Investigation of factors affecting arable farming profit, crop complexity and risk under the single farm payment policy

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Abstract

The paper investigates the effect of variations in soil type, rainfall, N fertilizer amount and crop prices on the objectives of arable farms operating in Nitrogen Vulnerable Zones (NVZs) and receiving the Single Farm Payment (SFP). Sensitivity analysis was carried out using a mixed-integer programming (MIP) arable farm model (farmR). The farmR model estimates the arable farming objectives of interest: farm profit, crop complexity and risk minimization. Applying the 2014 SFP flat rate and the maximum N limits (N max) values (prescribed in the NVZ guidelines) to each crop, N max was varied under different soil types and rainfall interactions. Crop prices were also varied to illustrate the effectiveness of the SFP under a scenario of high crop prices. The results showed that even though applying N above N max increases farm productivity under all soil and rainfall interactions, doing so and forgoing the SFP reduces farm productivity and increases risk. The SFP thus acts as a payment for the opportunity cost to farms for not being able to apply N above N max. However under a scenario of crop price increases, applying above N max and forfeiting the SFP could generate higher productivity than at the N max level.

Keywords: *Single farm payment; sensitivity analysis; nitrogen vulnerable zones; arable farming; mixed integer programming.*

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1 Introduction

Agricultural policy instruments have been designed to regulate production, make it more efficient and sustainable by promoting efficient input use or to provide financial support to farmers. Regulation, government intervention or changing policy in agriculture is probably the most critical driver in agricultural land use due to its influence on what and how farmers can produce (Halloram and Archer 2008; Angus *et al*., 2009). In the UK, one such policy instrument is the Single Farm Payment (SFP) under the Common Agricultural Policy (CAP), which provides financial support to arable farmers. In order to receive this payment farmers are required to adopt environmentally friendly agronomic practices or technologies with the aim of making arable farming more sustainable. For arable farmers to receive the SFP, some Statutory Management Requirements (SMRs) have to be satisfied and the farmland has to be kept in Good Agricultural and Environmental Condition (GAEC) (Nix, 2014).

Under some circumstances GAEC can only be achieved if the application of inputs such as nitrogen (N) fertilizer is restricted. In NVZs there are limits to the amount of N that can be applied (Defra, 2013). However reduced N inputs can clearly lead to reduced crop yields and hence profit margins. Thus, shifting to more sustainable arable farming systems through the adoption of new agronomic technologies or practices under the SFP policy could influence input as well as outputs levels, which in turn could influence the farming objectives whether profit or non-profit (Clark *et al*., 1999; Halloran and Archer, 2008; Hanson *et al*., 2008). Bojnec and Latruffe (2013) found that the provision of subsidies was negatively related to the technical efficiency but positively related to farm profitability. In this current paper, the effects of variations in soil types, rainfall, N amounts and crop prices on the objectives of arable farms in NVZs receiving the SFP are investigated.

Apart from policies such as SFP influencing the farming decision through the adoption of SMRs and GAEC, farm specific and climatic factors such as soil types and rainfall and economic factors such as crop prices could also influence input use. In NVZs, to receive the SFP, farmers are constrained by maximum N amounts limits (N max) prescribed in the NVZ guidelines even though some farms may be allowed to apply slightly above N max (Defra, 2013). Factors such as soil type, prevailing rainfall could determine the amount of N to apply and this may influence farmers to apply either above or below the

N max. This implies that under the SFP scheme, variation in N amount influenced by the above-mentioned factors could impact on farm productivity or farming objectives. Also, economic factors such as crop prices have direct relationship with farm productivity and therefore could influence farmers' decision on input use. Again, variation or volatility in crop prices can increase the risk faced by farmers (Harwood *et. al.*, 1999). Thus, how do variations in these factors affect the arable farming objectives? How different are the objectives of farms applying the N max and receiving the SFP and those applying above the N max and forgoing the SFP? Can increase in crop prices influence farmers to apply N above N max and forgo the SFP?

Soil types and rainfall are farm location specific and affect the scheduling of farm operations leading to yield reductions due to timeliness penalties (Webster *et al.*, 1977; Reith *et al.*, 1984; Rounsevell *et al.*, 2003; Cooke *et al.*, 2013). Soil characteristics such as soil depth, water holding/retention capacity, bulk density, nutrient levels and organic matter define the soil type, which in turn determines its suitability for supporting certain farm enterprise (Draycott and Bugg 1982; Reith *et al.*, 1984). Variations in rainfall have been found to cause variations in yield and hence affect farm profitability and as a result make farming business risky (Peterson *et al.*, 1990; Rao *et al.*, 2011; Brown *et al.*, 2013). With the effects of climate change and soil degradation on rainfall patterns and soil fertility respectively, it is important to understand mechanistically how changes in rainfall at a farm location and moving from one soil type to the other affect farming objectives.

