AperTO - Archivio Istituzionale Open Access dell'Università di Torino

Nutrient balance as a sustainability indicator of different agro-environments in Italy

This is the author's manuscript

Original Citation:

Availability:

This version is available http://hdl.handle.net/2318/126857 since

Published version:

DOI:10.1016/j.ecolind.2010.05.005

Terms of use:

Open Access

Anyone can freely access the full text of works made available as "Open Access". Works made available under a Creative Commons license can be used according to the terms and conditions of said license. Use of all other works requires consent of the right holder (author or publisher) if not exempted from copyright protection by the applicable law.

(Article begins on next page)

19 April 2024

UNIVERSITÀ DEGLI STUDI DI TORINO

This Accepted Author Manuscript (AAM) is copyrighted and published by Elsevier. It is posted here by agreement between Elsevier and the University of Turin. Changes resulting from the publishing process - such as editing, corrections, structural formatting, and other quality control mechanisms - may not be reflected in this version of the text. The definitive version of the text was subsequently published in Ecological Indicators 11 (2011) 715–723, March 2011, doi:10.1016/j.ecolind.2010.05.005.

You may download, copy and otherwise use the AAM for non-commercial purposes provided that your license is limited by the following restrictions:

(1) You may use this AAM for non-commercial purposes only under the terms of the CC-BY-NC-ND license.

(2) The integrity of the work and identification of the author, copyright owner, and publisher must be preserved in any copy.

(3) You must attribute this AAM in the following format: Creative Commons BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/deed.en), http://www.sciencedirect.com/science/article/pii/S1470160X10000853

NUTRIENT BALANCE AS A SUSTAINABILITY INDICATOR OF DIFFERENT AGRO-ENVIRONMENTS IN ITALY

Monica Bassanino[1], Dario Sacco[1], Laura Zavattaro[1*], Carlo Grignani[1]
*corresponding author

[1] Dipartimento di Agronomia, Selvicoltura e Gestione del Territorio, Università di Torino.
via Leonardo da Vinci, 44 - 10095 Grugliasco, Italy

NUTRIENT BALANCE AS A SUSTAINABILITY INDICATOR OF DIFFERENT AGRO-ENVIRONMENTS IN ITALY

Abstract

Regionally mandated budgets often ignore important sub-regional differences. To help identify *hot-spots*, where environmental pressures and agricultural activities combine and heighten the need to optimise farming strategies, we recommend using detailed spatial target analysis.

In this paper, we propose a methodology for identifying different agro-environments, test that method in a case-study territory in the western Po River plain (the largest and most intensive agricultural area in Italy), and then calculate the nutrient budget indicators of these defined agro-environments as a means to assess environmental sustainability.

We identified five Macro Land Units (MLUs) representing five different agro-environments from official datasets and territorial surveys, detected and quantified land use, crop productivity, and fertilisation management in these MLUs, and calculated nutrient budgets according to the IRENA European methodology. As expected, the highest nutrient surpluses (103, 39, and 95 kg ha^{-1} for N, P, and K, respectively) were detected in the most intensely managed area. N surpluses were attributed to excess mineral inputs and P surpluses to excess organic inputs. At the territorial scale, the manure N load was far below the 170 kg ha^{-1} threshold; at the crop scale, maize showed the least-optimised fertilisation management.

This work suggests that GIS-based analysis of environmental pressures of agricultural activities at a sub-regional level is useful for identifying areas and crops for which fertilization must be well managed. The proposed methodology depends on accurate collection and collation of farm data into GIS databases; public authorities should promote investment in planning and managing data collection in agriculture.

Key-words: Agro-environmental indicators, fertilisation management, GIS-based spatial analysis, gross nutrient balance, Po river plain, territorial scale.

Definitions

Municipality: According to EUROSTAT (1059/2003/EEC), an administrative unit corresponding to the LAU-2 territorial level. In the Piemonte region there are 1206 municipalities, with an average area of 2,100 ha.

Province: According to EUROSTAT (1059/2003/EEC), it corresponds to the NUTS-3 territorial level. In the Piemonte region there are 8 provinces, ranging from 91,000 to 690,000 ha.

Region: According to EUROSTAT (1059/2003/EEC), it corresponds to the NUTS-2 territorial level. The Piemonte region covers 2,540,753 ha.

1. Introduction

European agriculture contributes 30% to 80% of nitrogen (N) and 20% to 70% of phosphorus (P) loads to water bodies (OECD, 2008). The Water Framework Directive (2000/60/CE) states that protection of water resources can be achieved only through a reduction of pollution from all agricultural sources—both potential (nutrient loads from fertilisation) and actual (measurable pollutants reaching water bodies). This focus makes diagnosis of the environmental impact of farming systems the primary step in the process of assessing agricultural sustainability (Payraudeau and van der Werf, 2005).

