulations made are based on the current scheme in France where the individual yield history is that of the preceding 5 years, and the loss threshold to trigger insurance coverage is currently fixed at 20%. In our analysis, our data set covers 2010-2013, the first year of insurance subscription is 2010, and 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 values 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}) that takes the value 1 when the yield loss ratio is greater 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, and 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 party 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 ($Y_{l_{it}}$) in this context, correspond to the amount in $q.ha^{-1}$ of the crop yield losses relative to the APH. It is calculated as :

$$Y_{l_{it}} = (Y_{h_i} * LR_{it})/100 \tag{4}$$

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

Finally, on the basis of what we have 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

AYI uses an index which is the reference yield (for example the mean, median, or minimum yield) in an area (department, county, etc.). The reference yield corresponds to the normal yield (Y_n) of the area. In our simulation, we chose the normal yield to be the mean of the objective yields of all the plots in the data set for the year 2010 (beginning of the period).[4] When the contract is established, farmers choose 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 (Y_{c_i}), and is calculated according to the following principle: if the objective yield in 2010 for a plot is 10 $q.ha^{-1}$, and the normal departmental yield is 8 $q.ha^{-1}$, we then 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 concerning the coverage value. It simply corresponds to the individual objective yield for 2010, although in reality, the critical yield is limited to a specific range of the normal area yield.

As recommended by Halcrow (1949), to avoid adverse selection,[5] and for practical purposes, we consider a 4-year contract from 2010 to 2013 in which 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. In addition, the normal yield remains the same over the 4 years.

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

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

Consistent with 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 over a given year ($\bar{Y}_t$) is lower than Y_{c_i}, the eligible plots therefore receive the compensation $\tilde{m}$ in quintals per hectare expressed as :

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

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

Since AYI is not directly based on the individual plot yields, it may lead to basis risks, i.e., 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, in which case the farmer has experienced yield loss but since the mean yield for year t is not below the critical yield, he/she does not receive compensation. We highlighted the situations that generate 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 yield distribution.

[4] We chose a quite simple value for the normal yield since 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. It may then be necessary to assign weights to years if a long time period is considered.

[5] 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.

5 Estimations

5.1 Yield response to nitrogen fertiliser

Prior to analysing the relationship between nitrogen and insurance, it is important to describe the yield response to nitrogen. Since we are interested in yield-based crop insurance, we can assume that the effect of an input on the insurance will depend on the effect of that input on the yield. If an input does not affect the yield (expected values and/or variance), then we can expect no effect on the insurance mechanism. This step actually allows us to determine the input combination of our data set that affects the mean and variability of the yield. We applied a production function based on the production function of Just and Pope (1978, 1979) in which inputs influence the mean as well as 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 on X a set of independent variables (nitrogen, area, soil type, and 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 $\sigma(\varepsilon) = 1$.

On the basis of 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 fertiliser considering the plots characteristics, a square root functional form was fitted to the data. Most papers that study yield response to nitrogen use a non-linear functional form, generally a quadratic equation that accounts for the yields decrease after achieving the maximum yield. For this study, we rely on a square root functional form following Finger (2012) since the square root specification leads to the smallest cost of misspecification. The use of this functional form implies not only certain effects on yield mean but on yield variance as well. The nitrogen applied on the plots comes from two sources: mineral nitrogen and nitrogen from manure. With this in mind, we used the two types in one case, and the total nitrogen as the sum of mineral and manure nitrogen in the other case in the estimations described below.

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

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

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

In the above function, N represents the nitrogen variable: either mineral nitrogen (N_min) and manure nitrogen (N_man), or the sum of the two, i.e., total nitrogen (N_total). Area, Soil and Int are the variables for plot area, soil type and inter-crop type, respectively.[6]

The square root coefficient shows decreasing marginal productivity of nitrogen if $\beta_1 > 0$ and $\beta_2 < 0$. If this is fulfilled, yields monotonically increase up to some point of nitrogen rate and then monotonically decrease. In the case where $\beta_1 < 0$ and $\beta_2 > 0$, the square root coefficient shows an increasing marginal productivity of nitrogen fertiliser.

[6] For grasslands the specification does not include the Int variable since this variable is the same for all the grass plots in the sample and for all years.

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

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

On the basis of 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 production and variance 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, so we therefore choose a random effect panel estimator. Since Eqs (10) and (11) exhibit heteroscedasticity, heteroscedasticity-robust standard errors are used for the estimations.