Changes in fertilizer amounts have been found to affect crop yield, which is a significant determinant of farm profit (e.g. Greenwood *et al.*, 2001; Sylvester-Bradley *et al.*, 2008; Zhang *et al.*, 2009; Jannoura *et al.*, 2014). However the effect of fertilizer on crop yields has a diminishing effect with increasing use. From an economic viewpoint, in order to maximize profit, marginal revenue obtained for applying fertilizer on a crop must equal the marginal cost of applying the fertilizer (Farquharson, 2006). Thus, the current paper seeks answers to the following question: how do changes in N fertilizer under different soil types and rainfall affect the arable farming objectives?

The effects of soil types, rainfall and N fertilizer on farming objectives especially through crop yield variability detailed by other studies are normally tested using field experiments (e.g. Sylvester-Bradley *et al.*, 2008), biophysical crop response (e.g. Zhang *et* *al*., 2009) or econometric/statistical (e.g. Browne *et al*., 2013) models. Such analyses, based on the results of field trials and data, are useful in highlighting possible short-term effects, but less useful in generating long-term predictions or considering the effects of varying multiple parameters at the same time. However models have the capability to generate long-term predictions by capturing most of the complexities in arable farming systems and also providing a framework for organising quantitative information about the supply side of agriculture at different levels (Hazell and Norton, 1986). Again, with models a much wider spectrum of alternative conditions as well as external factors such as policy and farm environment can be examined mathematically (ten Berge *et al*., 2000).

Farm models have been developed as part of the efforts to promote efficient farm management to help in decision-making at the farm as well as to explore the effects of changing external factors. Such models include arable farming system factors as parameters. It is therefore imperative to investigate how these factors affect the farming objectives with respect to the arable farming objectives. In the farmR model, fertilizer amount serves as input parameter with N fertilizer used in the determination of simulated crop yields with exception yield for the leguminous crops. Soil types and rainfall serve as constraint parameters, which affect the sequencing of crop rotation, farm operations and scheduling leading to yield reduction due to rotational and timeliness penalties. Thus, changes in the parameters in farmR can result in the variations of the arable farming objectives estimated by the model.

In summary, variations in soil type, rainfall, N fertilizer and crop prices have been found to influence farm productivity and hence farming objectives. Fertilizer amount can affect the arable farming objectives through yield and farm cost variability. There is therefore the need to investigate the effect of its variation on the arable farming objectives. Although the literatures reviewed above give insight or some evidence into how variations in the above-mentioned factors affect arable farming productivity and hence the objectives, the findings are normally based on field experiments which seek to measure effect on crop yield. Also, with respect to the SFP, studies that link it to the interactions and variations in the above-mentioned factors are still lacking. Therefore, investigating the effect of farm and economic factors on the arable farming objectives under farm payment policy using a robust whole farm model (farmR) fit the purpose of the current paper. The current paper thus attempts to answer the questions raised above.

2 Methods

2.1 FarmR Model Structure

This section gives a brief description of the farmR model. Detailed description of the model design and description of the model objectives and parameters can be found in Cooke *et al*. (2013). The farmR model is an implementation of previous models by Annetts and Audsley (2002) and Rounsevell *et al*. (2003). It is a mixed integer-programming model (MIP) based on the assumption that a selected decision optimises a weighted contribution of all relevant objectives. The model optimises the overall farmers' utility, which comprises multiple objectives and each objective is the sum of contribution from each of the quantities of the various units. The current paper adopted the three main objectives investigated by Cooke *et al*. (2013): profit, risk minimization and crop complexity, which were ranked as the three most important objectives respectively by farmers.

The profit objective was defined in farmR as the annual net gross margin—the sum of gross margin of each crop less the cost of operations, machines and labour for each crop, subject to series of constraints (see Rounsevell *et al*., 2003; Cooke *et al*., 2013). It can be stated as follows:

$$Z_{profit} = \sum_{i} G_i a_i - \sum_{ijk} C_{ijk} x_{ijk} - C_m n_m \quad (1)$$

where G_i is the gross margin for the *ith* crop, a_i is the area of crop *i*, C_{ijk} is the cost of the *jth* operation on the *ith* crop in period *k* and x_{ijk} is the area of *jth* operation on the *ith* crop in period k. C_m is the cost of machinery and labour required to perform field operations and n_m is the number of machines of types *m* required to perform the field operations.

