Assessing the impact of RDP agri-environment measures on the use of nitrogen-based mineral fertilizers through spatial econometrics: The case study of Emilia-Romagna (Italy)

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~~Original Articles~~A~~Measuring~~ Assessing the impact of RDPs~~ ~~agri-environment measures on the use of nitrogen ~~based~~ -based mineral fertilizers through spatial econometrics ~~spatial econometric approach for assessing the impact of RDP agri-environmental measures on the use of itrogen-based mineral fertilizers: t~~~~nitrogen based mineral fertilizers: T~~The case study of Emilia-Romagna (Italy)

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Abstract

Agriculture is the main source of nitrogen loading (EEA, 2012) and is the sector with the largest residual emission reduction potential (~~Sutton et al., 2011~~~~Sutton et al., 2001~~Sutton et al., 2011). Moreover, surpluses of nitrogen are forecast to grow in the next decade (FAO, 2012). The objective of this study is to evaluate the determinants of the use of N-based mineral fertilizers in agriculture and the effectiveness of Agri-Environmental Schemes (AES) implemented in Emilia-Romagna, Italy, in preventing nitrate pollution.

The indicator N mineral fertilizer application rate in agriculture was first estimated at the municipality level for the years 2000 and 2010. Thereafter, we performed a Moran's statistics and a LISA (Local Indicators of Spatial Association; Anselin, 1995) analysis to test the data for local spatial autocorrelations. Finally, in order to provide a quantitative evaluation of the impact of the agri-environmental measures on the application rate of N fertilizers, we constructed an aspatial model (Ordinary Least Square model) and two spatial models (spatial lag and error models). All of the models are able to explain more than 70% of the change in the N mineral fertilizer application rate between the years 2000 and 2010 (the dependent variable).

The results indicate that the observed decrease in the application rate of N mineral fertilizers in the considered decade was positively influenced by both the uptake of specific AES and the location in Nitrate Vulnerable Zones (NVZ). Among the policy variables, the participation in AES is less important than the location in a NVZ for explaining the reduction in the N mineral fertilizer application rate in the municipalities of Emilia-Romagna. Other significant variables are farm size, population density and share of certified organic surface in the utili~~s~~zed agricultural area (UAA). The availability of finer scale data for the estimation of changes in nitrogen inputs would improve the robustness of the models.

Keywords: Spatial econometrics; Rural development plans; Agri-Environmental Schemes; Agricultural ~~N~~nitrogen; Nutrients pollution

1 Introduction

Nitrogen pollution-related damage in EU-27 countries varies between 70 and 320 billion Euro each year (Brink et al., 2011). Addressing the issue of preventing N release into water is important due to the wide range of consequences generated by its accumulation in the environment (Galloway et al., 2004).

Agriculture represents the largest single source of N (Granlund et al., 2005~~,~~; Sutton et al., 2011~~,~~; EEA, 2012) and contributes, on average, to about 40–60% of the total reactive N released in surface waters in Europe (Oenema et al., 2009). In Europe, 73% of the total agricultural N derives from N based mineral fertilizers, while the remaining 37% is derived from livestock manure (Leip et al., 2008). The application rate of mineral fertilizers and livestock manure is crop specific and varies across regions, according to local environmental conditions (soil type and climate) and socio-economic factors, such as location in remote areas, crop market prices and policy. In the last century, the overall increasing trend in the mineral fertilizer application rate has led to a decrease in crop yield variability, hence increasing farm income (Giovanopoulou et al., 2011). However, nutrients exceeding crop and forage needs can cause acidification of soils that in turn reduces soil fertility over the long term (Zalidis et al., 2002).

World demand for fertilizer nutrients is forecast to grow in the coming years at the average rate of 1.9 percent per annum from year 2012 to 2016 (FAO, 2012). This trend is expected even though the growth rate of the farm price of agricultural inputs is forecast to remain higher than in the last century (Heffer and Prud'homme, 2013). In fact, the price of N-based fertilizers almost doubled between year 2000 and 2010 (USDA, 2012). According to the projections of the International Fertilizers Industry Association, global demand for potash fertilizers will increase faster (+3.0% per annum) than the demand for N and phosphate fertilizers (+1.5% and +1.9% p.a., respectively). This trend was also anticipated by recent FAO projections (FAO, 2012), which indicated a comparable growth rate for the three main nutrients. As far as Western Europe is concerned (the location of the case study analyszed in this paper), the consumption of N is expected to marginally decline by 2016. On the contrary, the consumption of phosphate and potash will continue to grow at around 1% per annum until 2016. It is forecast that Western Europe's dependence on imports of N and phosphate will continue, as will its surplus of potash[1] (FAO, 2012).

The European Union's efforts to reduce nutrient over enrichment of waters were introduced in the early 1990s under the Nitrates Directive (1991), the aim of which is to protect water quality across Europe by preventing nitrates from agricultural sources from polluting ground and surface waters and by promoting the use of good farming practices. Moreover, the Common Agricultural Policy (CAP) contributes to the mitigation of nitrate pollution through the implementation of Agri-Environment Schemes (AES). AES were first introduced into EU agricultural policy in the late 1980s as an option to be applied by Member States. Since 1992, the integration of AES into national Rural Development Plans has become compulsory for Member States. The intervention strategy is based on direct support to farmers who voluntary apply agri-environment measures to reduce nitrate pollution, such as organic farming, low input farming, cover crops, efficient management of livestock waste and extensive farming. Moreover, the 2003 CAP reform introduced incentives for the achievement of basic environmental standards, which became compulsory to obtain direct payments, since their decoupling from productivity levels.

The EU requires that Member States evaluate RDPs. The need for “evidence for the effectiveness of policies and for evidence for what determines their success” (Sutherland, 2004) has also been stressed in the scientific literature, which aims to provide useful information for policy makers.

Due to the voluntary nature of AES, a great number of studies have analyszed the determinants of the uptake of specific agri-environmental measures and used the participation rate and the spatial distribution of uptakes to evaluate the success of a programme in terms of acceptance (Sattler and Nagel, 2010; Prager and Nagel, 2008; Hanley et al., 1999) and design (Prager et al., 2012; Peerlings and Polman, 2008; Flury et al., 2005).

Research seeking to establish the success of AES through the evaluation of environmental impacts has produced a smaller body of literature (Primdahl et al., 2003), mainly due to the lack of data (Yli-Viikari et al., 2007). Moreover, only 11% of the studies on AES have endeavoured to evaluate policy influence on the release of nutrients into the environment (~~sCMEF, 2006, ISTAT, 2010, OECD and EUROSTAT, 2007, Regione Emilia-Romagna, 2014, Sutton et al., 2001, Tamini, 2011 and~~ Uthes and Matzdorf, 2013~~Uthes et al., 2013~~). With regard to the concentration of nitrates in water (state indicator), direct measurements of environmental impacts are both costly (Kronvang et al., 2008) and time consuming, as the required information tends to be variable in both space and time. In fact, modelling studies performed with process-based biophysical models have concurred that the effect of changes in land use practices on the concentration of nutrients in water cannot be observed after only a few years due to the delay in the water response (Schmidt et al., 2008; Ekholm et al., 2007; Granlund et al., 2005; Marriott et al., 2005). Furthermore, this information is usually available as gridded data at different resolutions, whereas agricultural land use and farm structural data are often available at the administrative unit scale (Schmit et al., 2006), hence complicating the combination of the two categories of information in an integrated assessment. The lack of linearity, due to the lag between the pollution source and the impact measurements, and unequivocal causalities, due to multiple influences beyond policy, are the other two factors affecting the measurement of environmental policy impacts (Primdahl et al., 2003; Uthes et al., 2010).

The aim of this paper is to evaluate the role of the Agri-Environment Schemes of RDP 2007–2013 in the decrease in the N mineral fertilizer application rate per ha. The Italian region of Emilia-Romagna was selected as a case study as it represents the third most important region with respect to fertilizer sales (12% of the total fertilizer sales in Italy). N mineral fertilizer is the most commonly used nutrient source for crops and is the main agricultural N input in the study area, therefore its application rate was selected as the most accurate indicator for representing the agricultural impact on nutrient pollution. In particular, the change over time in the mineral fertilizer application rate represents a well-known pressure related indicator; it accounts for land management practices (Andreoli and Tellarini, 2000) and allows for the evaluation of both policy performance and outcomes (Oñate et al., 2000).