In the next section, using the same variables, we estimate the models in which I^{AYI} and I^{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. We used a binary-choice econometric model in which the variables I^{AYI} from Eq. (5) and I^{MPCI} from Eq. (2) are the dependent variables. We control with a set of explanatory variables relative to the plot size, the soil type and the inter-cropping type. Since this study is 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. A likelihood ratio test performed to compare 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 is more appropriate. We then estimated a random effect (RE) logit model taking the panel dimension of our data set into account. There too, heteroscedasticity-robust standard errors are estimated. The RE model allows us to obtain the probability of a positive outcome for each plot:

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

expressing the probability for each plot i in year t of 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. Finally, the random effects ν_i are assumed i.i.d., $N(0; \sigma_\nu^2)$.

The model was applied with 312 plot-years for maize and 1032 plot-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. As with the production function estimation, there too the estimations are made using the total nitrogen used on the plot in one case and the two different sources of nitrogen in the other.

6 Results

6.1 Descriptive Results

Tables 1 and 2 report the mean and standard deviation for nitrogen, yields and loss ratio for maize and grass plots, as well as their corresponding insurance variable status, and we use these tables to compare the characteristics of the plots (mean values). The plots are broken down by insurance scheme into those 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.

In total, out of 78 plots, 41 in 2010, 9 in 2011, 18 in 2012 and 56 in 2013 of the maize plots are not eligible for insurance compensation. For these plots, the mean yields are among the highest in the sample and the mean LR among the lowest.

Few plots would have received compensation in the same year in both AYI and MPCI. There is only one plot in 2010, two in 2011 and 2012 and one in 2013. They are eligible in both schemes because their yield characteristics have a strong correlation with the department mean yield and their LR is over 20%. Although MPCI and AYI are both yield-based crop insurances, their functioning strongly differs to the extent that the probability for a plot to be compensated in the two schemes at the same time is quite low.

Under AYI, there is a greater number of plots eligible for indemnification in comparison to MPCI (35 in 2010, 53 in 2011, 53 in 2012 and 23 in 2013). These plots have the biggest area and yields. With a small mean LR, these plot yields actually vary less compared to their individual yield histories. They are considered eligible to receive insurance although they have not suffered yield losses, revealing some sort of basis risk that favours big plots and reduces the efficiency of this type of insurance. Considering the small size of the sample (78), strong individual values may considerably affect the mean. However, these observations regarding AYI are the same for grass crops for which we have a larger sample. We can therefore suppose that AYI tends to favour bigger farms. However, in reality, this raises two important questions: the likeliness of bigger farms to adopt insurance and especially 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 to be eligible for MPCI alone in 2013. In reality, few plots out of the 78 plots in our sample are eligible for MPCI. Their yield mean values are the smallest with the largest variability in 2010 and 2011. Since the MPCI is based on LR, their LRs are the highest in the sample.

For all of the plots eligible or not for an insurance indemnity, the mineral and manure nitrogen mean values are comparable. There is not a clear fertilisation pattern characteristic of each group. What strongly differentiates them is the plot size (Area), and the mean area of the plots eligible for AYI indemnity is the highest in the sample for all the years.

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

				Yield(q/ha)		N_min(kg/ha)		N_man(kg/ha)		Area(ha)		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	.

There are similarities as well as differences between the grass plots and the maize plots. The grass plots that are not eligible for any insurance scheme have constant mean yields over all the years and their average yields are comparable to those of plots eligible under both insurance schemes.

For grassland, like for maize, the number of plots eligible for compensation under MPCI alone is the lowest. Their mean yields are the lowest, with 10 plots in 2013 suffering a 100% yield loss. For some reason, the data set does not reveal whether this corresponds to no harvest at all. As with maize plots, the plots eligible for AYI alone are the most numerous of the entire sample. Their mean yields for all years are also the highest. There too, basis risk is to be considered. However, in terms of plot area, the mean values are similar to those of the other groups.

In terms of fertilisation for the different groups, the plots that receive the most nitrogen fertilisers are those eligible for AYI and not eligible for any insurance. Although the mean differences with the other groups are not very large. We note that for the 10 plots eligible only for MPCI in 2013 and having suffered a 100% losses, some fertiliser was however applied.

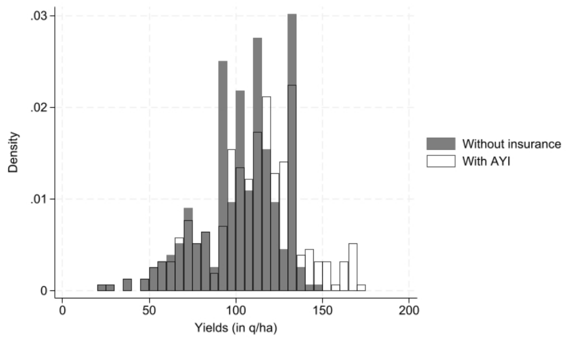
Table 2: Descriptive statistics and distribution by insurance type for grass plots

				Yield(q/ha)		N_min(kg/ha)		N_man(kg/ha)		Area(ha)		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

