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Determinants of Nitrogen Surplus at Farm Level in Swiss Agriculture

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Abstract.

This paper investigates the determinants of nitrogen surplus and of its two components – nitrogen intensity and nitrogen-inefficiency – at farm level in Swiss agriculture. Our analysis is based on a cross-section of 210 farms from the year 2010. The nitrogen balance of each farm is estimated according to the OECD soil-surface approach. The determinants are analysed by means of a three-equation regression model estimated using a robust SUR approach. Farm size, part-time farming, organic farming, arable cropping and farmer's age are found to negatively affect nitrogen surplus, whilst dairy, pig and poultry farming are associated with a higher nitrogen surplus.

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1. Introduction and Research Question

The sustainable use of natural resources, i.e. efficient use of these resources and limiting the environmental impacts associated with their use, is one of the main objectives of Swiss agricultural policy (SR 101, Article 104; FOAG, 2004; FOAG, 2010). Nitrogen (N) use is a key environmental issue in agriculture. The use of this nutrient, or more precisely, its addition to agricultural cropping systems, contributes to several environmental problems (Galloway et al., 2008; Roberson and Vitousek, 2009), among which are eutrophication, global warming and acidification. Eutrophication, which can be defined as the enrichment of water by nutrients, especially nitrogen and/or phosphorus and organic matter, having unacceptable adverse effects on the aquatic ecosystem and the quality of the water concerned (adapted from Rovira and Pardo, 2006), is the major environmental problem associated with nitrogen use in agriculture. The agricultural sector has been shown to be the main source of nitrogen eutrophication (Rovira and Pardo, 2006).

Water protection, and hence the reduction of nitrogen losses caused by agriculture, are key issues in Switzerland, owing to the country's geographical location and topography, as well as its associated role of major European water reservoir (e.g. the Rhine, Rhone, Inn, Ticino). Estimated at national level according to the OECD soil-surface approach, the nitrogen balance of the Swiss agricultural sector stood at 68 kg per ha agricultural land in the period 2007-2009 (OECD, 2013), which came very close to the average balance observed for the EU-15 of 65 kg/ha (OECD, 2013). Austria, a country similar to Switzerland in terms of natural production conditions (e.g. topography, climate, soils), as well as in terms of structural characteristics of the agricultural sector, recorded a nitrogen balance of 30 kg/ha over the same period, i.e. less than half that of the Swiss farming sector. This discrepancy between the two countries in terms of nitrogen balance suggests that there may be substantial room for reduction in Swiss agriculture's nitrogen surplus – a statement which is corroborated by a comparative analysis of changes in the national nitrogen balance per hectare of agricultural land of both countries between the periods 1998-2000 and 2007-2009. Starting with a nitrogen balance of 46 kg/ha agricultural land in 1998-2000 (i.e. a level lower than the nitrogen balance of Swiss agriculture in 2007-2009), Austrian agriculture managed to reduce its nitrogen surplus per hectare of agricultural land by 35% (or in absolute terms by 16 kg, from 46 to 30 kg N) by 2007-2009 (OECD, 2013). Over the same timespan, Swiss agriculture's nitrogen surplus increased by 5% (or in absolute terms by 3 kg, from 65 to 68 kg N per ha) (OECD, 2013).

Consequently, the Swiss agricultural-policy objective of reducing the national nitrogen surplus from agricultural activities to 95,000 tons by the time horizon of 2005 (Bundesblatt, 2006) has fallen short of the mark. Since the late 1990s, the national nitrogen surplus from Swiss agriculture has more or less stabilised at around 110,000 tons[1] (Herzog et al., 2005; Spiess, 2011), i.e. 16% above the agricultural-policy target.

The ability to formulate recommendations for achieving the objective of nitrogen-surplus reduction set by agricultural policymakers presupposes a better understanding of nitrogen use at micro-level – i.e. farm-level – where the decisions regarding the use of this nutrient occur. Unfortunately, no farm-level analysis of the current state of nitrogen use in Swiss agriculture is to be found in the literature. This is because until now, there has been no comprehensive and accurate data on the nitrogen-use pattern (i.e. detailed nitrogen balances) of Swiss farms available at micro-level. Recently, an Agri-Environmental Indicators Farm Accountancy Data Network (AEI-FADN) was introduced in Switzerland with the aim of environmentally monitoring Swiss agriculture on the basis of environmental data collected at farm level for a subsample of Swiss FADN farms (Stutz and Blaser, 2010). Initial data from this monitoring network are now available for the year 2010 for a sample of 210 farms. For each farm, a precise and detailed nitrogen balance was estimated on the basis of environmental data collected at farm level. The aim of this paper, which is based on these data, is to improve our understanding of the determinants of nitrogen surpluses in Swiss agriculture. More specifically, this paper attempts to answer the question of whether the characteristics of a farm and its manager impact the farm's nitrogen surplus. Our findings are of relevance for farm managers, farm advisers and policymakers.