A two-step methodology is followed. First, the annual mineral N fertilizer application rate per hectare was calculated for the entire 341 NUTS 5 level area of the Emilia-Romagna region. The NUTS 5 scale (municipality units) is the smallest spatial level of agricultural data available for Italy; the use of this aggregate level of observation differentiates this paper from other studies modelling individual farms participating in AES and their neighbours. The indicator N mineral fertilizer application rate was calculated following the method proposed by the ~~OECD (2007)~~OECD (2007) for the estimation at the sub-national level of a related indicator, the Gross Nitrogen Balance, which includes N mineral fertilizer as one of the input terms of the N balance. Second, in order to provide a quantitative evaluation of the impact of AES on the decreasing N mineral fertilizer application rate in Emilia-Romagna, we applied a spatial analysis and a spatial regression model. The econometric model was computed using the change in the N mineral fertilizer application rate in the decade from year 2000 to 2010 as the dependent variables. Through this model we disentangle the role of specific Agri-Environment Measures from the effects associated with other policies and farm characteristics in the variation of the main agricultural N input. The proposed model accounts for both spatial and temporal lags.

The model was built on the hypothesis that the determinants of the decrease in the N mineral fertilizer application rate in Emilia-Region do not necessarily coincide with the determinants of participation in AES. The literature on the determinants of policy uptake is broad and various studies have analyszed the links with several factors (farm structural aspects, farmer characteristics, business and situational factors), reaching the conclusion that all of them may indeed interact in the participation process. However, the scientific community has not reached a common understanding on the extent and the quality of these relations (De Francesco et al., 2008; Wynn et al., 2001; Beedell and Rehman, 2000). Furthermore, the spatial component of the analysis was assumed to be relevant, as it allows for better insight into the relevance of spill over effects and the existence of local factors that are likely to affect the reduction in the fertilization rate. These factors have been identified by the scientific literature in the imitation processes and the knowledge transfers that take place between neighbouring farmers. The information flows, including both technical innovations and attitudinal orientations, increase with the coverage and organiszational level of advisory services (Birner et al., 2006). ~~Tamini et al. (2011)~~Tamini (2011) have demonstrated that these factors are particularly relevant in the adoption of more environmental friendly practices, hence leading to environmental spill over.

The paper is structured as follows: the next section describes the econometric model, followed by the case study. The variables used are then presented, followed by the results and the discussion.

2 Theory and methods

As stated above, mineral fertilizers (inorganic N) and livestock manure (organic N) are the main N inputs in agriculture. The rationale for modelling the observed use of N can be derived from economic theory by assuming that farmers use quantities of organic and inorganic inputs that are optimal from an economic point of view, with respect to exogenous factors, such as structural and policy variables. The “input use problem” can be simplified as follows:

$$\pi = \pi(N, P, Pol, x) \quad (1)$$

~~Where π~~where π is the profit function ~~(1)~~(1), depending on: the fertilization rate *N*, the vector of prices *P* (including fertilizer price), the implemented policy (*Pol*) and the structural aspects of the farms (*x*). The optimal fertilization rate (N^*) corresponds to the maximum profit π^* obtainable, and is therefore the fertilization rate actually applied by the farmers. N^* depends not only on prices and policy factors, but also on physical and agronomic factors such as soil, water, nutrient content, land slope (linked to rainfall infiltration capacity) and local climate.[2] These factors are mostly linked to the geographical location of the farm and are captured in Eq. (1) through the structural aspects of the farm. The policy, market and structural aspects of the farm affect the optimal profit (and N^*) through the production function of the farm, which represents the (implicit) technology adopted.[3]

Among the four categories of variables affecting the profit function ~~(1)~~(1), the indicator measuring N mineral fertilizer application rate can be used as a proxy of *N*, and as the variable to be explained through the construction of the regression models applied in this study. The remaining variables correspond to the categories of explanatory variables used in the models, since they are all likely to influence the optimal fertilization rate adopted by the farmers according to the motivations listed above. Among those, this study focuses on policy-related variables and, in particular, on agri-environment actions that may directly influence the application of N mineral fertilizer.

Measure 214 (agri-environment payment) is by far the most important measure of the Agri-Environmental Schemes of RDP 2007–2013. In Emilia-Romagna, 69% of the AES budget is assigned to this measure, under which 13% of the regional UAA was enrolled in the 2007–2013 RDPs (Mazzotti, 2013). Agri-environment payments are provided for in Art. 39 of EU Regulation No. 1698/2005, which states that agri-environment payments shall be granted, on a voluntary basis, to farmers who make agri-environmental commitments that go beyond the relevant mandatory environmental standards. Such commitments are undertaken as a general rule for a period of between five and seven years. The payments are granted annually and cover additional costs and income foregone resulting from the commitment made.

Of the actions (sub-measures) included in measure 214, we selected the following as those potentially affecting the mineral N fertilizer application rate: 214/1 (integrated farming); 214/2 (organic farming: limits the use of N-based fertilizers); 214/8 (extensive meadows: conversion of intensive crops into pasture, fodder crops and grasslands); 214/9 (protection of natural, semi-natural and agricultural landscapes: limits the extent of intensive farming); 214/10 (set aside of arable land for environmental purposes: reduces the extent of intensive farming). These sub-measures are described in detail in the next section. The amount of land enrolled under these sub-measures was used as explanatory variables in the model.

We propose an econometric model that includes policy and structural variables, together with farmer characteristics. Prices have not been included as determinants in the model because input prices, such as mineral fertilizers, can be considered homogeneous in the study area. Fertilizer prices play an important role in the choice of the optimal application rate and have significantly increased since the introduction of the 2007–2013 RDPs. However, as their variation throughout the study area is negligible, they would not add information to the model. Output prices are more difficult to assess and may vary across the region according to several factors (Schmidtener et al., 2012), such as the distance from a central market, farm specialization and size and product quality. The spatial dimension of the model can capture these factors. The formulation of the model built for the analysis is derived from the work of Anselin (1988) and Le Sage (1999):

$$y = \rho W y + X\beta + \lambda W u + \varepsilon \quad (2)$$

where *y* is the dependent variable, *W* is the spatial weight matrix, *X* are the explanatory variables; β are the regression coefficients, λ is the spatial correlation coefficient, ρ is the spatial lag coefficient, *u* are the spatially correlated residuals, ε are the normally distributed errors, then Wy represents the average *y* value of the neighbouring observations and λ reflects the spatial correlation of the residuals *u*.

The spatial weight matrix ~~*W*~~*W* provides the structure of the spatial relationship among observations. We computed three spatial weight matrices, hereinafter referred to as queen 1, queen 2 and queen 3, following the queen contiguity criteria: polygons (municipalities) are neighbours (adjacent) if they share a common border and/or vertex (Cliff and Ord, 1973). The three matrices are respectively characteriszed by an increasing level of contiguity: in the first order (queen 1) the neighbours of a municipality are only the adjoining ones. In the following orders of contiguity, the municipality adjoining the neighbours identified in the previous order of contiguity are also included as neighbours. Thus, in the third order of contiguity (queen 3), a very large portion of the total land area is included as neighbours, due to the fact that municipality sizes are homogeneous and the shape of the region resembles that of a regular polygon.

A significant ~~ρ~~ρ (spatial lag coefficient, Eq. (2)) indicates that one or more of the explanatory variables correlated with the spatially lagged dependent variable ~~Wy~~Wy are omitted. Therefore, spatial dependency occurs as a result of agglomeration effects (Schmidtener et al., 2012). A significant ~~λ~~λ (spatial error coefficient) indicates spatial error dependence due to unobservable features or omitted variables associated with location (Patton and McErlean, 2003).

If λ ~~$\approx$~~ $\approx$ 0, it is assumed that all of the relevant spatially correlated exogenous variables are included in the model and the general model ~~(2)~~(2) is reduced to:

$$y = \rho Wy + X\beta + e \tag{3}$$

which is referred to as a spatial lag model ~~(3).If $\rho\approx$~~(3).

If ρ $\approx$ 0, spatial dependence is negligible and the general model (Eq. (2)) is reduced to:

$$y = X\beta + (I - \lambda W)^{-1}\varepsilon \tag{4}$$

which is referred to as a spatial error model (4), where *I* is the identity matrix.

If both coefficients (~~λ, ρ~~λ, ρ) equal zero, spatial dependence is negligible and Eq. (2) coincides with the common regression model:

$$y = X\beta + e \tag{5}$$

Eq. (5) describes the aspatial model used in this study.

The occurrence of a statistically significant spatial pattern is analy~~s~~zed through Moran's statistics. The Moran's ~~*I index (6)*~~ *I* index (6) measures the spatial autocorrelation at the scale of the entire study area (Moran, 1950) and is calculated as:

$$I = \frac{e' We}{e' e} \tag{6}$$

with

$$e = \frac{y - y_{av}}{sd(y)} \tag{7}$$

where y_{av} is the mean value of the dependent variable ~~y~~y.