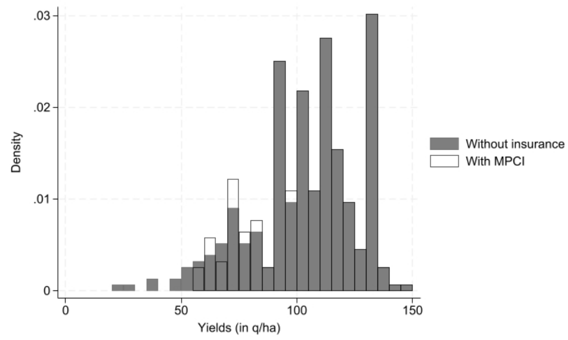
After having described which plots would receive insurance or not, we looked at the effect of insurance on the yield distribution. This depends on the mechanism of compensation that includes a deductible in the case of MPCI. Graphs 1 and 2 present the distribution of the actual yields and the distribution of the yields after adding what each plot yield would be if they were involved in an insurance scheme, for maize and grassland plots, respectively.[7] The insurance gain mentioned in this paper does not include the premium payment. In this case, it only refers to the yield coverage provided by the insurance. Moreover, we acknowledge that the benefit from an insurance programme accounts for 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 yield 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.

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



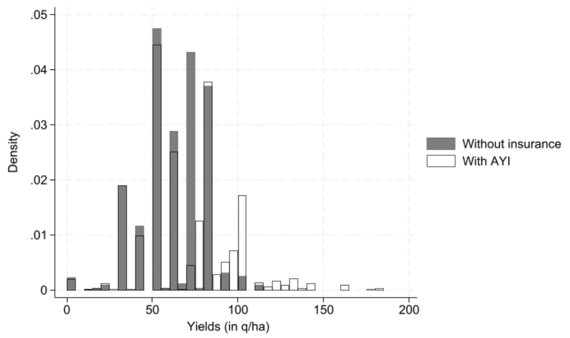
(a) AYI



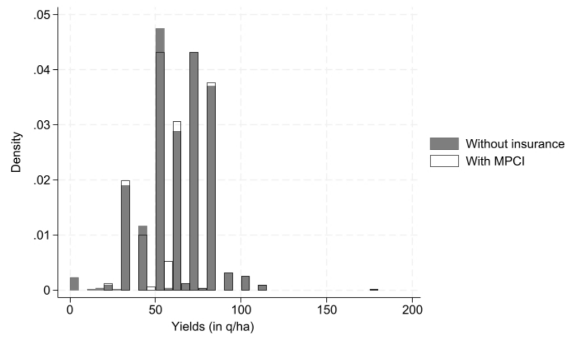
(b) MPCI

Figure 1: Maize yield distribution with and without insurance

For maize plots, the histograms confirm what we could observe with AYI on the previous tables. AYI, does not strongly affect the yields on the left side of the histogram since most of them are not eligible. The density of the plots with the smallest yields does not strongly change 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 that receive 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, the yields of all the eligible plots are equal to or less than 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 therefore does not strongly change the yield distribution.



(a) AYI



(b) MPCI

Figure 2: Grassland yield distribution with and without insurance

For grasslands, MPCI only affects the left tail of the histogram, like for maize plot, with a 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 begins for plot yields at around 50 $q.ha^{-1}$. The most important effect is for plots yields around 70 $q.ha^{-1}$.

6.2 Yield response to nitrogen fertiliser

The estimation results of Eqs. (8) and (9) are presented in Table 3 for maize, and Table 4 for grasslands. The columns labelled y_function show the results for the production function estimates, and the var_function columns show the results for the yield variance estimates. The tables present the significance level of each coefficient and robust standard errors are given between parentheses.

Table 3: Coefficient estimates of yield response to nitrogen fertiliser for maize plots

	y_function	var_function	y_function	var_function
$N\_min^{0.5}$	-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)		
$N\_total^{0.5}$			-9.23**	-104.95
			(4.14)	(130.68)
N_total			0.39***	2.88
			(0.14)	(4.43)
Area	1.49***	-6.42	1.52***	-7.30
	(0.39)	(7.17)	(0.39)	(7.92)
Soil_typ				
Int				
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				

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 variance 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. The inverted U-shaped relationship that expresses the decreasing marginal productivity of nitrogen fertiliser on the yields is what we can find the most in the literature (Cerrato and Blackmer, 1990; Finger, 2012). However, in our case, when we use this specification in Eq. (10), our results support a U-shape relationship, meaning that at extremely low levels of nitrogen, nitrogen fertiliser negatively affects the yield. Since the use of nitrogen increases, yield increases as well. There is no significant effect of total nitrogen on the yield variability. The plot area has a significant and positive effect on the production function alone.