Agro-environmental indicators (AEIs) are key tools for assessing the environmental impact of agriculture (Stein et al., 2001). Among the AEIs used for fertilisation management, nutrient budget is the most common (Langeveld et al., 2007). Its versatility is well-documented; it can serve as an analytical instrument (Isermann and Isermann, 1998), performance indicator (e.g.: Folmer et al., 1998; Bassanino et al., 2007a), or legislative threshold (Oenema et al., 2003) in the field (Kutra and Aksomaitiene, 2003; Sieling and Kage, 2006), on the farm (Bockstaller et al., 1997; Brouwer, 1998), or at the scale of the territory (Sacco et al., 2003; Kimura and Hatano, 2007). Nutrient budget analyses have most often focused on N, and to a lesser degree on P, even though agriculture can contribute large amounts of P inputs to water ecosystems leading to eutrophication (Chardon and Withers, 2003). Potassium (K) balances are often altogether ignored. Generally, K is not a limiting element for water system quality, but Öborn et al. (2005) finds agronomic value in determining K budgets for long-term soil sustainability, crop quality, and grassland yield purposes. Furthermore, a general interest in P and K optimisation exists due to the fact that these fertilisers come from limited, non-renewable resources.

The largest and most intensive agricultural area in Italy is the Po River catchment; 70,700 km^2 host 75% of the livestock and 36% of the Utilized Agricultural Area (UAA) at the national scale (ISTAT, 2000). Cropping system inputs in this area are often very high (e.g.: Bassanino et al., 2007a). Commensurate with the poor water quality of the Adriatic Sea, into which the Po River collects, the European Commission has asked Italy to extend the Nitrate Vulnerable Zones (now covering 50% of the Po plain) to the entire river catchment (ADAS and NIVA, 2004). Such an extension would fail to consider the very different agro-environments that co-exist in this expanse: stocking and stockless, irrigated and non-irrigated, intensive and extensive farming systems (AdBPo, 2006). According to Parris (1998), regional-scale budgets mask important sub-regional differences; hence, national values need to be interpreted with caution (OECD, 2008). A detailed spatial targeting analysis has been recommended (EEA, 2006) to start identifying "hot-spots," where the environmental pressures of agricultural activities are magnified and the need for farming strategy optimisation is urgent.

The western part of the Po river plain is a site where nutrient budgets can be applied at a sub-regional level to spatially define local agricultural pressure. The coexistence of different cropping systems makes analysis of sustainability scenarios complex, but informs us of the specifics that each agro-environment plays in the regional scale budget. In this paper, we have three objectives:

a) to develop a methodology for the geographical delineation of different agro-environments using existing databases and local data, and then test it in a case-study territory;
b) to assess the sustainability of previously defined agro-environments according to some nutrient budget indicators;
c) to verify the feasibility and effectiveness of the adopted indicators.

2. Materials and methods

2.1 The study area

The study focused on northwest Italy in the Piemonte region, between 44°20' and 45°50' N and 7°20' and 8°50' E, covering 35% of the Po River catchment. The climate is temperate sub-continental, with an annual mean precipitation of 850 mm (spring and autumn are the main rainy periods) and an annual mean temperature of 12°C. The total area of Piemonte is 2,540,000 ha; the Utilized Agricultural Area (UAA) accounts for 1,075,000 ha only, due to wide mountain areas.

According to Regione Piemonte (2000), agriculture takes place on the plain (41% of UAA), mainly with maize-based systems, and on the hills (31% of UAA), mainly with vineyards and winter cereals. Irrigation ranges from less than 10% (southeast hilly provinces) to more than 70% (northeast paddy area) of the UAA. Livestock farms account for 25% of all farms. The livestock density averages 1.0 livestock unit (LU) ha^{-1}, reaching 2.0 LU ha^{-1} in the central-southern provinces. At the scale of the farm, as many as 2.5-5.0 LU ha^{-1} are not uncommon due to intensive breeding systems of both swine and bovine livestock (Bassanino et al., 2007a).

This work focuses only on the plain, where agro-environments are defined mainly by land use, and are influenced by the role of livestock husbandry activities and by crop yield as a function of water availability for irrigation. Although it is easy to describe agro-environmental characteristics, their territorial boundaries are difficult to identify in a scientific way. Nevertheless, spatially targeted data are needed to assess the agro-environmental sustainability of a territory.