We also performed a LISA (Local Indicators of Spatial Association; Anselin, 1995) analysis in order to investigate the local spatial autocorrelation, which could show local clustering in the data. The analysis consists of the computation of the Local Moran's ~~*I (8)*~~ *I* (8), which only includes observations from areas (municipalities) adjacent to location *i* (~~*i*, *Anselin; 1995*~~*i*, Anselin, 1995):

$$I_i = e_i \sum_j W_{ij} e_j \tag{8}$$

where w_{ij} are the corresponding elements of the spatial weight matrix ~~W~~W and *e* is defined by Eq. (7), but only observations from regions neighbouring the region *i* are included.

The LISA analysis leads to the identification of local patterns of spatial autocorrelation (clustering) for the independent variable (N mineral fertilizer application rate change between year 2010 and 2000). The subsequent steps of the LISA analysis consist in the testing of the statistical significance of the clusters and in the construction of cluster maps. Both steps are performed by way of the software GEODA (Anselin, 2003), which also tests the significance of clusters using a randomization method (the threshold level for significance is set at 0.05).

Significant clusters may correspond to different categories of local spatial associations: High–high autocorrelations (“hot spot clusters”) indicate that municipalities with high values of the variable have neighbouring municipalities that also have high values of the variable; in low–low correlations (“cold spot clusters”) low values are surrounded by low values; in high–low correlations, high values are surrounded by low values; and finally, in low–high correlations, low values are surrounded by high values.

Finally, the explanatory variables were tested through the Variance Inflation Factor (VIF) in order to reduce the risk of multicollinearity in the model. As a conservative measure, only variables with VIF lower than 5 were kept in the model.

3 Case study, data and variables

The cropping pattern in Emilia-Romagna is dominated by arable production (about 75% of the agricultural land), while fruit trees (orchards, vineyards and olive groves) and grasslands (including permanent grazing) constitute about 15% and 10% of the Utilized Agricultural Area, respectively. Emilia-Romagna is the largest fruit-producing region in Italy. Fruit production is concentrated in the eastern side of the region, including the Ferrara, Ravenna and Forlì-Cesena provinces ~~(see the geographical map of the region in Appendix IIs)~~. Together with the dairy livestock production district, located on the other side of the region (provinces of Parma and Reggio-Emilia), the regional fruit district is characterized by the presence of skilled producer associations managing numerous agencies located throughout the region (Geie Agrosynergie, 2008). The cropping pattern did not change significantly between year 2000 and 2010. However, it is worth noting that the share of areas growing arable crops as a total of UAA has increased by 4% over the period of the study, whereas areas dedicated to grasslands have decreased by 1% over the same time period.

The dependent variable, the change in the N mineral fertilizer application rate over the course of the decade ranging from year 2000 to 2010, was identified by XX~~(name deleted to maintain the integrity of the review process)~~ as the source of nutrients most affected by the regional AES (with respect to the other major sources: livestock manure, and organic components of the GNB).

In this study, all of the variables were computed at the municipality level for all of the 341 municipalities in the Emilia-Romagna region and the spatial weight matrices were, therefore, geo-coded at the municipality scale.

The indicator was calculated for each municipality in Emilia-Romagna, which corresponds in Italy to NUTS 5 level, for both years (2000 and 2010). The ~~ISTAT~~ISTAT (National Statistics Institute) census was used as the data source for the cropping pattern extension.[4]~~.~~ The aggregation level is the municipality scale, NUTS 5, since the information is published by ISTAT in an aggregated form due to privacy issues. The dependent variable was obtained by subtracting the mineral N fertilizer value per hectare in year 2000 from the indicator value in year 2010 in the same municipality and given as kg per ha of UAA.

According to the ~~OECD (2007)~~OECD (2007) method, the amount (in kg) of N mineral fertilizers applied yearly in each municipality is estimated by multiplying crop specific application rates (in kg/ha) related to 8 cropping pattern elements by their area as registered in the ISTAT census. The crop categories considered in this study are the most common in the case study, representing more than the 88% of the UAA: cereals (other than wheat), wheat, vegetables, fruit, vineyards, olive groves, fodder crops, and grassland. In this study, ~~ad hoc~~ad hoc N fertilizer application rates were identified for each of the above-mentioned crop categories by integrating national mean values (EEA, 2005) with local data available from the technical literature (~~Emilia-Romagna, 2011~~Emilia-Romagna, 2011), which resulted in a list of crop specific N mineral fertilizer application rates that was used, in turn, for calculating the indicator (Table 1).

Table 1 N mineral fertilizer application rates in kg/ha for the eight crop categories considered in this study.

Crop	N mineral fertiliser application rate (~~K~~kg/ha)
Wheat	120
Cereals (other than wheat)	154
Vegetables	150
Fodder crops	32
Vineyard	41
Olive groves	98
Orchards	98
Grassland and permanent pasture	55

Finally, the amount of N mineral fertilizers applied yearly in each municipality, calculated by way of the method described above, is multiplied by an “adjustment factor” based on the amount of N mineral fertilizers actually sold (~~OECD, 2007~~OECD, 2007). This factor corresponds to the ratio between the amount of N mineral fertilizers applied yearly at the regional level and the amount actually sold.[5]~~.~~ Based on the available dataset, the adjustment factor was calculated at the province level, which corresponds to the NUTS 3 level in Italy. The same adjustment factor was applied only in the municipalities located in that province. Following this method, the crop specific application rates are kept constant in the two reference years, but the N mineral fertilizer input changes according to the variations in N mineral fertilizer sales across NUTS 3 units. The change in the N mineral fertilizer application rate during the decade 2000–2010 is provided in the map in Fig. 1, representing the value assumed by the dependent variable in each of the 341 municipalities in Emilia-Romagna. In the region, the average change in the N mineral fertilizer application rate (mean of 341 municipalities) in the considered time period is −23 kg per ha of UAA (Table 2). This reduction was expected as the price of N-based fertilizers almost doubled between year 2000 and 2010. This figure is difficult to compare with other sources in order to obtain validation. The preliminary results of the regional RDP valuation, indicates a reduction of 32 kg/ha of N based fertilizers in the land included under measure 214 (Mazzotti, 2013). These results correspond to a 42% decrease in the N fertilizer application rate in the enrolled land, and to an average decrease of 5% at the regional level, while our results correspond to an average 30% reduction in the use of N mineral fertilizers in Emilia-Romagna. However these results are not comparable, as the RDP estimate uses a counterfactual analysis in the same year, by comparing farms under measure 214 with similar farms that are not, while our study estimates a change in annual N balance over time. In addition, the temporal frame is different as the indicator calculated in this study represents a change between year 2000 and year 2010, whereas the RDP valuation focuses on the period 2007~~-~~–2013. As for the spatial distribution, the latest regional RDP annual valuation report (Regione Emilia-Romagna, 2013) indicates that N mineral fertilizer application rates decrease more in the mountains and hills (3~~9 kg/ha equal to 26,9% and 5,4 kg/ha equal to 20,~~.9 kg/ha equal to 26.9% and 5.4 kg/ha equal to 20.4%, respectively) than in the plain areas (5~~2 kg/ha equal to 5,5%)~~.2 kg/ha equal to 5.5%).[6]~~.~~ These values refer only to year 2013 and do not provide any indication of changes over the long term, which also limits any possible comparison.

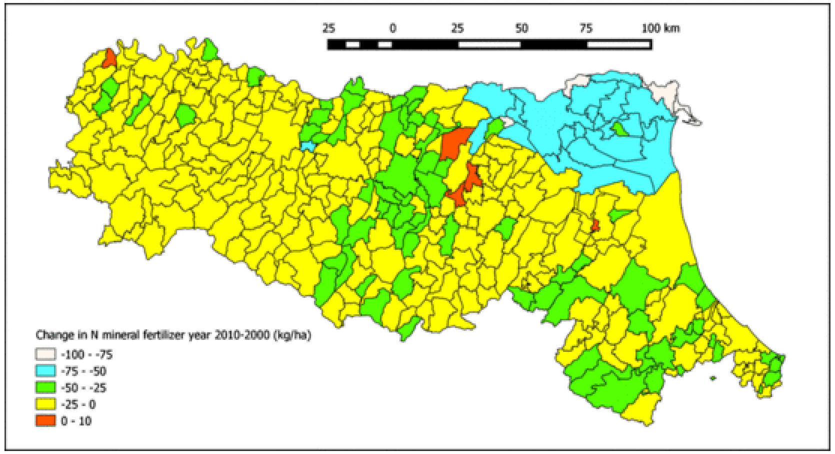

Fig. 1 Map displaying the change in the N mineral fertilizer application rate (kg per hectare of UAA) during the decade 2000~~-~~–2010 (values in year 2010 ~~-~~– values in year 2000). Each polygon corresponds to a municipality and all of the 341 municipalities of the Emilia-Romagna region are included in the map.