Table 4: Coefficient estimates of yield response to nitrogen fertiliser for grass plots

	y_function	var_function	y_function	var_function
$N\_min^{0.5}$	-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)		
$N\_total^{0.5}$			-4.79***	32.22
			(1.51)	(54.49)
N_total			0.26***	-2.46
			(0.06)	(2.23)
Area	0.14	-4.76	0.14	-4.46
	(0.36)	(7.90)	(0.36)	(7.95)
Soil_typ				
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				

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

6.3 Insurance vs nitrogen estimations results

Tables 5 and 6 show the random effect logistic regression estimated odds ratios, and the significance of each coefficient for AYI and MPCI, for maize and grassland, respectively.[8]

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

	I^{AYI}	I^{AYI}	I^{MPCI}	I^{MPCI}
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	
N_total$^{0.5}$		1.691		1.964
N_total		0.983		0.975
Area	1.383 ***	1.379 ***	0.852	0.857 **
Soil_typ				
Int				
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 maize plots, the coefficient estimates for *N_min*, *N_man* and *N_total* are not significant for any of the insurance schemes. The coefficient associated with *Area* is positive (odds ratio > 1) and significant in the AYI model. It shows that the probability of receiving indemnification in AYI increases with the plot size, whereas the probability of receiving insurance indemnification in MPCI decreases (odds ratio < 1) with the plot area, although this coefficient is significant only in the model using the total nitrogen (N_total) variable. This means that larger farms benefit more from AYI, and that MPCI would be the more advantageous for smaller farms.

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

	I^{AYI}	I^{AYI}	I^{MPCI}	I^{MPCI}
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 **	
N_total$^{0.5}$		0.097***		0.682
N_total		1.118***		1.014
Area	0.967	0.976	0.998	0.996
Soil_typ				
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				

[8] The details for the variables Soil_typ and Int are given in Appendix C.

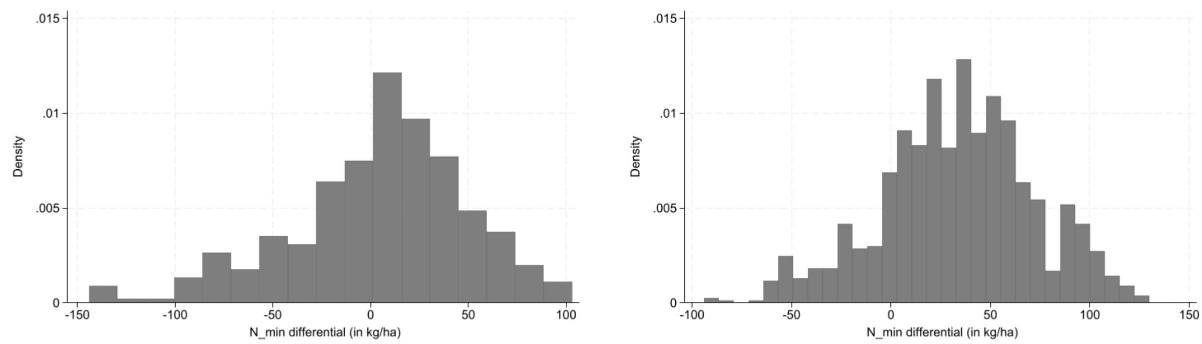
For grasslands the total nitrogen variable estimated coefficient is positive and significant (the square root term is significant and negative and indicates the threshold effect of the variable on the odds) in the estimation with AYI. For this variable, these results follow those obtained with the production function estimation. Bringing more nitrogen to the plot increases the probability of receiving AYI indemnification. Since nitrogen significantly increases the yield and AYI favors the plots with the greater yields, AYI tends to encourage the use of nitrogen. The manure nitrogen variable is significant (the square root term as well). The odds of indemnification in AYI decreases with the manure nitrogen up to a point, and then increases. Manure nitrogen has a significant and positive effect on the probability of receiving indemnification in MPCI (odds ratio > 1), however, with a small effect. Mineral nitrogen has no significant effect in any insurance schemes.

The plot area coefficient estimates is not significant for any insurance type.

We implicitly assumed that if an input had a significant effect on the yields, it would then be significant in determining the probability of receiving indemnification, especially, in an insurance scheme based on individual yield histories as well, such as MPCI. Nevertheless, we can see that even in cases where the nitrogen estimates showed a significant effect on the yields, it did not always result in a significant effect of nitrogen on the probability of indemnification. It is only the case for grasslands and with AYI.

6.4 Analysis of over-fertilisation

Some plots of the data set are concerned with over-fertilisation. The cooperative recommends the mineral nitrogen rate to apply on the plot based on the level of manure nitrogen available and on the nitrogen that remains in the ground. Sometimes, the actual mineral nitrogen rates do not follow these recommendations.[9] Some plots receive more or less mineral nitrogen than the amount recommended. We plotted the scale of the differential of mineral nitrogen fertilisation for each crop. The following histograms show the distribution of the difference between the recommended mineral nitrogen and the mineral nitrogen applied for maize and grass plots.