2. Data

This section provides a brief introduction of the sample of farms on which our study is based. In a second sub-section, we describe in detail the approach used to estimate the nitrogen balance of the farms in the sample.

[1] This objective refers to a nitrogen balance estimated according to the OSPAR approach (OSPAR, 1995), which is a farm-gate nutrient balance calculated at national level, the whole Swiss agricultural sector being considered as a single farm.

2.1. Sample of farms

Our investigation is based on a cross-sectional and non-random sample of 210 farms from the Swiss AEI-FADN. The farms of the sample are distributed across almost all strata of the farm population of the Swiss FADN, a stratum being defined according to the Swiss FADN typology (Meier, 2000) as a homogeneous group of farms in terms of farm type (agricultural activity) and agricultural region (plain, hill or mountain region). Despite this, several strata are not represented in the sample, either because no farm of the stratum in question was willing to take part in the agri-environmental monitoring network, or because too few observations were available for a given farm type, which would have posed a problem when performing the regression analyses in a subsequent step of the study. Even though the most important strata of Swiss agriculture are represented in the sample, the fact that some strata are missing should be borne in mind when interpreting and discussing the results of the investigation.

2.2. Estimating the farm soil-surface nitrogen balance according to the OECD approach

There are several types of indicators for assessing the environmental impact of agriculture. In this regard, Schröder et al. (2003) distinguish between means- and goal-oriented indicators. Whereas goal-oriented indicators are directly related to the ultimate goal pursued (e.g. eutrophication reduction), means-oriented indicators are only very weakly related with this goal, as they focus on production means (e.g. livestock density, nitrogen input via manure; Schröder et al., 2003). Nitrogen balance[2] – defined as the difference between nitrogen inputs (or 'intake') and nitrogen outputs ('uptake') per hectare of area – occupies an intermediate position between these indicator types (Schröder et al., 2003). Even though goal-oriented indicators are the best suited to assessing the ultimate environmental impact of nitrogen use, their implementation within an environmental monitoring network at farm-level is not feasible for a great number of farms, given the huge amount of data that would need to be collected to estimate these indicators. Consequently, nitrogen balance is used here as a proxy for the environmental impact generated by nitrogen use on the farms investigated.

Basically, there are two main approaches to assessing the nitrogen balance of a farm: the farm-gate approach vs. the soil-surface approach (Oenema et al., 2003; van Beeck et al., 2003; Hoang and

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[2] Nitrogen balance and nitrogen budget are used here synonymously.

Alauddin, 2010). These two approaches differ in terms of the spatial boundaries of the agricultural system investigated. Whereas a farm-gate nitrogen balance assesses the difference between the nitrogen flows entering and leaving the farm via the farm-gate, a soil-surface nitrogen balance quantifies the nitrogen flows entering the soil via the surface and leaving it via crop uptake (Oenema et al., 2003). The data required for estimating a nitrogen budget according to the farm-gate approach are more comprehensive and more difficult to assess accurately than those required for a nitrogen budget according to the soil-surface approach. For this reason, a soil-surface approach has been used in the present investigation.

The soil-surface nitrogen balance of the farms is estimated according to the approach developed by the OECD[3] (Parris, 1998; OECD, 2001; OECD and EUROSTAT, 2007). Nitrogen balance is defined as the difference between nitrogen input and output. Nitrogen input encompasses the following elements: fertilisers (inorganic fertilisers, livestock manure and any other organic fertilisers), biological nitrogen fixation, atmospheric deposition, and nitrogen contained in seeds and planting material (OECD and EUROSTAT, 2007). Nitrogen output comprises the nitrogen removed with the harvested crop (including fodder crop) or with the grazed fodder crop or grass (OECD and EUROSTAT, 2007). Basically, two kinds of soil-surface balances – the gross and net approach – can be distinguished, depending on whether emissions of environmentally harmful nitrogen compounds into the air are included in the balance (OECD and EUROSTAT, 2007). In the present paper, nitrogen losses from manure via ammonia volatilisation in farm buildings (livestock housing), during manure storage and during and after manure spreading are included in the balance, thereby implying the use of a gross-balance approach.