2.2 Data collection

According to Eswaran et al. (2000), an agro-environment is a geographic unit characterized by homogeneous agricultural use and land qualities. To do so required that we identify the different agro-environments in the study area on the basis of the soil, climate, land use and farming systems characteristics, delineate their spatial boundaries, and then characterize them through averaging spatially-distributed parameters (crop frequency, farming systems, yields). First, we defined working units at a more detailed scale and collected data for each. These units were homogeneous in climate, soil type, land use, and crop productivity, and were spatially delineated as follows. Official datasets provided data about climate (Regione Piemonte, 2008a), soil (Regione Piemonte, 2008b) and land use (ISTAT, 2000). Crop productivity data, on the other hand, were neither available at the desired level of detail, nor were they geo-referenced (Grignani et al., 2003). Given the lack of data, we were forced to use experts or educational extension technical literature as viable information sources (van Eerdt and Fong, 1998). As has been done in other studies (e.g.: Bindraban et al., 2000; Yli-Viikari et al., 2007), we conducted a territory-wide crop management practice survey utilising expert agronomists. Given their familiarity within the territory, they were able to select and personally interview a representative set of local farmers and technical advisors. In total, they collected information on a surface of 593,000 ha in the study area from which they were able to describe 23 main crops and identify, detail, and geo-reference 1094 fertilisation techniques (combinations of fertiliser type, amount, and timing).

2.3 Spatial analysis

In order to select the proper spatial units for data collection, a digital intersection of the available data (Table 1), similar to Folmer et al. (1998), was done by means of a geographical information system (GIS). Data combination, also reported in Bassanino et al. (2006), allowed the identification of 125 land units (Agronomic Land Units, ALUs) defined by homogeneous climate, soil type, land cover, and crop productivity.

ALUs were outlined according to the cadastral borders (Regione Piemonte, 2008c) to allow for further joining with other datasets. We integrated ALU information with the animal stocking rate official dataset (ISTAT, 2000), available at the municipality level. We coupled the stocking rates to the NPK excretion coefficients adopted for Italian application of the Nitrate Directive (D. Lgs. 152/2006) to calculate the manure input per municipality and per ALU.

ALUs represent the smallest homogeneous units of land that can be identified at the working scale, and they can differ only for very specific aspects. They are too detailed to be regarded as agro-environments of the study region. In order to aggregate units into a higher hierarchical level, ALUs were grouped using a cluster analysis procedure (Leeson et al., 1999; Silva et al., 2006) applied to land use variables. Land use was sufficient to separate clusters because it condensed soil and climate characteristics, as it depends on them. Euclidean distance was used as the separation method. The cluster analysis produced a higher-scale set of units for the study territory and allowed us to identify a clear spatial structure at the aggregated level that identified five separate areas, that we called Macro Land Units (MLUs). As these areas were different in terms of agricultural use and land quality, and geographically separate, we regarded them as agro-environments.

Once the MLUs were spatially defined, a set of descriptive farm-scale characteristics (farm types, stocking rate, land use, and management) and nutrient budget indicators were calculated. The differences between MLUs, both in terms of nutrient budget components and indicator results, were statistically analysed through a Kruskal-Wallis test. Parametric tests were not applied as data were not normally distributed and variances were not homogeneous.

2.4 Nutrient budget indicators

Conceptually, the nutrient budget is a mass balance between nutrients exported with the harvested crops and forages, and nutrient inputs to the soil from both natural and agricultural sources. It is usually adopted for a wide range of formulae and scales of data analysis (Brouwer, 1998; van der Molen et al., 1998; Koelsch and Lesoing, 1999; OECD, 2001; Sacco et al., 2003; van Beek et al., 2003; Halberg et al., 2005).

Since the year 2000, the IRENA (Indicator Reporting on the Integration of Environmental Concerns into Agriculture Policy) European Project coordinated by the European Environmental Agency (COM, 2000) selected and identified 35 AEIs, including two nutrient budget indicators: Gross Nitrogen Balance (GNB, IRENA 18.1) and Gross Phosphorus Balance (GPB, IRENA 18.2).

IRENA indicators are intended specifically to help target agro-environmental measures and they provide information concerning agro-ecosystems in the European Union (EEA, 2006). As the IRENA gross nutrient budgets are the most recent set of indicators for an interregional comparison of agro-environmental performance, we tested them in a territorial case study, in part to evaluate their feasibility and effectiveness.

Gross balances were calculated for N (GNB), P (GPB), and K (GKB) according to the following equation contained in the IRENA operation sheets:

$$GB = \text{fertilisers} + \text{manures} + \text{others} - \text{harvested}, \tag{1}$$

where fertilisers represents N, P, or K in applied mineral fertilisers; manures represents N, P, or K in manure inputs; others equals N from wet and dry atmospheric depositions and legume crop symbiotic fixation; harvested represents N, P, or K collected from the field through grain, straw, and forage.

Positive values of GB indicate a nutrient surplus while negative values a deficit.

As the K balance is not included in the IRENA indicators, we computed the GKB indicator in a similar way to the GPB indicator.