(a) Maize (b) Grass

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

We observe a longer right tail for grasslands than we have with maize plots. Meaning that over-fertilisation concerns the grass plots more than the maize plots. Table 7 reports some statistics regarding the nitrogen values and the yields for over-fertilised (1) and the non-over-fertilised (0) plots.

[9] Regressions have been made integrating over-fertilisation (0 or 1) as a control variable. As a result, over-fertilisation does not significantly affect the probability of receiving insurance indemnification in the both insurance schemes.

Table 7: Descriptive statistics by over-fertilisation

(a) Maize

OVER_FERT			
	0	1	Total
Mean			
N_min(kg/ha)	120.3523	119.8739	120.1699
N_man(kg/ha)	121.2073	119.2101	120.4455
Yield(q/ha)	104.2699	97.64958	101.7449
sd			
N_min(kg/ha)	30.67182	41.82319	35.27777
N_man(kg/ha)	38.66885	54.3131	45.20326
Yield(q/ha)	22.50519	23.02759	22.8966

(b) Grass

OVER_FERT			
	0	1	Total
Mean			
N_min(kg/ha)	53.93158	107.9677	62.04748
N_man(kg/ha)	56.84721	76.93548	59.86434
Yield(q/ha)	60.05895	58.59613	59.83924
sd			
N_min(kg/ha)	21.36554	33.65725	30.49772
N_man(kg/ha)	31.32215	40.59088	33.63395
Yield(q/ha)	18.54705	19.01924	18.61672

The manure and mineral mean value of the maize plots are quite close for the over-fertilised plots and those that are not. Moreover, these values are close to the total sample mean values. For maize plots, this could mean that the recommended values of the cooperative for nitrogen fertiliser are low for the over-fertilised plots. For grasslands, the mean values of manure and mineral nitrogen for over-fertilised plots are much greater than those for non-over-fertilised plots and they are also greater than to the total mean values. For maize like for grass plots, the mean yields are not much different for the over-fertilised plots and those that are not over-fertilised. The need for over-fertilisation could also be dependant on the soil type for the maize plots. However, for the grass plots, since the soil type for all the plots is the same, over-fertilisation could not be linked to the soil type.

7 Discussion and Conclusion

Our study presents results from the simulation of two yield-based insurance schemes and estimates the effect of nitrogen fertiliser on both insurance schemes using plot data of the French Deux-Sèvres department for maize and grass production. After having simulated the two insurance schemes and estimated the yield response to nitrogen fertiliser and other plot characteristics variables, we performed a binary-choice model estimation using a random-effect logit regression to assess the relationship between insurance and nitrogen.

Overall, we found that AYI provides larger coverage for both crops compared to MPCI. One curious fact observed in our analysis is 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. The condition for the success of AYI is that no single farm is large enough to be able to strongly influence the index. In this case, the small size of the sample of maize plots makes that the largest plots have more weight on the insurance and therefore benefit the most from AYI. 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, an important point to solve in order to reduce basis risk. One of the most important elements in the design of 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 may not be representative of the department. The time horizon to be used for the calculation of the normal yield is also important if we are 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 yield losses in comparison to AYI, especially for maize. This is due to the existence of a deductible. In reality, in MPCI, the farms making up the insurance portfolio are geographically dispersed, reducing the risk for the insurer. However, in our case, since our simulation only covered plots located in the same department, we can obviously assume a strong correlation of individual risks and a systemic risk, which is a positive point in the case of AYI but not desirable for MPCI. For both insurance schemes, we could observe that the mean nitrogen values were not necessarily smaller for the plots eligible for insurance than for the non-eligible plots. Moreover, indemnity insurance is not offered for grasslands in France. For the latter, index insurance is more widespread and used in France as well as in most European countries (Vroege et al., 2019). Nevertheless, we wanted to submit this crop to the MPCI for comparison purposes.

The general conclusion that emerged from the regression analysis is that the effect of nitrogen on insurance indemnification probability in both of the insurance schemes is mixed. Depending on the situation, the implications for insurance differ. If nitrogen negatively affects the probability of receiving insurance compensation, the existence of adverse selection implies that farmers who use the most nitrogen will have less incentive to insure themselves, and those who use the least will have an incentive to take out insurance. In presence of moral hazard, we could observe a reduction in the quantity of nitrogen used after subscribing to an insurance policy, with the objective to increase the probability of being covered. In this case, regulations limiting the amount of nitrogen to be applied to crops below a certain level, or an increase in the price of nitrogen fertilisers, would have a positive effect on the use of insurance. Moreover, concerning insurance, if the majority of insured farms are the least nitrogen-intensive, it is to be expected that coverage costs will be higher. In this case, the premium would be set taking this parameter into account and would be high.