The risk minimization objective was based on the principle of minimization of total absolute deviation (MOTAD) (Tauer, 1983; McCarl and Önal, 1989) in profits. It is the summation of the product of *i*th crop area (x) and the standard deviation in output per hectare for the *i*th crop (σ), multiplied by a constant factor (λ=1) (Cooke *et. al.*, 2013).

$$Z_{risk} = \lambda \sum_{i} x_i \sigma_i \quad (2)$$

The risk values are linked to farmer satisfaction and represent the best or worst possible farm income deviation a farmer would expect over a 5-year period. The number of crop types grown measured the crop complexity. The number of crop types grown is associated with a number of different operations and a level of difficulty.

In terms of validation, the output of the farmR socioeconomic model was compared with empirical data using the Farm Business Survey. For farmers' preferences on profit, risk and crop complexity, an interview was conducted using multicriteria decision analysis framework with 47 farmers in England (Cooke *et al.*, 2013). From the responses of the survey and through a recalibrated utility function, achieving 0% satisfaction meant a profit of £60,000 and 100% satisfaction meant £180,000 based on 250 ha farm. This implies that as profit increases from £60,000, farmers' satisfaction begin to rise.

The crops used in farmR and adopted in the current paper were winter wheat, spring and winter beans, spring and winter barley, ware potatoes, winter oilseed rape (here after WOSR) and sugarbeet. Also, set-aside land was included. The model codes were written in R and Java programming languages and initially implemented as a package in the open source statistical environment, R. The model still runs using R but on a Linux Ubuntu Virtual Machine and it uses the COIN-LP numerical library (http://www.coin-or.org/) to solve the underlying MIP model. The farmR package being command based, made it suitable for the purpose of the current paper in the sense that the XML file which contains the parameters can be written into to change any of the parameters of interest.

2.2 Sensitivity Analysis

Each parameter or combination of parameters in farmR contributes to the production of an output and with sensitivity analysis, any or all of the parameters of interest can be varied (Pannell, 1997). The sensitivity analysis was carried out following approaches and strategies in line with the ones suggested in Pannell (1997). To be able to achieve the aim of the paper using sensitivity analysis, the following assumptions were made:

1. All arable farms are operating in NVZs and have to comply with the SMRs and GAEC as well as apply the N max amounts in order to receive the SFP. However, some farms may be allowed to apply slightly above the N max (see Defra, 2013) and a

result, in this paper, we assumed that farmers in NVZs are only allowed 10% above the N max limit and that farms increasing the N amount above 10% would lose the SFP.

2. In order to simplify the analysis, N amounts and prices of all crops were varied simultaneously even though in reality a farmer may decide the N amount of which crop to alter or prices of different crops may not increase by the same margin.

2.3 Parameter selection and range of variation specification

In NVZs, arable farmers have to follow certain guidelines in order to receive the SFP. As part of the guidelines, farmers are required to apply N up to the prescribed N max however; the type of soil and prevailing rainfall could also influence N application. While the type of soil could determine the amount of N to apply, rainfall could influence the scheduling of N application. This means that soil type-rainfall-N interactions could influence farming decision and hence farming objectives. The three factors were therefore selected and varied. In terms of the range of variation, the N max amount for each crop was varied between -20% and +50%. To illustrate how economic factors affect the farming objectives under SFP, crop prices were varied to determine whether or not increase in crop prices could influence farmers to apply N above N max and forgo the SFP. Crop prices in the model were increased from 5% to 30% by setting N amount at 40% above N max and SFP to zero. The range of variation for crop prices was informed by wheat price projection by Willenbockel (2011). Table 1 shows the three soil types and three rainfall classes (used in Defra, 2010) and the N max amounts chosen for the sensitivity analysis.