2.5 Calculation of nutrient budgets

According to the methodology described in Figure 1, we calculated N, P, and K nutrient budgets for each ALU. We calculated crop nutrient removal through the average yield described by the territorial survey within each ALU as well as the average NPK content of kernel and straw collected by local experimental data (Grignani et al., 2003).

Crop mineral supply was calculated from the type and amount of mineral fertilisers described by the territorial survey and the concentration of nutrients in each fertiliser (ISNP, 2003). Within each ALU, if more than one fertilisation strategy was identified for a crop, then all the existing agronomic techniques were weighted based on their frequency to describe only one average fertilisation technique per each crop and ALU.

We assumed that the manure produced within a municipality to be homogeneously spread to all crops in the municipality. This simplified assumption, also adopted by de Koening et al. (1997) and Saam et al. (2005), was formed from two considerations. First, data from farmers of single crop manure applications are often incomplete, inconsistent, or unreliable, as reported in Piemonte (Grignani and Zavattaro, 1999) and other European regions (Oenema et al., 2003; Bechini and Castoldi, 2006). Some authors (e.g.: Lesschen et al., 2007) used to estimate the manure spread according to crop requirements, but we now know that farmers often neglect organic input in their fertilisation planning, accounting for mineral fertilisers only. The second consideration stems from legislation in Piemonte today requiring farmers to delocalise excess farm manure to surrounding neighbourhoods to better balance manure N load at the territorial scale. This practice effectively makes manured cropland match the total amount of available cropland (Sacco et al., 2003).

We calculated the biological N fixation of legume crops and forage legume species according to local reference coefficients (Grignani et al., 2003) expressed as a percentage of total N uptake, and according to legume crop frequency within the ALU.

Due to the lack of official data, we estimated the wet and dry N depositions based on local data collected at an experimental monitoring station (Grignani et al., 2003). This input value (26 kg N ha^{-1}) is slightly higher than the national average (20 kg N ha^{-1}, according to the law D.M. 7 aprile 2006).

All crop management data obtained at the ALU scale were weighted within each MLU based on relative UAA in order to account for crop area and frequency.

3. Results

3.1 Geographical identification of the agro-environments

Cluster analysis of ALU data allowed geographical identification of five MLUs (Figure 2) characterized by different soil properties, land uses (Table 2), farming system attributes (Table 3), and main crop productivity (Table 4). This allowed each MLU to uniquely and geographically identify an agro-environment.

Livestock husbandry set apart two MLUs. While more than 30% of the farms in each contained livestock, MLU3 was a widely irrigated, highly productive maize-based area and MLU4 was a scarcely irrigated, but productive grass-based area. Conversely, the other MLUs conducted little livestock husbandry—less than 10% of the farms housed animals. Among these three areas, MLU5 was a highly productive, rice-based paddy area while MLU1 was a non-irrigated, low-productivity area with widespread winter wheat and vineyards, and MLU2 was a scarcely irrigated, but productive winter wheat-based area.

Of the two MLUs with high livestock levels, MLU3, covering 43% of the total UAA, showed a lower livestock density, but many more farms housing animals. This area was in Piemonte where swine, dairy cows, or bulls were bred. Soils were characterised as silt loam, silt or sandy loam, sub-acidic; all had a normal content of both organic matter and Olsen P. The availability of water for irrigation provided for high crop productions; animal feeding was mainly covered by farm crops and forages in a zero-grazing system which allowed a very intensive farm stocking rate (see also Bassanino et al., 2007a). Due to the role of winter wheat, leys, and meadows in the farm rotation, one hectare out of four was permanently covered during winter. Two thirds of the land was ploughed every year, thanks to a strict rotation.

MLU4 covered 18% of the total UAA, mainly in the piedmont areas around the plain. Soils were silt loam or silt, sub-acidic, all with a normal levels of organic matter and Olsen P. Livestock husbandry was widespread, but with low farm stocking rates. Bovine breeding was conducted extensively on large grassy surfaces, which were often grazed in spring and autumn, leaving only 44% of the MLU available for ploughing. Irrigation was not common due to a colder climate, thus limiting the summer cereal productivity.

MLU1 and MLU2 were stockless areas. Here, the lack of water for irrigation had traditionally limited the presence of maize and grass, the most common forage crops. Soils were silt loam, silt, or silty clay loam, sub-alkaline, with a poor content of organic matter and a normal content of Olsen P. Due to the fine soil texture, fields were usually ploughed in autumn and left bare during the winter. In MLU2, farm size was slightly larger than the regional average, and crop productivity was good thanks to farmers' technical skills. In MLU1, where irrigation was rare, winter cereals and vineyards were the prevailing crops. Farms were smaller and crop productivity was much lower than average.

MLU5, covering 21% of the total UAA, was one of the largest paddy rice systems in Europe. Soils were silt loam, silt, or sandy loam, acidic, with a high content of both organic matter and Olsen P. Farms were on average the largest in size; soils were ploughed annually, and usually left bare during the winter. According to a rice-based system, livestock farms were few, but intensively-managed, yielding a very high farm livestock density.