Conversely, if nitrogen positively affects the probability of receiving compensation under an insurance scheme, as is the case here for grass plots with AYI, the use of insurance may encourage an increase in the use of nitrogen and a deterioration in environmental quality. Similarly, conditions that would lead to a reduction in the use of nitrogen fertilisers would make this type of insurance unattractive to farmers. In this configuration, it would be preferable for insurance portfolios to be constituted of less nitrogen-intensive farms in order to avoid high coverage costs. For an index-based insurance, the design of the index is very important if it is to significantly reduce the undesirable effect on the environment and the weight of the larger farms.

In a French context where nitrogen best management practices are more than necessary, it is important to understand the effects on yields and the implications in terms of the effectiveness of crop insurance. The main environmental problem with nitrogen fertiliser concerns the over-application that results from the quantity as well as the period of application, meaning that this last consideration should complete the quantitative one. Insurance must therefore take both the effects of a change in the nitrogen application period and those of a change in the quantity applied into account. One important implication of the results is that, in general, some crops may be more suited to a certain type of insurance than others, and that it may be important to offer insurance based on the specificity of the crop.

Of course, it is understood that our results are not intended to be generalised since this is not a purely empirical study, and some elements such as interactions that exist between the various inputs are not taken into account. Crop yields are determined not only by the amount of nitrogen used, but also by the use of other fertilisers, soil quality, pesticides, irrigation, etc. To really understand the effect of the nitrogen variable alone on yields, some papers rely on experimental frameworks (Cerrato and Blackmer, 1990) or on the use crop simulation models (Finger, 2012) in which it is possible to control for the other inputs and to vary nitrogen rates. Another important factor that we have not been able to take into account is the premium. Therefore, we only consider the effect of the compensation on the gain of the insured party, whereas the actual net gain is what remains after the deduction of the premium. While this is not a problem in absolute terms in AYI since the pure premium in an index insurance like AYI would be the same for all, in MPCI, the pure premium would be different, and the plots with bigger variations in their APH would pay higher premiums. Thus, the net gain from insurance, including the premium, might be different.

This paper raises the issue of crop insurance and the need to propose one that is effective to face weather and environmental risks. In this paper, we are not interested in the insurance demand. Thus, the farmer's attitude towards risk is not considered and we cannot predict whether an index-based insurance would be more welcome in France compared to the current MPCI. However, these results highlight the need to study alternative index insurance schemes and some important points that need to be taken into account in developing them, especially the fact that some agri-environmental practices lead to a reduction in most of the inputs used in conventional agriculture, and yield reductions are to be expected in some cases. Since it is important for European countries such as France to achieve sustainable development goals 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: Variable definitions

Variable	**Definition**
Years	4 years: 2010-2011-2012-2013
Yield	Yield in quintals per ha
Ob_yield	The objective 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

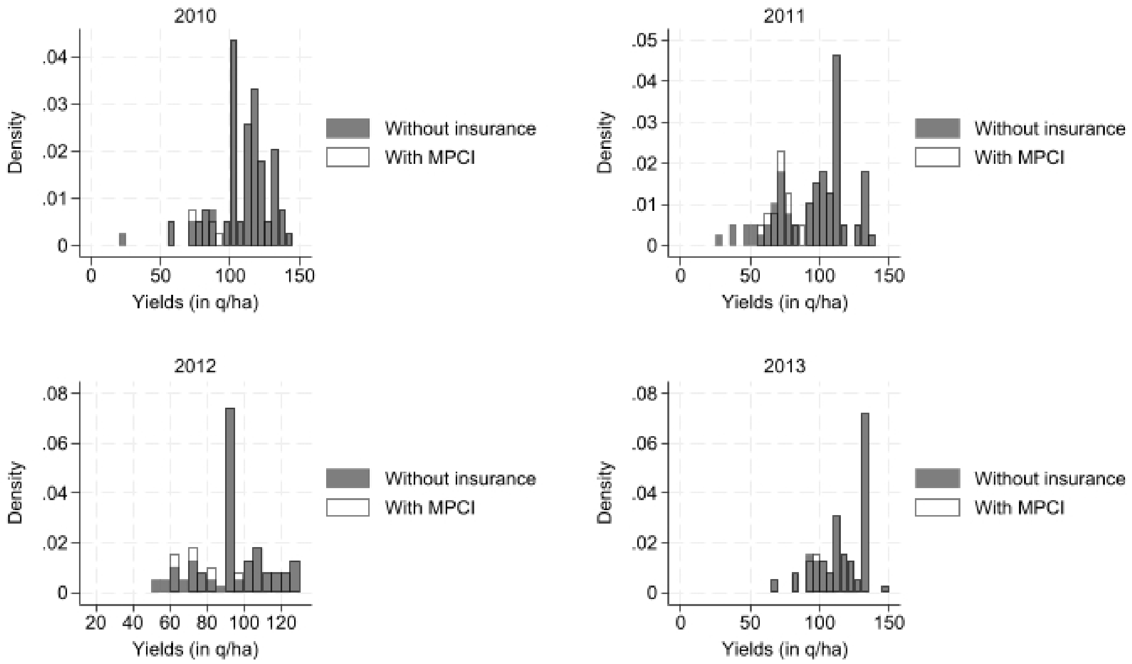

Figure 4: Yield distribution with and without MPCI (maize)