Table 2 Descriptive statistics: change in N mineral fertilizer application rate (dependent variable of the econometric model), change in N from livestock manure usage, and change in GNB. All of the indicators are given as kg N per hectare of UAA and are calculated as the difference between observed values in year 2010 and year 2000.

I~~NDICATORmeandev stminm~~ndicator	Mean	Dev st	Min	Max
N mineral fertilizers (dependent variable)	~~-2315.7-~~–23	15.7	–92	9
Gross nitrogen balance	~~-3675.5-~~–36	75.5	–319	999
N deriving from livestock manure	~~-770.9-~~–7	70.9	–256	1010

When compared to the change in the GNB (Fig. 2) and in livestock manure production (organic N), it is noted that these indicators also show a reduction in the considered time period, but their average decrease is characteri~~s~~zed by higher standard deviations, as indicated by the descriptive statistics in Table 2. Both the application rate of N mineral fertilizers and the GNB in years 2000 and 2010 are displayed, respectively, in the maps in Figs. 4 and 5 in Appendix I. Finally, the reduction in the production of organic N is significantly lower with respect to the decrease shown by the other indicators (Table 2).

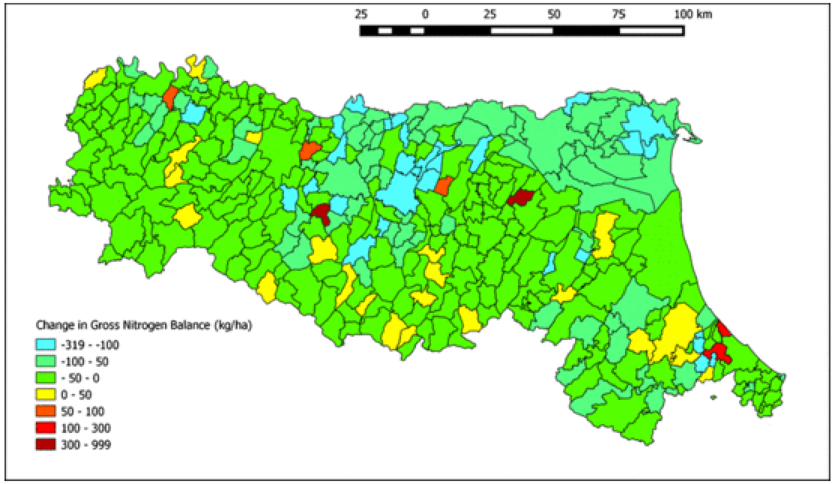

Fig. 2 Map displaying the change in the GNB (kg per hectare of UAA) during the decade 2000~~-~~–2010 (values in year 2010 ~~-~~– values in year 2000). Each polygon corresponds to a municipality and all of the 341 municipalities in the Emilia-Romagna region are included in the map.

The highest reduction in the N mineral fertilizer application rate was recorded in the Ferrara (~~-~~–66 kg/ha) and Forlì-Cesena (~~-~~–33 kg/ha) provinces, located in the easternmost side of the region (see the geographical map of Emilia-Romagna in Appendix II). The remaining provinces show a quite homogeneous reduction in their inorganic N application rates.

The explanatory variables initially included in the model can be divided into three main groups: farmer characteristics, structural and policy variables (Table 3).

Table 3 Descriptive statistics of the explanatory variables included in the econometric model.

Sub-measure	Land enrolled in ha (% of the total land enrolled under measure 214)	Expected reduction of N mineral fertil~~ersPreferential~~ ~~L~~izers	Preferential location	Minimum years of commitment	New and old enroll~~e~~ment	Actual location
214/1 (integrated farming: it restrains the application rate of N fertilizers);	52~~-000 ha35%30%o~~,000 ha 35%	30%	Only in preferential areas, only in farms larger than 50 ha	5 years	~~new enrolle~~New enrollment encouraged through higher payments than in land already enrolled in RDPs 2000~~-2006g~~–2006	Greater uptake in areas characteri~~s~~zed by a large share of fruit production (eastern part of the region)
214/2 (organic farming: it restrains the use of nitrogen based fertilizers);	45~~-~~,000 ha, 30%	According to the law of organic production	~~o~~Only in farms larger than 50 ha	5 years	~~new enrolle~~New enrollment and maintenance are both allowed at equal conditions	~~c~~Concentrated in hill-mountain areas (extensive crops), with the exception of the Ferrara Province, which is a flat area dedicated to arable crops and fruit production
214/8 (extensive meadows: it promotes conversion of intensive crops into pasture, fodder crops and grasslands, the abolition of mineral fertilizers and the reduction of livestock density);	13~~-364 ha, 9%100%arable land (new enrolle~~,364 ha, 9%	100%	Arable land (new enrollment) and grassland (maintenance)	5 years	~~new enrollement allowed for arable land, old enrolle~~New enrollment allowed for arable land, old enrollment can be renewed with almost full payments ~~n~~No overlaps with other sub-measures allowed	~~g~~Greater in the hill and mountain areas and in the plain area of the Parma and Reggio~~-~~-Emilia provinces
214/9 (protection of natural, semi-natural and agricultural landscape: it restrains the extension of intensive cultivation);	175 ha, 0.1%	5%	~~p~~Plain and areas unrolled under action 2 in the hills	10 years	~~only new enrollements allowedm~~Only new enrollments allowed	Mainly concentrated in the plain area (northeastern side of the region)

214/10 (set aside of arable crops for environmental purposes: it reduces the extension of intensive farming).	180 ha, 0.1%	100% in the set aside	~~p~~Plain and preferential areas in the hills	20 years	~~only new enrolle~~Only new enrollments allowed and only in arable land, payments are significantly higher than for other sub-measures	~~m~~Mainly concentrated in the plain area (northeastern side of the region)

The farmer characteristics are from the agricultural census of year 2000, before the beginning of the last RDP and include information on age, education, and the ratio of owners running individual companies over the total number of farms.

With regard to the structural variables, some are related to the condition of the farms prior to the implementation of the last RDP: percentage of farms smaller than 5 ha, share of certified organic land, percentage of mid-sized farms (between 5 and 30 ha), population density and altitude (Table 3).

The remaining structural variables are given as the difference between year 2010 and 2000 for the factors potentially affecting the change in the use of N mineral fertilizers, such as the average size of farms, and the ratio of UAA over the Total Agricultural Areas (TAA). Negative values of these variables indicate a decrease from 2000 to 2010 and vice versa in the case of positive values. The percentage of UAA on the regional total extension decreased from 50% in year 2000 to 47% in 2010. In the meantime, the number of farms decreased by 33%, while the average farm size increased from 11 ~~ha~~ to 22 ha.

The farmer characteristics were obtained from the agricultural census for the year 2000 (ISTAT, 2001), hence prior to the beginning of the last RDP, and include information on age, education, and the ratio of owners running individual companies over the total number of farms.

Policy variables are related to the uptake of AES, the occurrence of a NVZ and the location in Less Favoured Areas (LFA). The regional government provided information on the uptake of measure 214 for each municipality. The data refer to the whole measure 214 and to sub-measures n.~~1,2,8,~~ 1, 2, 8, 9, and 10 in terms of share of enrolled area on the total UAA of the municipality. The uptake refers to the cumulated frequency of years 2007~~-~~–2008. The geographical distribution of AES uptake in the Emilia-Romagna region, the amount of land enrolled, the length of commitment (in years) and other details about each sub-measure are provided in Table 4.

Table 4 Information on AES sub-measures included in the model as explanatory variables.

Code	Description	Mean	Standard deviation
Policy variables			
~~214-1 EXTENSION~~214-1 extension/UAA	Percentage of enrolled agricultural surface (ha) under integrated production on total UAA (year 2008)	1.02	2.54
214-2 ~~EXTENSION~~extension/UAA	Percentage of enrolled agricultural surface (ha) under organic production on total UAA (year 2008)	4.84	7.03
214-8 ~~EXTENSION~~extension/UAA	Percentage of enrolled agricultural surface under extensive meadows (ha) under on total UAA (year 2008)	2.34	6.46
214-9 ~~EXTENSION~~extension/UAA	Percentage of enrolled agricultural surface (ha) under protection of natural landscape on total UAA (year 2008)	0.24	0.38
214-10 ~~EXTENSION~~extension/UAA	Percentage of enrolled agricultural surface (ha) under environmental set-aside on total UAA (year 2008)	0.33	0.95
Y NVZ ~~MUNICIPALITIES~~municipalities	1 if the municipality belongs to NVZs, 0 otherwise	~~–Y LFA MUNICIPALITIES~~–	–
Y LFA municipalities	1 if the municipality belongs to LFAs, 0 otherwise	~~–Structural variables~~–	–
Structural variables			
D UAA/TAA	Difference between UAA (ha)/TAA (ha) in year 2010 and UAA (ha)/(ha) TAA in year 2000	0.004	0.091
D ~~AVERAGE FARM SIZE~~average farm size	Difference between average farm size in year 2010 (ha) and average farm size in year (ha) 2000	11.17	14.32
F~~ARM <~~arm <5	Percentage of farms with size lower than 5 ha in year 2000 on total number of farms	5	39
F~~ARM BETWEEN~~arm between 5-30	Percentage of farms with size in the range 5-30 ha in year 2000 on total number of farms	7	13
L~~IVESTOCK UNIT~~ivestock unit/UAA	Number of LSU/UAA (ha) in year 2000	1.67	2.94