3.2 Assessment of the agro-environmental performances

Table 5 reports the N, P, and K budget results for each MLU. Statistically significant differences were found for both indicators and nutrient budget components ($P<0.000$) among the MLUs. MLU3 was the most intensively managed of the agro-environments as shown by its highest crop productivity (161 kg N ha^{-1}), high mineral inputs (127 kg N ha^{-1}) and large water supply. MLU3 also ranked highest in net nutrient surpluses. Even though surpluses (103 kg ha^{-1} for N, 39 for P, and 95 for K, respectively) were principally driven by the quantity of manure spread, reflecting the high livestock density, mineral fertiliser management still played an important role in determining the surpluses. The manure input, combined with N natural sources, covered 85%, 139%, and 104% of the harvested N, P, and K, respectively; therefore, the mineral input added to manure could easily be reduced.

MLU2 showed the second highest level of nutrient surpluses: 74, 18, and 20 kg ha^{-1} for N, P, and K, respectively. This agro-environment was characterized by a reduced availability of water; nonetheless, it showed some elements of intensive farming including high crop productivity (121 kg N harvested per each hectare) and high fertiliser inputs (140 kg N ha^{-1} were applied).

The other three agro-environments yielded lower nutrient surpluses. In the case of the paddy rice area (MLU5), a detailed agro-environmental study has been presented by Zavattaro et al. (2006 and 2008).

On average, the entire territory, based on all the MLUs combined, reported surpluses of 77, 24, and 65 kg ha^{-1} for N, P, and K, respectively. To better explain the results obtained at the territorial scale, further analysis at the crop level was helpful. To this end, we calculated an MLU-specific soil-surface balance for N, P, and K for the main crops (named in Table 4) according to equation 1, and reported the results in Table 6. In general, farmers tended to overestimate the nutrient requirements for maize and grain and underestimate it for grass surfaces. Although this result might be biased by the assumption that manure was homogeneously spread in the municipality, this result was consistent with previous farm scale fertilisation surveys conducted in northern Italy (Grignani and Zavattaro, 1999; Bechini and Castoldi, 2006; Bassanino et al., 2007b).

With regard to fertilisation management, since the mineral inputs play a part in defining surpluses, we also explored the role of top dressing for N mineral fertilisation. Results are reported in Table 7. Although the spreading strategy for maize is more uniform, a wide difference is shown with regard to winter wheat, suggesting the possibility that a large improvement in farm fertilisation technique results in nutrient surplus reduction. No differences between stockless and stocking farms were detected with regard to quantity of mineral fertiliser spread each year, or spread timing. As farmers tend to ignore the nutritional role of farm manures, especially for P and K, they prefer to spread a mineral quota plus the manure, the so-called "insurance N" of Schröder et al. (2000), often setting the farm fertilisation beyond crop needs. Therefore, it seems possible to reduce mineral inputs without decreasing the crop productivity in order to lower the NPK surpluses at the MLU scale.

4. Discussion

4.1 Are the studied agro-environments sustainable?

The calculation of selected nutrient budget indicators suggests that Piemonte farming systems generally display a net surplus for all the main nutrients. However, within that general tendency, substantial differences among different agro-environments exist. Although the Po plain is usually treated as a uniform geographical entity (as in ADAS and NIVA, 2004), we were able to geographically identify different agricultural systems by highlighting wide differences in land use, input amounts (e.g. fertilisers and water), and surpluses.

Several attributes should be considered when assessing farming system pressure on the environment. A given crop or farming system is not dangerous *per se*, but can be more or less harmful according to specific operations and/or management choices (Bechini and Castoldi, 2006). Maize (the most diffuse crop in the Po valley) was the most frequently over-fertilised crop. Yet, not all maize-based agricultural systems necessarily increase the nutrient surplus of an area. Rain-fed maize, for instance, can have a low nutrient surplus because it is highly efficient at utilising soil resources. Nevertheless, not all irrigated systems menace the environmental quality more than rain-fed ones (as in Morari et al, 2004) as irrigation can enhance crop N uptake, and thereby reduce N losses (Aarts et al., 2000; Langeveld et al., 2007).