Table 1

Parameters used for the sensitivity analysis

Parameters	Crops	N max limit (kg N/ha)
N fertilizer amount	Spring barley (SBAR)	150
	Winter barley (WBAR)	180
	Winter beans (WBEA)	0
	Spring beans (SBEA)	0
	Winter wheat (WWHT)	220
	Sugar beet (SBEE)	120
	Ware potatoes (WPOT)	270
	Winter oilseed rape (WSOR)	250
Soil/rainfall	Soil types/rainfall amounts	Assigned values
Soil type	Light soil (LS)	0.5
	Medium soil (MS)	1.5
	Heavy soil (HS)	2.5
Rainfall	Low rainfall (mm) (LR)	550
	Moderate rainfall (mm) (MR)	650
	High rainfall (mm) (HR)	750

2.4 Factor variations/interactions and model runs

To ensure soil-rainfall-N interactions, N max was varied under soil and rainfall interactions, with and without SFP to compare variations in the arable farming objectives. In all nine soil type-rainfall interactions were generated. The N max data were obtained from Defra (2013) whereas the soil types and rainfall values were based on information from the farmR model (Cooke et al., 2013) and Defra (2010) respectively. In farmR, soil types ranged from 0.5 through 2.5 representing specific soil types from light through heavy soils (Audsley *et al*., 2008; Rounsevell *et. al.*, 2003) and out of these soil types, the three shown above were selected. Crop price data were obtained from the farmR model. In order to capture the SPF in the farmR model, the 2014 flat rate for lowland farmers in England (£207/ha) (Nix, 2014) was applied to each crop enterprise and the model was run under each soil-type rainfall interaction for each variation in N amount and crop price.

3 Results and discussion

3.1 Effect of N variations under light soil and rainfall interactions

An increase in N amount under all light soil and rainfall interactions increased the profit; however increasing the N max by more than 10% and forgoing the SFP reduced the profit. (see Figure 1). For example applying N max and receiving the SFP generated a profit of £169,265; however increasing N max by 40% and forfeiting the SFP reduced profit to £127,976 (24% decrease). The results imply that although there is room for arable farmers to increase farm productivity (yield and hence profit) by applying N above N max, doing so will reduce profits due to loss of the SFP.

Crop complexity remained unchanged at four indicating that under light soils and rainfall interactions, with or without the SFP the number of crop selected by farms may not be affected by N variations. The risk increased with increase in N under all interactions meaning that risks associated with N levels equal to or below N max are lower. This result can be related to the finding of Monjardino *et al*. (2013) that, higher N rates contributed to higher yields but were associated with higher yield variance translating into higher economic risk. Thus, aiming to receive the SFP by applying below or up to the N max could reduce farm risk.

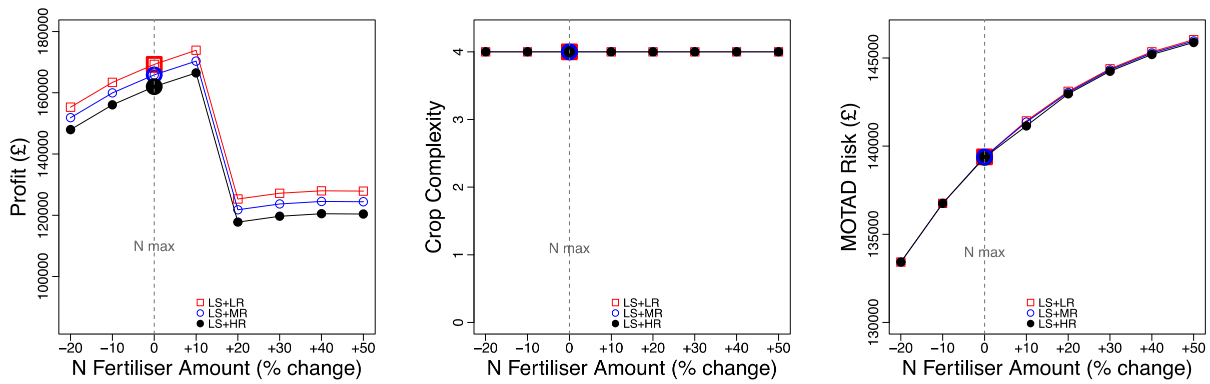

Figure 1. Variations in arable farming objectives due to N fertilizer amount variations under light soil-rainfall interactions

3.2 Effect of N variations under medium soil and rainfall interactions

Applying N max under medium soil and low rainfall interaction generated a profit of £136,794 (lower than profit under light soil at N max level) whereas increasing N max by 40% reduced the profit to £93,373 (32% reduction) (see Figure 2). The result shows that compared to light soils, farms operating on medium soils have lower profits and the implication is that such farms will be better off operating at N max level and receiving the SFP.

Again, crop complexity remained mainly unchanged by increasing N max by 40%. Since farms receive SFP irrespective of the crop grown; it is possible that on a medium soil the number of crops selected by farms may not depend on whether or not farms receive SFP. Increasing the N max by 40% increased the risk by 4% and this may be due to the fact that the estimation of the MOTAD risk was based on farm output (yield and price) and that any increase in farm output will translate into increase in the risk (Monjardino *et al*., 2013). Thus, farmers will be better off by at most fertilising crops at the N max level associated with low risk.