I~~NDIPENDENT COMPANIES/TOT COMPANIES~~ndependent companies/tot companies	Percentage of farms managed as independent companies on total number of farms (year 2000)	91	9
N ~~MINERAL FERTILIZER~~mineral fertilizer/UAA (2000)	Nitrogen base mineral fertilizers distributed (kg)/UAA (ha), all referred to year 2000	77.64	25.08
C~~ERTIFIED ORGANIC LAND~~ertified organic land	Certified organic agricultural land (ha)/UAA (ha) in year 2000	0.07	0.23
A~~LTITUDE~~ltitude	Altitude (m)	211.29	259.26
P~~OPULATION DENSITY~~opulation density	Inhabitants/kmq in year 2000	217.83	317.53
Population's characteristics			
~~AGE BETWEEN 40~~ Age between 40 and 54	Percentage of farmers with age between 40 and 55 years (year 2000) on total farmers	22	5
A~~GE~~ge > 55	Percentage of farmers older than 55 years (year 2000) on total farmers	60	9
H~~IGH SCHOOL DIPLOMA~~igh school diploma	Percentage of farmers with high school diploma (year 2000)	4	3
U~~NIVERSITY DEGREE~~niversity degree	Percentage of farmers with high university degree (year 2000)	21	18

The regional budget for measure 214 exceeded the application requirements; therefore all of the eligible applications for measure 214 were funded by the RDP 2007~~-~~–2013. For all of the sub-measures, farmers are the direct beneficiaries of the payments.

With regard to the other policy variables, 29.9% of regional land belongs to NVZs, which are located along the plain-hill boundary across the entire region and in the province of Ferrara (the whole province was included in the NVZs in 2006, see Appendix II). The establishment of action programmes to be implemented by farmers on a compulsory basis in NVZs was implemented in 2007 and overlaps with the last RDP intervention.

4 Model results and discussion

The first step of the analysis was to determine whether spatial autocorrelation of the dependent variable in the municipalities exists. The resulting values of the global Moran's ~~I~~I index suggest positive spatial autocorrelation for the change in Inorganic N in the period 2010~~-~~–2000 (Table 2). In all of the three spatial weight hypotheses, the global Moran's ~~I~~I value for the change in the usage of N mineral fertilizer is greater than zero, hence demonstrating that there is a significant spatial association of values observed at the municipality level. By increasing the order of queen contiguity, the autocorrelation is reduced from 0.66 (queen 1) to 0.24 (queen 3).

On the contrary, the change in livestock manure production shows a Moran's ~~I~~I close to zero at all levels of contiguity, indicating that there is no evidence of spatial autocorrelation (Table 5).

Table 5 Global Moran's ~~I~~I of the change in the N mineral fertilizer application rate (dependent variable of the econometric model) and of the change in N from livestock manure usage between years 2010 and 2000, calculated using three spatial weight matrices (queen 1, queen 2 and queen 3). Both indicators are given as kg N per hectare of UAA.

I~~NDICATORSPATIAL WEIGHT MATRIXqueen 1queen 2q~~ndicator	Spatial weight matrix		
	Queen 1	Queen 2	Queen 3
N mineral fertilizers (dependent variable)	0.656	0.497	0.238
N deriving from livestock manure	~~-0.004~~ –0.004	–0.003	0.013

The LISA analysis allows for the identification of local patterns of spatial associations (clustering) for the variable N mineral fertilizer change 2010~~-~~–2000. LISA cluster maps are provided in Fig. 3. The red colours represent a hot spot cluster (high~~-~~–high associations), whilst the blue indicates the cold spot cluster (low~~-~~–low associations). The pink areas represent high~~-~~–low correlations and the sky-blue colour depicts the low~~-~~–high correlations. The white municipalities correspond to association clusters that are not spatially significant. In Fig. 3A, describing the LISA results under the most precautionary hypothesis of contiguity level, the clustering of similar low values (cold spot, in blue) corresponds to almost the entire province of Ferrara. As stated before, the greatest reduction in the N fertilizer application rate was recorded in the Ferrara province: ~~-~~–34% from year 2000 to 2010 (see also Fig. 1 for comparison). Hot spots of this variable are located in relatively smaller areas in the Bologna, Parma and Piacenza provinces (Fig. 3A). The occurrence of high~~-~~–high correlations indicates the clustering of similar high values of the indicator, which correspond to areas where N fertilizer application rates increase homogeneously across neighbouring municipalities, even though the average reduction at the province level is aligned with the surrounding provinces. When compared with the actual values of the dependent variables, displayed for each municipality in Fig. 1, it is possible to observe that the hot spots include the municipalities with increased N mineral fertilizer application rates (in red) and with stable application rates (in yellow).

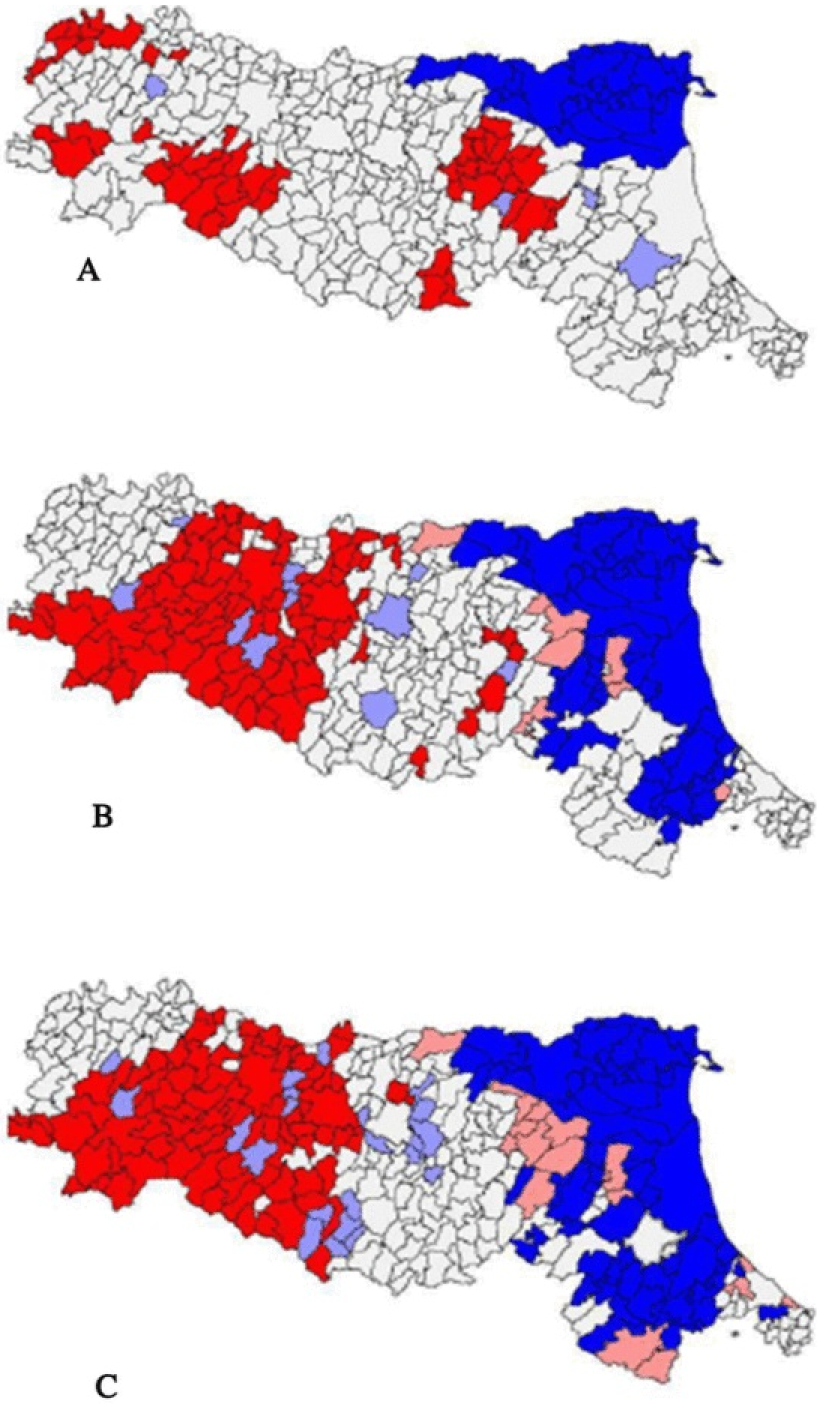
A
B
C

Fig. 3 LISA of the dependent variable: change in N mineral fertilizer per hectare. The analysis is conducted at the municipality level and under the hypothesis of three increasing levels of contiguity: (A) queen 1, (B) queen 2, queen 3 (C).