Crop utilisation type is also crucial. Our survey results revealed that maize is often fertilized with large amounts of manure and fertiliser, independent of the product collected from the field (kernel only, kernel and straw, silage), therefore the fate of straw has a great impact on the nutrient surplus. According to data obtained at both the territorial and crop scales in the studied agro-environments, NPK surpluses could be lowered to near zero at the MLU scale mainly through mineral input reduction since manure spread alone often satisfies crop needs. Some authors (e.g.: Killingsbaek and Hansen, 2007) have reported that crops utilize the commercial fertiliser N better than manure organic N because of greater gaseous losses in the latter. Moreover, mineral fertilisers are managed more easily and are without constraints associated with livestock husbandry. In fact, the N in mineral fertilisers has been shown to be equally prone to loss as the N is in organic fertilisers (e.g. Sacco et al., 2006). A reduction in mineral inputs, in the interest of a wider use of well-managed organic wastes, could be a sound solution for improving territorial agro-environmental sustainability.

4.2 Are the adopted indicators feasible?

According to Yli-Viikari and Lemola (2004), an indicator is deemed feasibly “good” when input data are readily available. This case study has highlighted several data availability problems: a) the high cost of data collection which leads to few updates; b) heterogeneity of the available data relative to scale and source; and c) little crop scale data on manure spread which forces simplifications in the balance methodology adopted. In this case study, the simplification might have introduced a bias that would underestimate manure inputs to summer crops, and overestimate them to winter crops. Manure might also have been exchanged between MLUs, but such an exchange would be small compared to the agro-environmental scale. Recently, the availability of information about manure spread is rising in Italy due to local application of the Nitrate Directive. In Piemonte for example, large farms have recently been asked to prepare a detailed fertilisation plan, including the amount and timing of both mineral fertiliser and manure spreads. Unfortunately, official statistical data on mineral fertiliser spreads are still not geo-referenced, nor available at a useful scale as they are monitored only at the provincial scale. A simple listing of these many limitations stresses the need for Europe to develop a uniform recording methodology of official agronomic data.

IRENA nutrient budgets were developed to be applied at NUTS 2/3 levels. Even though this scale is administrative, and thus very different from the system-related scale adopted in this study, the applied methodology is shown to be flexible and adaptive to available datasets. Clearly, data collection on a smaller scale is required for environmentally meaningful results (Petersen, 2004), but generally, a GIS-based approach allows broad use of adopted indicators. They could, for instance, be used for practical application of spatial analyses within the context of agricultural policy-making across different scales, from the sub-region to the whole of Europe.

4.3 Are the adopted indicators useful?

If spatial and temporal boundaries of the study are properly defined, the adopted indicators can easily be used for insight into agricultural management in both intensive and extensive environments across different scales.

For example, the GNB indicator calculated for the entire study area (77 kg N ha^{-1}) varied considerably from those reported by OECD (2008) by nation in 2002-2004. GNB was 83 kg ha^{-1} for EU-15 ranging from 39 kg ha^{-1} for Italy and 229 kg ha^{-1} for the Netherlands. Only the Netherlands and Belgium reported national manure rates higher than the threshold of 170 kg N ha^{-1} specified by the Nitrate Directive, whereas manure rates for Italy were approximately 40 kg N ha^{-1}. This study showed an average manure input of 57 kg N ha^{-1} for the Piemonte plain, ranging from 14 kg N ha^{-1} in MLU1 and MLU5 to 94 kg N ha^{-1} in MLU3. Even at the sub-regional scale, the manure N applied in Piemonte was far below the 170 kg N ha^{-1} threshold, suggesting that local farmers understood better the role of mineral fertilisers in increasing the N surplus.

Another application of the adopted indicators was recently performed in Piemonte with regard to P. According to Withers and Haygarth (2005), a high P content in the topsoil increases the risk of losses to the environment. Due to the accumulation of P in farmed soils and its slow transport time, high concentrations in water could persist, even as P surpluses diminish. In Italy, the local application of agro-environmental measures has led to a general decrease in the use of P mineral fertilisers (-26% in the last 15 years, according to OECD, 2008). However, in some areas of Piemonte the amount of soil P has continued to increase (Bourlot et al., 2007). A geo-referenced analysis of more than 18.000 soil analytical data points available in the Regional Soil Analysis database (Menardo et al., 2006) has shown that soil P is increasing in MLUs characterized by the highest P budget surpluses and manure inputs, thus stressing the need for local regulation of manure P crop inputs.

It should be remembered, however, that nutrient budgets are indicators of potential environmental impact and unsustainable resource use. The real nutrient loss in any specific year and site cannot be calculated through the use of soil-surface balances. Territorial data analysis therefore, can be of help in evaluating the temporal changes in the amount of inputs and outputs (e.g.: Liu et al., 2007) or highlight the spatial differences among areas (so-called *hot spots*) where an improved application of the legislation may be more effective.

5. Conclusions

We have developed a geographically-based process for the spatial delineation of different agro-environments, using climate, soil type, land use data from official datasets, and crop productivity data from a territory-wide survey on crop management practices. The described procedure might be extended from this case study to other regions.

The process utilised calculated nutrient budgets in defined agro-environments as indicators of the environmental pressures caused by agricultural activities at the sub-regional and crop levels. These indicators allowed quick assessment of the relative importance of different inputs in surplus determination, thereby enhancing the potential for improved management techniques.