Each nitrogen input and output element is assessed on the basis of data collected specifically for this purpose on each farm. A detailed description of the approach used to estimate each separate element of the nitrogen balance can be found in Spiess (2010).

[3] Organisation for Economic Co-operation and Development

3. Analysis of the determinants of nitrogen surplus

3.1. Approach

The determinants of farm nitrogen surplus per ha UAA[4] are investigated using a three-equation regression model. Below, we set out the conceptual underpinning of the approach followed.

Conceptually, as shown in Equations 1 to 5, a high nitrogen surplus per hectare (Eqs. 1 to 3) can be the result either of high nitrogen intensity, defined as the nitrogen input per ha UAA (Eq. 4); of high inefficiency in nitrogen use, 'inefficiency' being defined here as the ratio between nitrogen surplus per ha and nitrogen input per ha (Eq. 5); or of both high nitrogen intensity and inefficiency. In order to better understand the causes of high nitrogen surpluses, we must identify not only the determinants of nitrogen surplus, but also those of its two components, nitrogen intensity and inefficiency. In the present study, we therefore estimate three regression models: one explaining the determinants of nitrogen surplus per ha UAA, the second investigating the determinants of nitrogen intensity per ha UAA, and the third examining the determinants of nitrogen inefficiency (in %).

$$N\_surplus = N\_input - N\_output \qquad (1)$$

$$N\_surplus = N\_input \times \frac{N\_Input - N\_output}{N\_Input} \qquad (2)$$

$$N\_surplus = N\_intensity \times N\_inefficiency \qquad (3)$$

$$\underline{with}: N\_intensity = N\_input \qquad (4)$$

$$N\_inefficiency = \frac{N\_input - N\_output}{N\_input} \qquad (5)$$

$$\begin{aligned} \underline{where}: N\_surplus &= \text{Nitrogen surplus in kg N per ha} \\ N\_input &= \text{Nitrogen input in kg N per ha} \\ N\_output &= \text{Nitrogen output in kg N per ha} \\ N\_intensity &= \text{Nitrogen intensity in kg N per ha} \\ N\_inefficiency &= \text{Nitrogen inefficiency in \%} \end{aligned}$$

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[4] Utilised Agricultural Area

3.2. Specification of the regression models

The regression models were specified on the basis of theoretical considerations supplemented by a literature review of the determinants of farm performance, whilst bearing in mind the availability of the variables in the AEI-FADN database. The potential determinants included in the regression models (see Table 1) can basically be classified into six groups: the farm's natural environment; its structural characteristics; its production system; its production orientation (farming activities); its degree of specialisation; and the socio-demographic characteristics of the farm manager.

<< Table 1 around here >>

The natural production conditions of the farms are represented by two dummy variables – hill region and mountain region – derived from the categorical variable 'agricultural production region of the farm', which encompasses three modalities: plain, hill and mountain region. The delimitation of the agricultural production regions of Switzerland is based on three groups of criteria: climatic conditions, especially the length of the vegetation period; accessibility in terms of transport; and topography (S.R. 912.1). The variable 'agricultural production region of the farm' is thus very well suited to the comprehensive representation of the natural production conditions of the farms.

Two variables related to the structural characteristics of the farm were incorporated into the model: farm size and farming form. Farm size is measured by the utilised agricultural area of the farm (in ha). Farming form consists of two dummy variables: full-time farm with secondary income, and part-time farm. The production form, represented by a dummy variable (conventional vs. organic farming), describes the farm's production system. Production orientation, i.e. the type of farming activities found on the farm, is represented by three variables measuring the proportion of output from arable crop, dairy farming and granivores (pigs and poultry) in the farm's agricultural output[5,6]. Production orientation could have also been represented by several dummy variables indicating the type of farm; however, due to the multiplicity of farm types and to the higher information content of continuous variables, we opted to use the farm output-proportion variables.

[5] Agricultural output without any direct payments, and without the farm output from forestry-related activities.

[6] We were unable to include the output-proportion variables related to all possible farm activities, as this would have led to multicollinearity problems. For this reason, we limited ourselves to the most important farm activities.

For the ‘nitrogen surplus’ and ‘nitrogen intensity’ regression models, we also included the squared term of the two regressors ‘proportion of output from dairy farming in farm’s agricultural output’ and ‘proportion of output from granivores in farm’s agricultural output’, owing to the nonlinearity of the relationship between the dependent and independent variable. Thus, for these two variables, the model specification is of the form $b_1x^2+b_2x$.