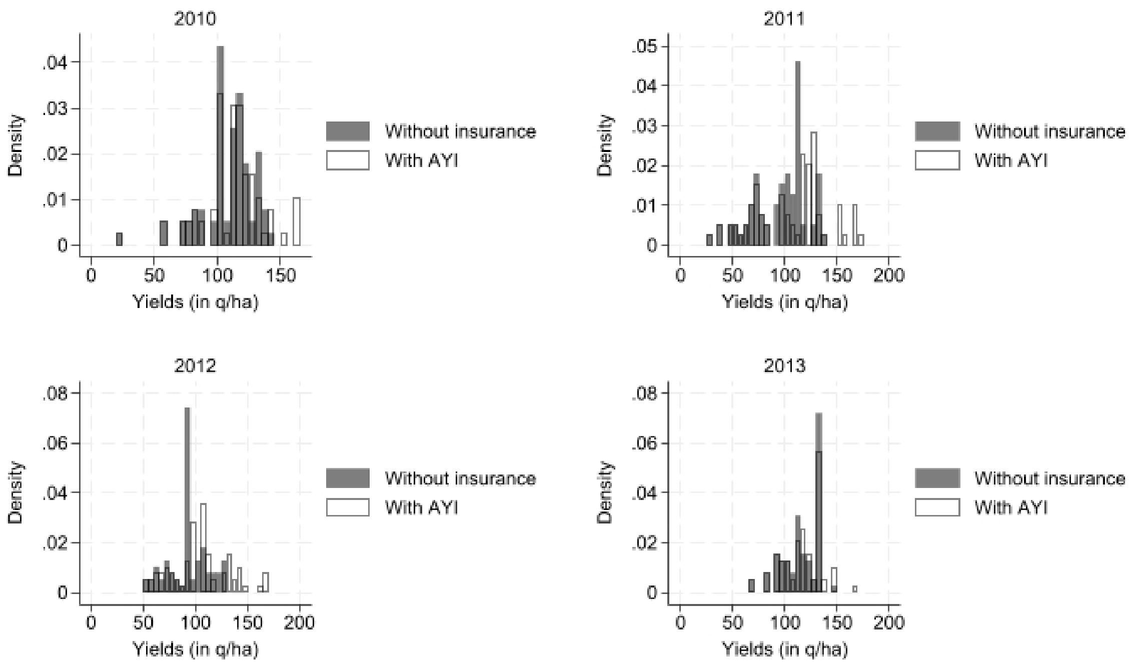

Figure 5: Yield distribution with and without AYI (maize)