When considering the hypothesis of higher levels of contiguity (queen 3, Fig. 3C), the LISA results identify two main clusters surrounded by outliers, which correspond to the two main production districts. The hot spot is, in fact, located in the western side of the region and coincides with the provinces of Parma and Reggio-Emilia, where the dairy livestock district is more developed thanks to efficient producer organizations (e.g. Consorzio Produttori Parmigiano-Reggiano[7]). The cold spots correspond to the eastern side of the region, and in particular to those provinces already mentioned as being more speciali~~s~~zed in fruit (orchards) and vegetable production, where producer organizations have a branch-like coverage (see ~~section 3~~Section 3 for more details and the geographical map in App~~.~~endix II).

Based on the results of the spatial analysis, the econometric model explaining the variation in the use of inorganic N in the considered decade was constructed in both aspatial (Eq. (5)) and spatial forms (Eqs. (3) and (4)). Both the spatial lag and spatial error models are constructed under the hypothesis of the first level of contiguity (W = queen 1).

The results of all three of the models (aspatial, spatial lag and spatial error) are provided in Table 6, which shows the beta coefficients related to the explanatory variables for each of the models (asterisks indicating statistically significant variables). The ~~*R*~~*R*-squared is 0.43 in the aspatial model and increases up to 0.7 and 0.74 in the spatial lag and spatial error models, respectively. Both the spatial coefficients (~~ρ and λ~~ρ and λ) are highly significant.

Table 6 Model explaining the change in N-based mineral fertilizer input per hectare of UAA between the years 2010 and 2000. The beta coefficients associated to the explanatory variables are given for each of the models (aspatial, spatial lag and spatial error).

~~Dependent variable: CHANGE OF N MINERAL FERTILIZERS BETWEEN YEAR 2010 AND 2000 (kg/ha)MODELASPATIALSPATIAL LAGSPATIAL ERRORESTIMATION METHODOLSMLMLR SQUARED~~Model	Aspatial	Spatial lag	Spatial error
Dependent variable: Change of N mineral fertilizers between year 2010 and 2000 (kg/ha)			
Estimation method	OLS	ML	ML
R squared	0.43	0.69	0.74
S~~TANDARD ERROR OF REGRESSION~~tandard error of regression	12.25	8.63	7.98
E~~XPLANATORY VARIABLESCONSTANT~~xplanatory variables			
Constant	3.9796	10.0401	6.8708
214-1 E~~XTENSION/UUA-0.8763 ***-0.5562 ***-0.4658 **214-2 EXTENSION/UUA-0.2162-0.0419-0.0256214-8 EXTENSION/UUA-0.0726-0.0781-0.0076214-9 EXTENSION/UUA-4.6034~~xtension/UUA	–0.8763***	–0.5562***	–0.4658**
214-2 Extension/UUA	–0.2162	–0.0419	–0.0256
214-8 Extension/UUA	–0.0726	–0.0781	–0.0076
214-9 Extension/UUA	–4.6034**	0.8799	1.3306
214-10 E~~XTENSION/UUA2.7655 ***1.5655 ***1.2638 **Y NVZ MUNICIPALITIES-8.3623 ***-4.5237 ***-4.115 ***Y LFA MUNICIPALITIES1.0674-0.1696-0.1316D UAA/TAA-0.21530.8435-6.9074 **D AVERAGE FARM SIZE-0.0623-0.0357-0.0137FARM < 5-0.2226 **-0.1284 **-0.0188FARM BETWEEN 5-30-0.2038-0.09550.0142LIVESTOCK UNIT/UUA0.0535-0.0722-0.0891INDIPENDENT COMPANIES/TOT COMPANIES0.15580.0969-0.0109N MINERAL FERTILIZERS/UAA-0.3049 ***-0.1657 ***-0.3654 ***CERTIFIED ORGANIC LAND-5.0579-5.7988 ***-4.4987 **ALTITUDE-0.0033-0.0028-0.0021POPULATION DENSITY0.0097 ***0.0064 ***0.0047 ***AGE BETWEEN 40-540.1058-0.0262-0.0010AGE > 550.0845-0.00540.0260HIGH SCHOOL DIPLOMA-0.3467-0.2171-0.0578UNIVERSITY DEGREE~~xtension/UUA	2.7655***	1.5655***	1.2638**
Y NVZ municipalities	–8.3623***	–4.5237***	–4.115***
Y LFA municipalities	1.0674	–0.1696	–0.1316
D UAA/TAA	–0.2153	0.8435	–6.9074**
D average farm size	–0.0623	–0.0357	–0.0137
Farm < 5	–0.2226**	–0.1284**	–0.0188
Farm between 5 and 30	–0.2038	–0.0955	0.0142

Livestock unit/UUA	0.0535	−0.0722	−0.0891
Independent companies/tot companies	0.1558	0.0969	−0.0109
N mineral fertilizers/UAA	−0.3049***	−0.1657***	−0.3654***
Certified organic land	−5.0579	−5.7988***	−4.4987**
Altitude	−0.0033	−0.0028	−0.0021
Population density	0.0097***	0.0064***	0.0047***
Age between 40 and 54	0.1058	−0.0262	−0.0010
Age >55	0.0845	−0.0054	0.0260
High school diploma	−0.3467	−0.2171	−0.0578
University degree	0.0195	0.0025	0.0136
~~ρ0.6635 ***λ0.8043~~ ρ		0.6635***	
λ			0.8043***

Number of observation = 341.

** and *** indicate statistical significance at the 5% and 1%.

In all of the models the constant is not significant, which could suggest that the change in inorganic fertilizers is not homogeneous throughout the study area and/or that the variability is captured entirely by the independent variables included in the model.

In the two most widespread sub-measures, integrated production and organic farming, only the uptake of sub-measure 214-1 is significant in all three of the models. Integrated production has a negative coefficient, meaning that an increase in the share of land involved in this action results in a decrease in the application rate for inorganic N over the course of the decade.

Within the remaining agri-environmental sub-measures, voluntary set aside (sub measure 10) is significant in all of the models with a positive coefficient, which could suggest that lower reductions in inorganic N are recorded in the municipalities where the sub-measure is concentrated. Sub-measure 9 (protection of natural, semi-natural and agricultural landscapes) is significant only in the aspatial model, meaning that the spatial component of the spatial model captures its significance. However, it is unlikely that there is a strong causal effect behind this role, even in the aspatial model, due the fact that only a very small area is included in this sub-measure (they represent only 0.03% of regional UAA, this value referring to the sum of the areas of land under the two sub-measures, see Table 3 for details on each sub-measure).

All of the models show that the reduction in inorganic N was greater in municipalities belonging to NVZs (negative and significant beta coefficients) than in those located outside of the NVZs boundaries, which is consistent with expectations. Regional NVZs are, in fact, located in the Ferrara province and in the hilly belt. Moreover, the LISA analysis indicated that a homogeneous association of low values of the dependent variables occurs in the Ferrara province (cold spot cluster, Fig. 3), where the highest reduction in N fertilizer sales was recorded. The magnitude of the coefficients suggests that if the municipality is located in a NVZ, the application rate of N-based mineral fertilizers is reduced by about 6 kg/ha (average value between the beta coefficients of the three models). This result differs from what was reported in the latest regional RDP annual valuation report (Regione Emilia-Romagna, 2013), which indicates that the influence of AES measures on the reduction in the N mineral fertilizer application rate was slightly greater in non NVZs (−4.8 kg/ha in non NVZs vs. −4 kg/ha in NVZs). However, the annual evaluation of RDPs refers only to year 2013 and does not analyze changes over time. On the contrary it focuses on a comparison among farms using different technologies, while our results refer to a before and after situation with respect to the implementation of the NVZs in Emilia-Romagna in year 2006. The results presented in this study also differ from those presented in the RDP Valuation Report when analyzing the altitude variable, which does not appear to be a significant variable in our model. On the contrary, the RDP valuation report indicates that in year 2013, the N mineral fertilizer application rate declined more with increasing altitudes. In addition to the fact that the proposed model is dynamic (compares two time periods), while the RDP valuation refers only to one year, this difference may also be due to the use of the altitude variable instead of the location in mountains, hills and plains (see ~~section 3~~Section 3 for details on the variable choice). The ratio of certified organic land on the UAA is significant (with a negative coefficient) only in the two spatial models. The sign of the estimated coefficients indicates that a reduction in inorganic N occurs where the share of certified organic land on the UAA was higher in year 2000, before the implementation of RDPs. According to the estimations, if the total UAA of a municipality was converted to certified organic land, the N fertilizer application rate would be reduced by about 5 kg/ha (average values of the spatial models coefficients).