The degree of specialisation of the farm – measured by the Herfindahl index – was also meant to be included in the regression models. This index is calculated by summing up the squared term of the proportions of the different outputs in farm’s agricultural output. Given that this variable was by definition strongly correlated with the variables associated with production orientation, it had to be excluded from the regressor set.

Two variables related to the socio-demographic characteristics of the farm manager were included in the model: the age of the farm manager in years, and a dummy variable for his/her level of agricultural education.

In the regression model analysing the determinants of each of the two components of the nitrogen surplus, the other component was included in the model as a control variable. This was done because the two nitrogen surplus components – nitrogen intensity and nitrogen inefficiency – are correlated ($r=0.30$, $p<0.001$). Owing to this property, when analysing the effect of a variable x (e.g. the dummy variable ‘mountain region’) on one of the two components (e.g. nitrogen inefficiency, hereafter referred to as ‘y’), it is necessary to control for the other component (in the example: nitrogen intensity, hereafter referred to as ‘z’) – i.e. to ensure that the other component is kept constant[7]. This is accomplished by introducing the other component (z) as an independent variable in the regression model. If we do not control for the other component z in the regression model (i.e. if we do not introduce it as an independent variable), then the x variable would not only enter directly into the model, but might also enter indirectly into it as a variable correlated with z (see Figure 1). This would imply that we would not be measuring the direct effect, defined as the ceteris paribus effect of x on y (i.e. the effect of x on y when, inter alia, z is kept constant), but both the direct effect as well as the indirect effect over z (see Figure 1).

[7] The effect of a predictor ‘x’ on nitrogen inefficiency or nitrogen intensity may well depend on the degree of nitrogen intensity or inefficiency.

<< Figure 1 around here >>

3.3. Estimation procedure

The classic approach used to estimate a regression model is the OLS or Ordinary Least Squares approach. The three-equation system presented in Section 3.2 will not, however, be estimated via the OLS approach owing to (i) the presence of outliers and (ii) the presence of a contemporaneous correlation between the error terms across equations.

The classic OLS estimator of regression models is very sensitive to outliers. Essentially, there are two main strategies for dealing with outliers in a regression setting (Stevens, 1984; Rousseuw and Leroy, 1987). The first consists in dropping them from the dataset once they have been detected by means of outlier diagnostic tools such as studentised residuals or Cook's distance measure (Stevens, 1984; Rousseuw and Leroy, 1987). This first strategy, however, suffers from a lack of robustness, and might be unable to detect outliers, especially in a multivariate context (Rousseuw and Leroy, 1987). The second strategy is to use robust regression approaches which are relatively insensitive to outliers (Stevens, 1984; Rousseuw and Leroy, 1987). In the present study, we use iteratively reweighted least squares (IRLS), a robust regression technique implemented in the rreg estimation procedure of the Stata software Package (StataCorp, 2011; Hamilton, 1991). This robust regression approach consists in (i) performing the regression using OLS, (ii) attributing a weight to each observation according to the outlierness of its residual[8], and (iii) within an iterative procedure, regressing again, using the weights calculated in the previous regression iteration, until the maximum change in weights falls below a predefined level (Hamilton, 1991). The weights are derived from two weighting approaches – the Huber and biweight weightings, both of them defined as a function of the scaled residuals (Hamilton, 1991). The more extreme an outlier, the less heavily it is weighted when estimating the parameters of the model. Once the iterative procedure is completed, the final weight associated with each observation is used in the second step of the estimation procedure described below.

Because the error terms are correlated across equations (Breusch-Pagan test for independent equations, $p<0.001$), the three-equation model is estimated using the approach developed by Zellner (1962) for seemingly unrelated regressions (SUR). In point of fact, when the error terms

[8] The residual outlierness is assessed by means of the scaled residual, defined as the ratio between the residual and its absolute deviation from the median residual (Hamilton, 1991).

are contemporaneously correlated across equations, the SUR estimation approach proposed by Zellner (1962) leads to estimators that are “at least asymptotically more efficient than an equation-by-equation application of ordinary least squares (OLS)”. The two-stage FGLS (feasible generalised least squares) procedure is used here to estimate the SUR equation system. In a first step, each equation is estimated by OLS. The residuals obtained from the OLS estimate are then used to estimate an error variance-covariance matrix, which is then used in the second estimation step of the SUR procedure (Cameron and Trivedi, 2009: 163).