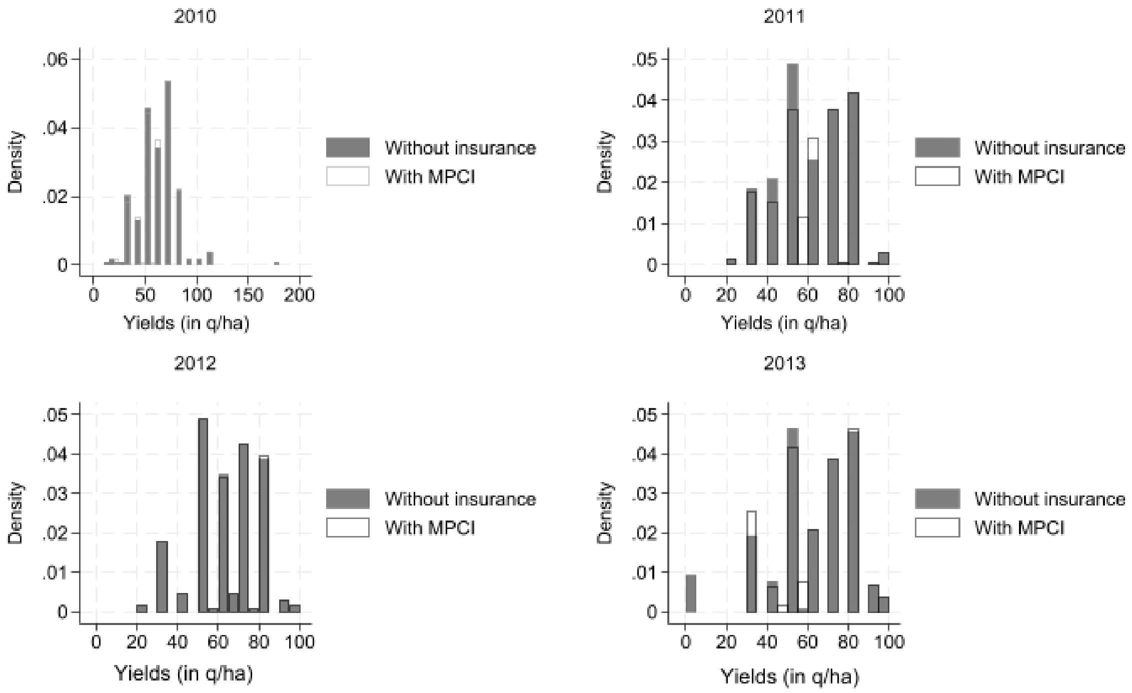

Figure 6: Yield distribution with and without MPCI (Grass)

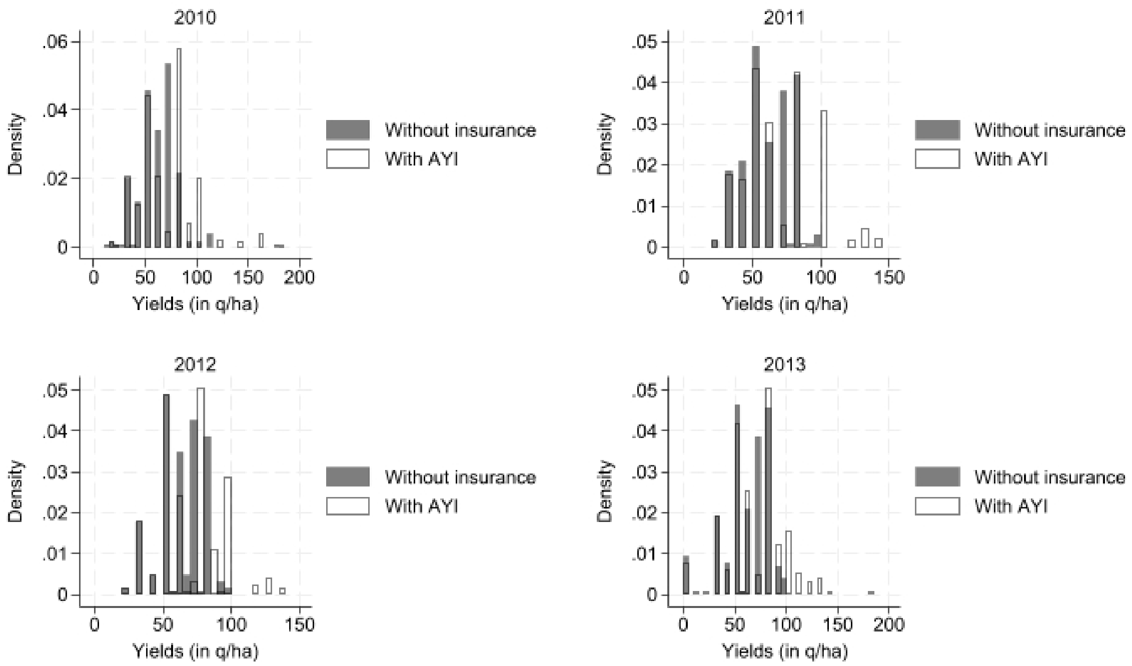

Figure 7: Yield distribution with and without AYI (Grass)

Appendix C Regression results

Table 9: Yield response to nitrogen fertiliser (maize)

	y_function	var_function	y_function	var_function
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)		
N_total$^{0.5}$			-9.23**	-104.95
			(4.14)	(130.68)
N_total			0.39***	2.88
			(0.14)	(4.43)
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)
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

Table 10: Yield response to nitrogen fertiliser (grass)

	y_function	var_function	y_function	var_function
$N\_min^{0.5}$	-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)		
$N\_total^{0.5}$			-4.79***	32.22
			(1.51)	(54.49)
N_total			0.26***	-2.46
			(0.06)	(2.23)
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)
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

Table 11: Nitrogen effect on insurance probability for maize plots

	I^{AYI}	I^{AYI}	I^{MPCI}	I^{MPCI}
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	
N_total$^{0.5}$		1.691		1.964
N_total		0.983		0.975
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
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

Table 12: Nitrogen effect on insurance probability for grass plots

	I^{AYI}	I^{AYI}	I^{MPCI}	I^{MPCI}
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 **	
N_total$^{0.5}$		0.097***		0.682
N_total		1.118***		1.014
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
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