Population density proves to be highly significant, with positive coefficients in all models. This suggests that inorganic N has decreased less where population density is higher, which is compatible with the notion that vicinity to cities encourages intensive farming systems, or, more realistically, that more intensive farming tends to develop in the best land areas, which are also often the most intensively populated. The share of small farms (<5 ha) is also a significant variable with negative coefficients in the aspatial and spatial lag models indicating that the reduction in inorganic N is favoured by the presence of small farms compared to middle size and large farms (>5 ha). This result could be interpreted as a result of the extensification of small farms. Furthermore, in the spatial error model, the change in the ratio of UAA to the total agricultural land (TAA) is significant with negative beta coefficients. Consistent with expectations, this result indicates that the on-going process of land extensification/conversion to non-agricultural uses, partly due to land abandonment, has contributed to the decrease in the application rate of N mineral fertilizers. More specifically, the magnitude of the beta coefficients associated to this variable indicates that if all of the land in a municipality is extensified/converted to other uses, the decrease would be 6 kg/ha. However, this interpretation is meaningful only in the actual range of the UAA/TAA ratio. Extreme values of these variables (UAA/TAA equal to one or zero) are not likely to have an impact comparable to the estimation obtained through the model.

The ratio of the mineral fertiliser application rate in year 2000 to the UAA is significant in the three models and is characteri~~s~~zed by a negative coefficient. This result indicates that the reduction in the inorganic N application rate in the decade under consideration is greater in municipalities where the N mineral fertiliser application rate was higher in year 2000. In those cases, the marginal cost associated with the decrease in the fertilization rate is lower and may be due to the technological advancements that occurred during the decade, for which the increasing cost of N fertilizers could have acted as a driver.

Finally, concerning the temporal and spatial dimension of the analysis, it is necessary to keep in mind that the selected variables do not allow for a complete temporal overlap with the AES implementation during the last CAP programming period (RDPs 2007~~–~~–2013). Therefore, it is difficult to compare the results presented in this study with the available valuations of the regional RDPs. In addition, the model could account for other relevant policies implemented in that period, such as the Nitrate Directive. Moreover, the analysis of the changes in N mineral fertilizer application rates between years 2000 and 2010 were likely also affected by AES already implemented in the RDPs 2000~~-~~–2007 (e.g. share of certified organic land in each municipality). From a spatial point of view, spill over effects include the impact of AES on non-participants, as farmers adopting AES measures may, directly or through advisory services, share knowledge/attitudes with neighbouring farmers resulting in a modification of their decisions/outcomes (~~Tamini et al., 2011~~Tamini, 2011). This implies some critical reflections on methodological and scale issues, and on data problems, notably that a comparison of participants and non-participants through traditional counterfactual methods between samples of single farms can underestimate the AES impact due, among others, to the occurrence of unaccounted spill overs between neighbouring farms (Anderson and Feder, 2007). On the other hand, limitations with regard to data availability at the farm scale can be at least partially overcome assuming that relevant farmer decisions, such as converting to organic farming or to integrated production, are shared at the aggregate level (Schmidtener et al., 2012).

5 Conclusions

The relationship between the change in the use of N mineral fertilizer between the years 2010 and 2000 and the uptake of AES schemes was investigated through both aspatial and spatial models as the spatial dimension of the analysis was assumed to be relevant due to the hypothesis that neighbouring farmers share information and influence each other's choices. The model results proved that the use of spatial models (spatial lag and spatial error) are more effective at explaining the change in inorganic N application rates compared with the aspatial model. This is consistent with the outcomes of the spatial analysis (Moran's statistics), which appears to be useful at predicting the spatial dependence of the indicator and supporting the interpretation of results. In fact, in this research, the spatial analysis indicates that significant clusters are located in areas characteri~~sed by highly-specialis~~zed by highly-specialized crops. This result is consistent with expectations since crops are usually highly clustered in space. However, the occurrence of spatial dependence may also indicate that an underlying process leading to a clustered distribution of variables is taking place, or that there is a mis-match between process and spatial units causing systematic errors, or both simultaneously. Thus, the spatial dimension of the dependent variable cannot be interpreted in a straightforward manner as a result of spill over effects in the variable itself. It is and most likely related to spillovers in its determinants or similar production conditions in neighbouring areas. While this is relevant, however, in the case of the Emilia-Romagna region, the model also reveals the presence of spatial effects due to unobservable features and suggests that some variables associated with location are omitted since the spatial coefficients (~~ρ and λ~~ρ and λ) are both highly significant.

On the whole, this study proves the value of using spatial econometrics in the context of the evaluation of the effects of AEMs, but also underscores the need for caution in the interpretation of results. This is primarily because the dependent variables are not observed data but are rather derived through calculation, which can result in a degree of bias due to hypotheses adopted in the process. In particular, access to farm level information and genuinely measured impact parameters are key to ensuring a better exploitation of the potential of spatial econometrics. Enhanced econometric models may also improve the quality of analysis. For example, a more detailed analysis of these variables through the use of alternative spatial models, such as the Geographically-Weighted Regression, could represent a further step in this research. On the whole, the use of more complex Spatial Auto Regressive models in policy analysis could be an advancement in this field of research, in particular when dealing with environmental policies since both social and physical phenomena are often highly clustered in space (see Kelejian et al., 2004~~ and~~; Arraiz et al., 2010, for a statistical treatise on SAR models).

According to the results of the econometric model, integrated production, the most widespread Agri-Environment Measure in Emilia-Romagna, only has a slight effect on the reduction in the use of N mineral fertilisers if compared to other factors contributing to the mitigation of agricultural nitrate pollution. In particular, areas with constraints from the Nitrate Directive had a greater influence on the decrease in the N mineral fertilizer application rate. The model estimates that the reduction that occurred in the municipalities located in NVZs was on average 5.5 kg per ha of UAA higher than in the municipalities located elsewhere. The decrease associated with the location in NVZs is 3.1 kg of mineral N per hectare of UAA at the regional level; this reduction is ten times greater than the 0.02 kg/ha estimated for the land enrolled under integrated production. It should be noted that this trend is shown in all of the models. Accordingly, it is not ascribable to some unaccounted effect captured by the spatial component. The second most widespread AEM, organic farming, appears not to be linked to the decrease in the usage of mineral fertilisers, although a reduction in inorganic N occurs where the share of certified organic land was higher in year 2000, prior to the implementation of the RDPs. This result suggests that the enrollment of land under organic certification leads to a conservation effect with regard to the reduction in N mineral fertiliser usage. Furthermore, the reduction in inorganic N usage in the decade under consideration is greater in municipalities that already had a relatively lower mineral fertiliser application rate, which may also be an effect induced by the on-going process of land abandonment.

From a policy perspective, this study may yield several insights. First, there is an ongoing process of extensification as a result of land abandonment or reduction of UAA, which may already be sufficient to bring N mineral fertilizer usage down in several areas in the future. This may be an important reminder to first evaluate the actual need for policy intervention before any action is taken.

Uncited reference

CMEF (2006).

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Appendix ~~AAppendix IFigs. 4 and 5.~~I