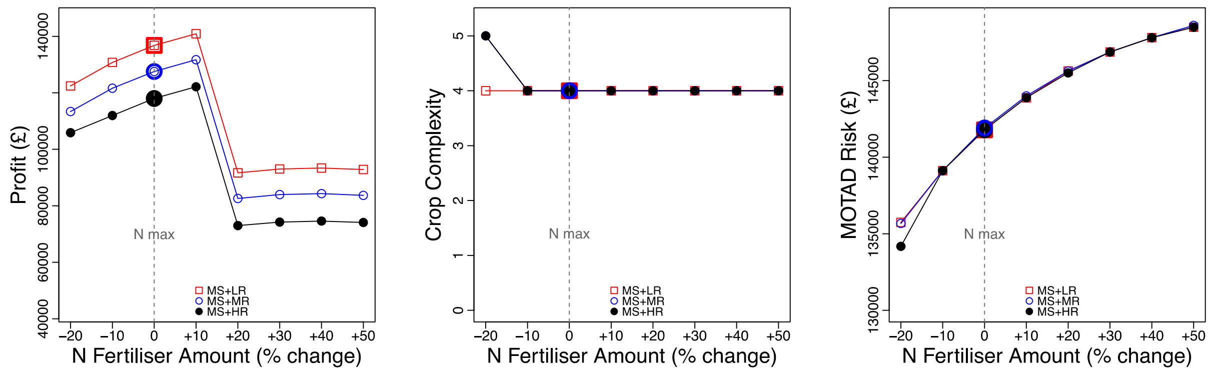

Figure 2. Variations in arable farming objectives due to N fertilizer amount variations under medium soil-rainfall interactions

3.3 Effect of N variations under heavy soil and rainfall interactions

Applying N max generated a profit of £85,237 whereas increasing the N max by 30% reduced profit to £39,243 (54% decrease). With or without SFP, farms operating on heavy soils recorded the lowest profits. Thus, under a scenario of no SFP, farms on heavy soils would be worse-off.

A 30% increase in N max under heavy soil and low rainfall changed crop complexity from six to seven but remained unchanged under heavy soil and moderate rainfall. Under heavy soil and high rainfall, it reduced from seven to six. The changes in crop complexity were mainly driven by the interactions of heavy soil, rainfall and N fertilizer which determine the types of crops to be grown and not due to receipt of the SFP. The risks associated with N max levels were lower than risks associated with increasing N max by 30%. For example the risk for applying N max was £144,202 whereas that of 30% increase in N max was £148,496 (3% increase). The implication is that applying the N max on a heavy soil and receiving the SFP would be associated with lower risk. The SFP can therefore be said to reduce farm risk.

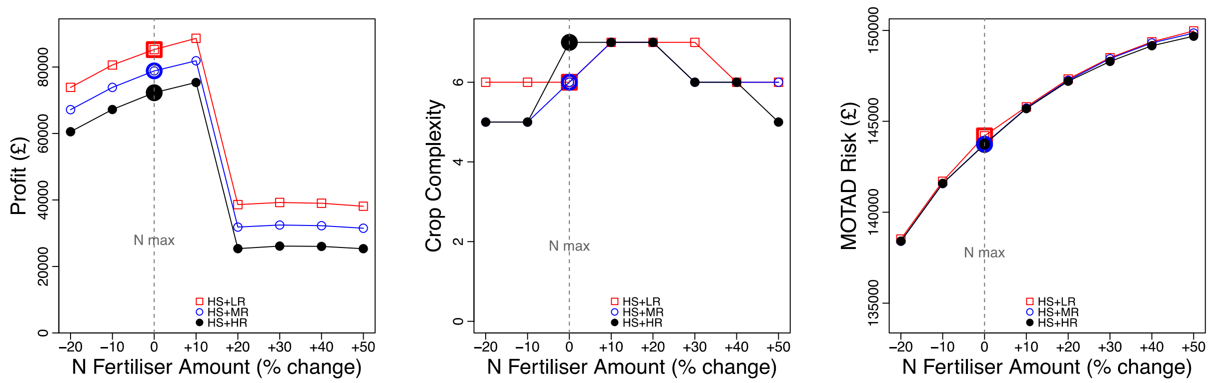

Figure 3. Variations in arable farming objectives due to N fertilizer amount variations under heavy soil-rainfall interactions