Our work stressed the possibility of a general lowering of mineral fertilisers spread on crops in the study area. The adoption of best practices for fertiliser management could significantly reduce environmental pressures and help reach the 2020 goals to reduce the N, P, and K surpluses by 25 %, 70 %, and 57 %, respectively (EEA, 2005). The concentration of stocking activities in only one out of five studied agro-environments enhances the availability of manure for territorial redistribution. A strategy that moves manure excesses to meet the fertilizer needs of stockless areas would also result in a beneficial increase in the soil organic matter.

The inputs and outputs we relied on to calculate nutrient budgets are simple, consistent with the spatial scale of available data, and widely used for similar agro-environmental studies (e.g.: Folmer et al., 1998; Lesschen et al., 2007, Sleutels et al., 2007). The strength of the nutrient balance approach lies in regular monitoring of related data sets (de Koening et al., 1997; Bechini and Castoldi, 2006). If officially recorded data are not easily manipulated, then costs become a hurdle and updates are difficult and infrequent. Enhancement in the level of detail and in the ease of data recording will lead to wider scientific significance of the described indicators. For instance, in Italy, the availability of all fertilisation-related information is slowly increasing due to the Action Programmes applied locally according to the Nitrate Directive. The creation of a data warehouse aimed at organising both farm-scale and territorial-scale information would be a powerful tool for the evaluation of different sustainability scenarios.

Acknowledgements

This work was funded by Regione Piemonte, Assessorato Agricoltura Tutela della Fauna e della Flora. The authors wish to thank Joan C. Leonard for her helpful suggestions in the text revision.

References

Aarts, H.F.M., Habekotté, B., van Keulen, H., 2000. Groundwater recharge through optimised intensive dairy farms. J. Environ. Qual. 29, 738-743.

ADAS Consulting Ltd, NIVA, 2004. Assessment of NVZ designations in Italy. Report to EC DG Environment, Contract B4-3040/2001/345431/MAR/B.1, Scientific and technical assistance in relation to the implementation of the Nitrates Directive (91/676/EEC), 130 pp.

AdBPo (Autorità di Bacino del Fiume Po), 2006. Caratteristiche del bacino del Fiume Po e primo esame dell'impatto ambientale delle attività umane sulle risorse idriche. 643 pp., available online at www.adbpo.it (verified 26/03/2010) (in Italian).

Bassanino, M., Sacco, D., Zavattaro, L., Grignani, C., 2006. Aree agronomicamente omogenee. In: (ARPA Ed.) Rapporto sullo stato dell'ambiente in Piemonte 2006, page 231 (in Italian).

Bassanino, M., Grignani, C., Sacco, D., Allisiardi, E., 2007a. Nitrogen balances at the crop and farm-gate scale in livestock farms in Italy. Agric. Ecosys. Environ. 122, 282-294.

Bassanino, M., Grignani, C., Sacco, D., Allisiardi, E., 2007b. Stimare entrate e uscite di azoto per allevamenti più efficienti. Inf. Agrario 30, 28-33 (in Italian).

Bechini, L., Castoldi, N., 2006. Calculating the soil surface nitrogen balance at regional scale: example application and critical evaluation of tools and data. Italian J. Agron. 4, 665-676.

Bindraban, P.S., Stoorvogel, J.J., Jansen, D.M., Vlaming, J., Groot, J.J.R., 2000. Land quality indicators for sustainable land management: proposed method for yield gap and soil nutrient balance. Agric. Ecosys. Environ. 81, 103-112.

Bockstaller, C., Girardin, P., van der Werf, H.M.G., 1997. Use of agro-ecological indicators for the evaluation of farming systems. Eur. J. Agron. 7, 261-270.

Bourlot, G., Barberis, E., Del Vecchio, A., Menardo, S., Sacco, D., 2007. Il Suolo Agrario Piemontese. Analisi, organizzazione dei dati e applicazioni. Quaderni della Regione Piemonte - Agricoltura 56 suppl., 63 pp. (in Italian).

Brouwer, F., 1998. Nitrogen balances at farm level as a tool to monitor effects of agri-environmental policy. Nutr. Cycl. Agroecosys. 52, 303-308.

Chardon, W., Withers, P., 2003. Introduction to papers from the EU-COST Action 832. Quantifying the agricultural contribution to eutrophication. J. Plant Nutr. Soil Sc. 166, 401.

COM, 2000. Indicators for the integration of environmental concerns into the Common Agricultural Policy. Bruxelles, available online at www.europa.eu (verified 26/03/2010).

de Koening, G.H.J., van der Kop, P.J., Fresco, L.O., 1997. Estimates of sub-national nutrient balances as sustainability indicators for agro-ecosystems in Ecuador. Agric. Ecosys. Environ. 65, 127-139.