4. Results

4.1. Descriptive statistics for the nitrogen-use pattern of Swiss farms

Table 2 sets out a selection of descriptive statistics for the nitrogen balance of the farms investigated. The average nitrogen balance of the farms of the sample stands at 89 kg/ha, deriving from an average nitrogen intensity of 255 kg/ha and an average nitrogen inefficiency of 34%, viz. 34% of the nitrogen input is lost into the air, water and soil. The nitrogen balance varies substantially between farms, with a coefficient of variation of 0.58. The variability of nitrogen intensity and inefficiency is lower, with the coefficient of variation of these variables being equal to 0.36 and 0.31, respectively.

<< Table 2 around here >>

4.2. Determinants of nitrogen surplus and its components

The results of the estimation of the parameters of the regression models specified in Table 1 are provided in Table 3.

For all three regression models, we can reject the H0 hypothesis that all coefficients of the model are equal to 0, i.e. that none of the predictors is linearly associated with the predicted variable (F-Test of overall significance, $p<0.001$). The highest goodness-of-fit can be observed for the regression model explaining the nitrogen input (R^2=0.69). The goodness-of-fit is substantially lower for the model explaining the nitrogen balance (R^2=0.47), whilst the model explaining the nitrogen inefficiency has the lowest coefficient of determination (R^2=0.31). The results of the regressions are presented in detail below.

<< Table 3 around here >>

The natural environment of a farm is shown to influence its nitrogen-use pattern. Whereas hill farms do not significantly differ from plain farms with regard to their nitrogen surplus, mountain farms – despite significantly higher nitrogen inefficiency (-12%, $p<0.001$) – have a lower nitrogen balance (-23 kg N per ha, $p=0.003$) than plain farms. This is because mountain farms have a significantly lower nitrogen intensity (-109 kg N per ha, $p<0.001$). Even if farm size (UAA) has a positive effect on nitrogen inefficiency (+0.2% per additional ha UAA, $p<0.001$), it has a significant negative impact on nitrogen balance (-0.3 kg N per additional ha UAA, $p=0.058$) due to the negative impact of farm size on nitrogen intensity (-1.8 kg N per additional ha UAA, $p<0.001$). This negative impact outweighs the positive impact of farm size on nitrogen inefficiency. Farming form is also shown to influence nitrogen balance. Whereas full-time farms with secondary income sources do not differ significantly from full-time farms without secondary income sources in terms of nitrogen balance, part-time farms are characterised by a significantly lower nitrogen surplus (-16.5 kg N per ha, $p=0.007$) than their full-time counterparts. This stems from the significantly lower nitrogen intensity of part-time as compared to full-time farms (-41 kg N per ha, $p<0.001$), which is, however, partially offset by the formers' higher nitrogen inefficiency (+2.5%, $p=0.059$). Production system, represented by the variable 'production form', also turns out to affect the nitrogen balance. Organic farms have a significantly lower nitrogen surplus (-29.7 kg N/ha, $p<0.001$) than conventional farms, essentially owing to their significantly lower nitrogen intensity (-41.6 kg per ha, $p<0.001$). Production orientation, depicted by the output-proportion variables, is shown to be an important determinant of nitrogen balance and its components. An absolute increase of 1% in the proportion of farm agricultural output coming from arable crops leads ceteris paribus to a decrease in nitrogen balance of 0.4 kg/ha ($p=0.027$), owing to the fact that this 1% increase is associated with a lower nitrogen intensity (-0.9 kg N per ha, $p<0.001$). As regards the proportion of farm agricultural output deriving from dairying (referred to hereafter as 'proportion of dairying'), both linear and quadratic terms have a significant effect on the nitrogen balance ($p=0.003$ and $p=0.009$, respectively). The cumulative effect of the proportion of dairying on the nitrogen balance is a parabola of equation $0.664x-0.06x^2$. Its maximum of 18 kg N/ha is reached for a value of $x = 55\%$. The marginal effect of the proportion of dairying comes to $0.664-0.012x$, and is a decreasing function of x which is positive in the range 0 to 55% and then becomes negative. The proportion of dairying influences both components of nitrogen balance. Its cumulative and marginal effect on nitrogen intensity amount to $1.124x-0.006x^2$ and $1.124-0.012x$, respectively, while its effect on nitrogen inefficiency is linear and negative, and amounts to -0.06% inefficiency per additional per cent of dairying in the farm output. The proportion of granivores in the farm agricultural output (referred to hereafter as 'proportion of granivores') also has a significant impact on nitrogen balance. Both linear and quadratic terms of this predictor have a significant effect on the predicted variable ($p<0.001$ for both terms). The cumulative effect equals $1.909x-0.021x^2$, and reaches its maximum (43.8 kg N/ha) for a value of $x = 45\%$. The marginal effect is equal to $1.909-0.042x$. Looking at the components of the nitrogen balance, we discover that the proportion of granivores affects both nitrogen intensity and nitrogen inefficiency. The cumulative and marginal effects on nitrogen intensity stand at $2.314x-0.03x^2$ and $2.314-0.06x$, respectively. The marginal effect on nitrogen inefficiency is linear, and comes to 0.05%[9] inefficiency per additional per cent of granivores in the farm output. The socio-demographic characteristics of the farm manager are also shown to be important factors for explaining the variability of the nitrogen balance. Farm manager's age is shown to have a negative impact on nitrogen surplus ($p=0.005$). An additional year's age leads to a decrease in the nitrogen balance of 0.7 kg N/ha. This can be explained by the fact that nitrogen intensity significantly decreases with the age of the farm manager (-1.2 kg N/ha per additional year's age, $p<0.001$). Inefficiency remains unaffected by the age of the farm manager. The farm manager's education is shown to be an important factor in explaining farm nitrogen balance. Farms with managers of a higher agricultural education level[10] exhibit a significantly higher nitrogen balance (+9.3 kg N/ha, $p=0.056$) than those with managers of a lower agricultural education level. This is the result of the significantly higher nitrogen intensity of better-educated managers (+24.4 kg N/ha, $p<0.001$), which is nevertheless partially outweighed by a lower inefficiency (-1.8%, $p=0.102$).