3.4 Effect of crop prices on farming objectives under the SFP

This section illustrates how economic factors such as crop prices affect farming objectives with respect to the SFP. Under heavy soil and higher rainfall interaction, the results (see Figure 4) showed that with 15% increase in crop prices, applying 40% above N max and losing the SFP, farm profit (£91,695) was higher than the profit for applying the N max and receiving the SFP but at the base crop prices (£72,260). Under the same scenario, crop complexity was lower (six) however MOTAD risk was higher (£171,209) than the risk at the base crop prices (£149,159). The implication is that higher crop prices can influence farmers to apply N above the N max level and forgo the SFP since doing so will increase farm productivity (profit) and reduce management complexity than applying N max and receiving the SFP.

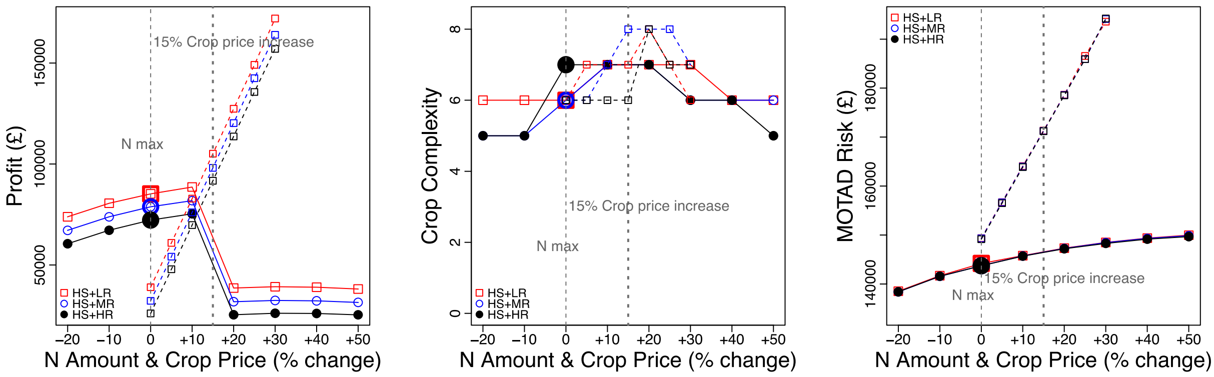

Figure 4. Variations in arable farming objectives due to N amount and crop price (red, blue and black dashed lines) variations under heavy soil-high rainfall interaction

4 Conclusion

The paper investigated the effect of variations in soil type, rainfall, N fertilizer amount and crop prices on the objectives of arable farms operating in Nitrogen Vulnerable Zones (NVZs) and receiving the Single Farm Payment (SFP). Sensitivity analysis was carried out using a mixed-integer programming (MIP) arable farm model (farmR). The model estimates three arable farming objectives: profit, crop complexity and risk minimization. Applying the 2014 SFP flat rate for lowland farmers in England to all crop enterprises and the maximum N limits (N max) values to each crop, N max and crop prices were varied under different soil types and rainfall interactions.

We showed that the profits of farms applying the N max and receiving the SFP were higher than that of farms applying above the N max and losing the SFP, and farms on heavy soils would be worse-off. There were more variations in crop complexity under heavy soil and rainfall interactions. The risk increased with increase in N under all interactions implying that risks at N max level or below are lower. We also showed that farms in NVZs have potential to increase farm productivity by applying N above N max under all soil and rainfall interactions; however, doing so and forgoing the SFP reduces farm productivity and increases farm risk. There is thus an opportunity cost to farms for not being able to apply N above N max to increase productivity; however the SFP acts as a payment (compensation) for the opportunity cost to farmer to cut nitrate leaching by applying low levels of N. The SFP can be said to bring some form of Pareto efficiency in that farms benefit through the SFP scheme and society also benefit from an environment with less nitrate pollution. However, increase in crop prices could influence farmers to increase N amount above N max and forgo the SFP in the sense that increase in crop prices contributed more to farm profit than the SFP. The implication is that although the SFP may be a good support or compensation scheme, its effectiveness could be affected due to the influence of the factors considered especially crop prices on farming decisions and hence the farming objectives. Going forward, future farm payments could be estimated taking the factors looked at into consideration. Also, more discussions as well as research on the formulation of a payment scheme linked to variations in soil types, climate (rainfall) and prevailing crop prices are needed to better inform both farmers and policy makers.

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