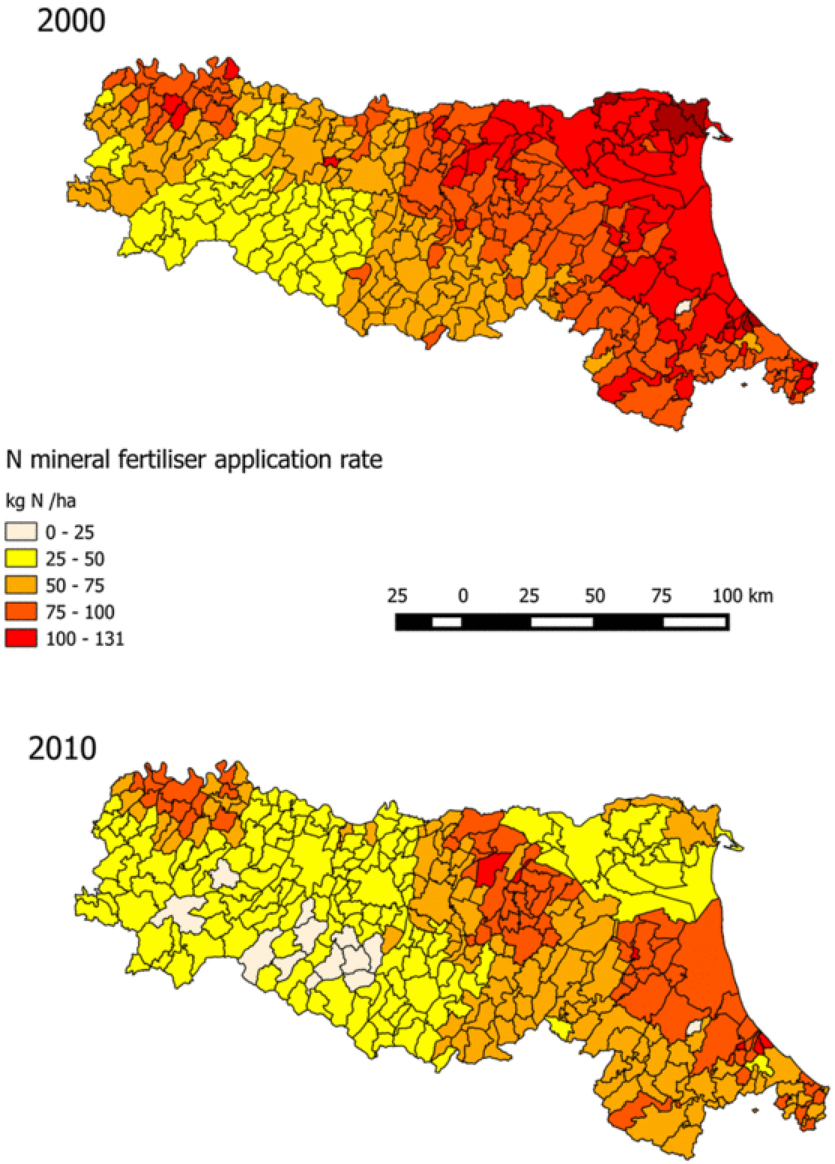

Fig. 4 Map displaying the N mineral fertilizer application rate (kg per hectare of UAA) in the years 2000 (top) and 2010 (bottom). Each polygon corresponds to a municipality; all of the 341 municipalities of the Emilia-Romagna region are included in the map.

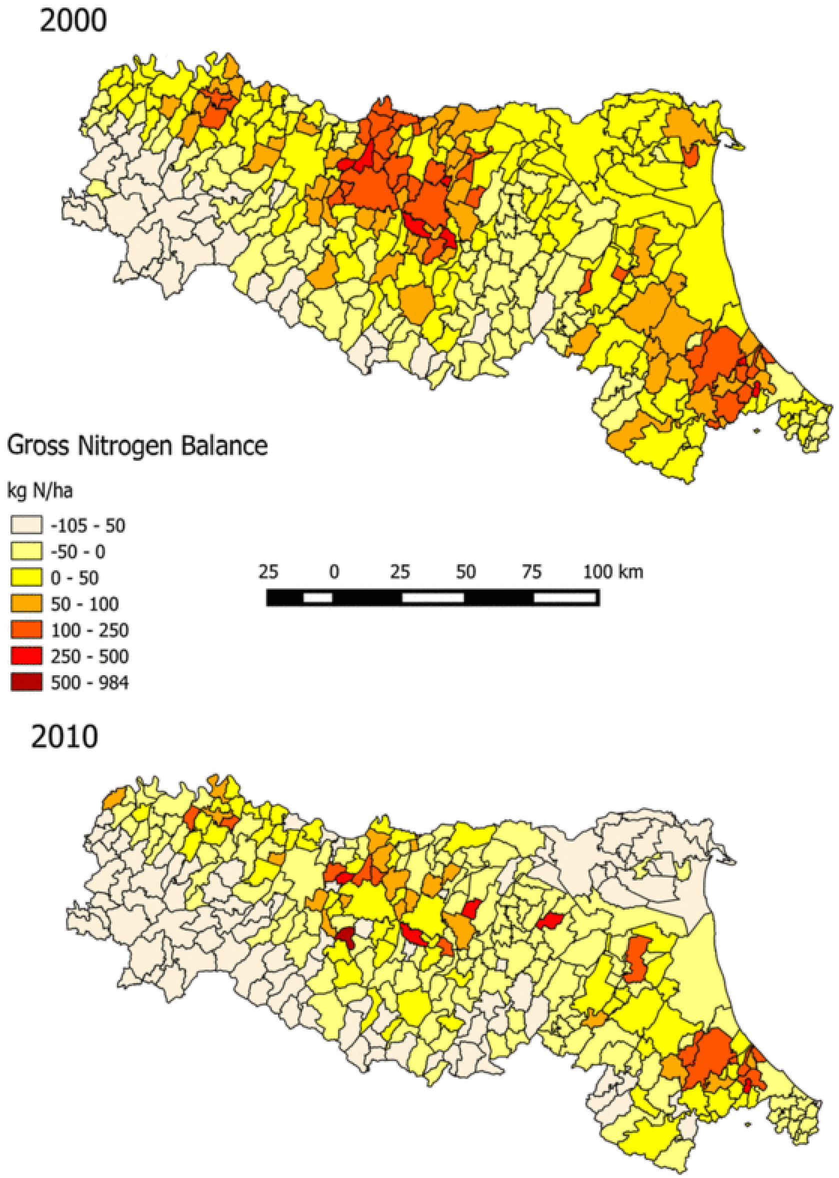

Fig. 5 Map displaying the Gross Nitrogen Balance (kg per hectare of UAA) in the years 2000 (top) and 2010 (bottom). Each polygon corresponds to a municipality; all of the 341 municipalities of the Emilia-Romagna region are included in the map.

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Footnotes

[1] In the FAO fertilizer outlook, the potential nutrient balance (or nutrient surplus) is defined as the difference between N available for fertilizers and N fertilizer demand, as a percentage of N fertilizer demand. This definition differs substantially from that of the Gross Nutrient Balance (or nutrient surplus) as described in OECD (2008). In the following text, the nutrient surplus and the Gross nitrogen Balance are mentioned referring to the OECD definition of the indicator.

[2] More specifically, when water availability is adequate for crop production, nitrogen fertilization boosts crop yields and increasing the biomass (Van Herwaarden, 2003). On the contrary, if water is inadequate to support the increase in biomass, the crop responds by fading. In this case, despite the fact that the initial growth was enhanced by fertilization, the final yield is lower than in crops with less nitrogen available, due to water stress. This process, known as 'haying-off', can cause serious economic loss to farmers as it decreases yield, reduces crop quality (e.g. occurrence of pinched grains in cereals), and wastes costly nitrogen fertilizers.

[3] Similarly to the profit function (~~π~~π), the optimal fertilization rate (N) depends on relative prices and markets (Miranowski and Carlson Gerald, 1993) and on policy intervention (Zalidis et al., 2004), both in terms of regulations and public incentives (USDA, 1991). Structural characteristics of the farms, such as farm size, specialization and access to irrigation water, are commonly considered to be relevant because the optimal fertilization rate (N) is, respectively, crop specific, can be better estimated in small farms and, as stated previously, varies with soil water content.

[4] ISTAT censuses are carried out every ten years and collect data at farm scale as well as through face-to-face interviews with all farmers operating in Italy.

[5] The amount of N fertilizers sold yearly in Emilia-Romagna has only been available from the regional statistical institute at the province level since 2003. Thus, the adjustment factor for year 2000 was calculated based on the 2003 data. The total amount of N mineral fertilizers sold in year 2003 equals 2,023,178 q. Up until 2008, the amount of N mineral fertilizers sold in the region stayed in the range of 2,000,000 – 2,500,000 q/years. Since 2009, however, sales of N mineral fertilizers have decreased considerably: in 2009 sales declined by 31% with respect to the reference year (2003); in 2010, 1,235,438 q of N mineral fertilizers were sold, which indicates a 39% reduction in the regional sales compared to 2003. On the whole, these values indicate that the amount of nitrogen sold as mineral fertilizers has decreased by 34% over the course of the decade under consideration.

[6] Variables specifically associated with mountains, plains and hills were tested for the inclusion in the model. However, it was decided to substitute them with the more general variable ~~"altitude"~~"altitude" as this reduced the risk of multicollinearity: the variable ~~"altitude"~~"altitude" has a VIF level lower than 5, while the variables ~~"mountain", "hill" and "plain"~~"mountain", "hill" and "plain" have VIFs greater than 5.

[7] i.e. The consortium of Parmigiano-Reggiano cheese producers.

Highlights

- An indicator for the measurement of agricultural nitrogen input is computed at NUTS5 level.
- In the case study it is shown that spatial autocorrelation of the indicator occurs.
- A spatial regression model is applied for evaluating agri-environmental policies.
- Integrated farming is identified as effective in preventing nitrate leaching.
- Compulsory policies are the most effective in reducing nitrogen use in agriculture.

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