5. Discussion and conclusions

We have shown that the nitrogen balance of the sample of farms investigated varies substantially between farms. This heterogeneity is attributable to both components of nitrogen balance, viz., nitrogen intensity and inefficiency. Using a three-equation model estimated via a robust SUR approach, we were able to pinpoint the determinants of nitrogen surplus and understand the mechanisms of action of the different factors investigated. Surprisingly, hill farms do not exhibit a lower nitrogen surplus than plain farms. Location in the mountain region was found to lead to a lower nitrogen surplus, owing to lower nitrogen intensity and despite higher nitrogen inefficiency.

[9] This value refers to an absolute percentage change and not to a relative one.
[10] i.e. above a completed apprenticeship

Farm size was shown to have a negative impact on nitrogen surplus, since larger farms – despite their slightly higher nitrogen inefficiency – were significantly less nitrogen-intensive than smaller ones. In spite of their higher nitrogen inefficiency, part-time farms were shown to have a significantly lower nitrogen surplus than full-time farms, owing to the lower nitrogen intensity of the former. Organic farming was associated with a lower nitrogen surplus than conventional farming, due to the substantially lower nitrogen intensity of the organic production form. Arable crops proved to be synonymous with a lower nitrogen surplus because of their lower nitrogen intensity compared to other agricultural activities. Both dairy farming and pig and poultry production were shown to be associated with higher nitrogen surpluses as a consequence of their higher nitrogen intensity. Interestingly, the effect was shown to be nonlinear, and reached its maximum for farms with a proportion of around 50% of these activities – indicating that these two farming activities are associated with higher nitrogen surpluses, especially where they are combined with other activities, i.e. in the case of mixed farming. In addition to the characteristics of the farm itself, the characteristics of the farm manager play an important role when explaining the determinants of nitrogen surplus. Farms whose managers are young and better educated exhibit a higher nitrogen surplus as a result of the higher nitrogen intensity of farms with this type of manager. It is worth mentioning here that although farms with better-educated managers did indeed exhibit higher nitrogen intensity, this was nevertheless coupled with lower nitrogen inefficiency, the latter of which, however, is not sufficient in degree to completely outweigh the former.

When interpreting the results, the sample-related limitations of the study should be taken into account. The first limitation lies in the fact that the sample was not drawn at random, with the associated consequences in terms of representativeness. The sample must be expected to be positively biased, i.e. to include farms that – in environmental terms – perform better than the average farm. In point of fact, because collecting the data represents a highly demanding task for the farm manager, participation in the monitoring network is on a voluntary basis. It is therefore highly likely that the farms participating in this environmental monitoring network are more sensitive to environmental issues than the average farm of the population. The second sample-related limitation lies in the fact that the sample does not cover the whole Swiss farming sector; in fact, a number of farm types are wholly missing from the sample. Last but not least, the fact that this study relies on cross-sectional data is a weakness of which we are aware. In the ideal case, panel data would be available, which would enable us to conduct a more robust analysis by controlling for unobserved individual heterogeneity. At the current stage of introduction of the

AEI-FADN, however, no panel data are yet available. Despite these sample-related weaknesses, the research carried out here represents a highly valuable initial attempt to better understand – at farm level – the determinants of nitrogen surplus in Swiss agriculture. To the best of our knowledge, the Netherlands is the only other European country with an equivalent system to the Swiss AEI-FADN[11].

In addition to these sample-related issues, when interpreting the results of this paper, it is important to bear in mind that it focuses on just one dimension of the environmental performance of a farm – i.e. the local dimension. The global environmental performance of a farm – defined as the ability of a farm to produce a maximum output per unit of environmental impact generated over the entire production chain up to the farm gate (Jan et al., 2012) – has not been taken into account.

This paper provides evidence that the nitrogen surplus of a farm is dependent on the farm's characteristics, and can therefore be controlled by agricultural policymakers. By increasing farm size (i.e. through scale effects) and promoting organic and part-time farming, major reductions in Swiss agriculture's nitrogen surplus could be achieved. For the three factors under consideration, the reduction in nitrogen surplus occurs through a reduction of nitrogen intensity. The finding that dairy as well as pig and poultry farming lead to a higher nitrogen surplus – especially when combined with other agricultural activities – is not a new one, as the problem of high groundwater nitrate concentrations is also found in regions with these types of farming. The high nitrogen surpluses found in dairy, pig and poultry farming would appear to stem primarily from an intensity problem. This implies that addressing nitrogen intensity is the key to sustainably reducing the nitrogen surpluses associated with this type of animal production. The fact that the hill region has neither a lower nitrogen surplus nor a lower nitrogen intensity than the plain region indicates that, in the hill region, nitrogen fertilisation may not be suited to the natural production conditions. In fact, owing to the shorter vegetation period of the hill region, we would expect a significantly lower nitrogen intensity, and hence a lower surplus, than in the plain region. The fact that the farms of younger and better-educated farm managers have higher nitrogen surpluses due to their higher nitrogen intensity is quite surprising: because of their more recent (in the case of young farmers) or more thorough education (in the case of more highly-qualified farmers), we would have expected younger and better-educated farmers to be more aware of environmental issues, and thus for their

[11] Other farm-level analyses of the nitrogen issue found in the literature rely for the most part on FADN data and estimate the nitrogen balances on the basis of accountancy data, with the associated consequences in terms of accuracy of the assessment.

farms to have a lower nitrogen surplus. The fact that this hypothesis is empirically rejected might indicate that not enough importance is being attached to environmental issues in the agricultural education programmes of future farm managers. Either the environmental awareness of these farm managers is insufficiently developed, or the practical implementation knowledge and tools associated with these environmental issues are missing. A rethinking of the education and training of future farm managers would therefore appear to be necessary in order to reduce nitrogen surplus. More generally, the fact that the goodness-of-fit of the model explaining nitrogen inefficiency is significantly lower than that of the model explaining nitrogen intensity indicates that it may be more challenging to reduce nitrogen surplus by reducing nitrogen inefficiency than by decreasing nitrogen intensity, as the former may be dependent on a multiplicity of factors that could be very difficult to control.

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[12] Systematische Rechtssammlung (Systematic Collection of Law)

7. Appendix

Table 1. Specification of the three regression models estimated

Category	Variable		Nitrogen Balance *[nbalance]* in kg N/ha	Nitrogen Intensity *[nintensity]* in kg N/ha	Nitrogen Inefficiency *[ninefficiency]* in %
	Independent Variable		**Dependent Variable**		
Natural environment of the farm	Production region	Hill region (0: no; 1: yes) ***[hill]***	x	x	x
		Mountain region (0: no; 1: yes) ***[mountain]***	x	x	x
Structural characteristics of the farm	Farm size: Utilised agricultural area (UAA) in hectares ***[uaa]***		x	x	x
	Farming form	Full-time farm with secondary income (0: no – 1: yes) ***[secondary]*** Part-time farm (0: no – 1: yes) ***[parttime]***	x	x	x
Production system	Production form ***[organic]*** 0: conventional farming 1: organic farming		x	x	x
Production orientation	Proportion of output from arable crops in farm's agricultural output* in % ***[arablecrop]***		x	x	x
	Proportion of output from dairy farming in farm's agricultural output* in % ***[dairying]***		x	x	x
	Squared term of the proportion of output from dairy farming in farm's agricultural output* in % ***[dairyingsqr]***		x	x	
	Proportion of output from granivores in farm's agricultural output* in % ***[graniv]***		x	x	x
	Squared term of the proportion of output from granivores in farm's agricultural output *in % ***[granivsqr]***		x	x	
Degree of specialisation	Herfindahl index		d.m.	d.m.	d.m.
Socio-demographic characteristics of the farm manager	Age in years ***[age]***		x	x	x
	Education ***[education]*** 0: <= completed apprenticeship 1: > completed apprenticeship		x	x	x
Nitrogen-use pattern	Nitrogen inefficiency (in %) ***[ninefficiency]***			x	
	Nitrogen intensity in kg N per ha ***[nintensity]***				x

Source: Own representation
Legend: 'x' means that the independent variable in question has been included in the regression model. 'd.m.' means that the independent variable has been dropped from the regression model for multicollinearity reasons.
* Agricultural output without any direct payments and without farm output from forestry-related activities.
The names in the square brackets are those assigned to each variable in the model.

Table 2. Soil-surface nitrogen balance of the farms investigated

	Nitrogen Balance (in kg N per ha)	Nitrogen Intensity (in kg N per ha)	Nitrogen Inefficiency (in %)
Arithmetic average	89	255	34
Standard Deviation	52	91	11
Coefficient of Variation	0.58	0.36	0.31
Median	81	254	35

Source: Own calculations (n=210 farms)

Table 3. Robust SUR estimates of the three-equation system

			Dependent Variables					
			Nitrogen Surplus (in kg N per ha)		**Nitrogen Intensity** (in kg N per ha)		**Nitrogen Inefficiency** (in %)	
	Name	**Unit**	Coefficient	P>|z|	Coefficient	P>|z|	Coefficient	P>|z|
Independent Variables	hill	0:no; 1:yes	-0.5	0.938	-8.6	0.277	1.1	0.419
	mountain	0:no; 1:yes	-22.8	0.003	-108.8	0.000	12.0	0.000
	uaa	in ha	-0.347	0.058	-1.754	0.000	0.189	0.000
	secondary	0:no; 1:yes	-8.0	0.192	-19.2	0.014	1.0	0.463
	parttime	0:no; 1:yes	-16.5	0.007	-41.0	0.000	2.5	0.059
	organic	0:no; 1:yes	-29.7	0.000	-41.6	0.000	0.4	0.822
	arablecrop	in %	-0.357	0.027	-0.936	0.000	0.056	0.123
	dairying	in %	0.664	0.003	1.124	0.000	-0.058	0.001
	dairyingsqr	in %	-0.006	0.009	-0.006	0.054		
	graniv	in %	1.909	0.000	2.314	0.000	0.049	0.083
	granivsqr	in %	-0.021	0.000	-0.030	0.000		
	age	in years	-0.73	0.005	-1.18	0.000	0.030	0.606
	education	0:<=apprenticeship 1:>apprenticeship	9.3	0.056	24.4	0.000	-1.8	0.102
	ninefficiency	in %			2.9	0.000		
	nintensity	in kg N per ha					0.08	0.000
	constant	in kg N per ha	123.7	0.000	254.6	0.000	6.4	0.091
	R^2		0.47		0.69		0.31	
	P>F		<0.001		<0.001		<0.001	

Source: Own calculations (n=210 farms)

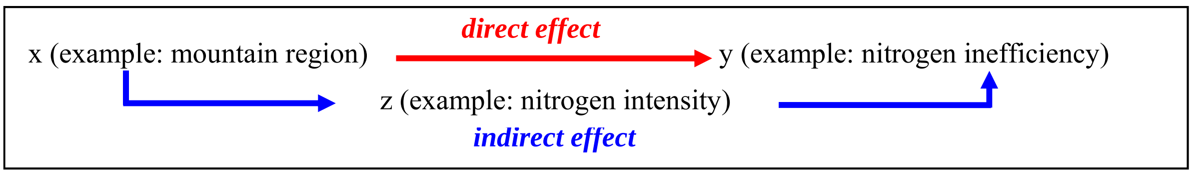

Figure 1: Direct and indirect effect of a predictor