D.Lgs. 152/2006 (Decreto Legislativo 3 aprile 2006, n. 152). Norme in materia ambientale. G.U. n. 88, Suppl. ord. n. 96, del 14 aprile 2006, available online at www.parlamento.it (verified 26/03/2010) (in Italian).

D.M. 7 aprile 2006 (Decreto Ministeriale - Ministero Politiche agricole e forestali). Criteri e norme tecniche generali per la disciplina regionale dell'utilizzazione agronomica degli effluenti di allevamento, di cui all'articolo 38 del decreto legislativo n. 152 del 1999. G.U. n. 109 del 12 maggio 2006, available online at www.parlamento.it (verified 26/03/2010) (in Italian).

EEA (European Environmental Agency), 2005. European environment outlook. Report 4 –2005, Copenhagen, Denmark.

EEA (European Environmental Agency), 2006. Integration of environment into EU agriculture policy— the IRENA indicator-based assessment report. Report 2 -2006, Copenhagen, Denmark.

Eswaran, H., Beinroth, F.H., Birmani, S.M., 2000. Resource management domains: a biophysical unit for assessing and monitoring land quality. Agric. Ecosys. Environ. 81, 155-162.

Folmer, E.C.R., Geurts, P.M.H., Francisco, J.R., 1998. Assessment of soil fertility depletion in Mozambique. Agric. Ecosys. Environ. 71, 159-167.

Grignani, C., Zavattaro, L., 1999. Migliorare la gestione agronomica dei reflui zootecnici. Inf. Agrario 41, 28-32 (in Italian).

Grignani, C., Bassanino, M., Sacco, D., Zavattaro, L., 2003. Il bilancio degli elementi nutritivi per la redazione del piano di concimazione. Riv. Agron. 37, 155-172 (in Italian).

Halberg, N., Verschuur, G., Goodlass, G., 2005. Farm level environmental indicators; are they useful? An overview of green accounting systems for European farms. Agric. Ecosys. Environ. 105, 195–212.

Isermann, K., Isermann, R., 1998. Food production and consumption in Germany: N flows and N emissions. Nutr. Cycl. Agroecosys. 52, 289-301.

ISNP (Istituto Superiore di Nutrizione delle Piante), 2003. Rassegna dei concimi minerali presenti sul mercato italiano. Inf. Agrario 50 (suppl. 1), 50 pp. (in Italian).

ISTAT (Istituto Nazionale di Statistica), 2000. V Censimento nazionale dell'agricoltura. Dataset available online at www.istat.it (verified 26/03/2010) (in Italian).

Killingsbaek, A., Hansen, J.F., 2007. Development in nutrient balances in Danish agriculture 1980-2004. Nutr. Cycl. Agroecosys. 79, 267-280.

Kimura, S.D., Hatano, R., 2007. An eco-balance approach to the evaluation of historical changes in nitrogen loads at a regional scale. Agric. Sys. 94 (2), 165-176.

Koelsch, R., Lesoing, G., 1999. Nutrient balance on Nebraska livestock confinement systems. J. Anim. Sci. 77 (2/J), 63–71.

Kutra, G., Aksomaitiene, R., 2003. Use of nutrient balances for environmental impact calculations on experimental field scale. Eur. J. Agron. 20, 127–135.

Langeveld, J.W.A., Verhagen, A., Neeteson, J.J., van Keulen, H., Conijn, J.G., Schils, R.L.M., Oenema, O., 2007. Evaluating farm performance using agro-environmental indicators: recent experiences for nitrogen management in the Netherlands. J. Environ. Manag. 82, 363-376.

Leeson, J.Y., Sheard, J.W., Thomas, A.G., 1999. Multivariate classification of farming systems for use in a integrated pest management studies. Can. J. Plant Sci. 79, 647-654.

Lesschen, J.P., Stoorvogel, J.J., Smaling, E.M.A., Heuvelink, G.B.M., Veldkamp, A., 2007. A spatially explicit methodology to quantify soil nutrient balances and their uncertainties at the national level. Nutr. Cycl. Agroecosys. 78, 111-113.

Liu, C., Watanabe, M., Wang, Q., 2007. Changes in nitrogen budgets and nitrogen use efficiency in the agroecosystems of the Changjiang River basin between 1980 and 2000. Nutr. Cycl. Agroecosys. 80, 19-37.

Menardo, S., del Vecchio, A., Sacco, D., Bourlot, G., 2006. Elaborazioni statistico-descrittive della Banca Dati Regionale dei Terreni Agrari. In: (ARPA Ed.) Rapporto sullo stato dell'ambiente in Piemonte 2006, 226-230 (in Italian).

Morari, F., Lugato, E., Borin, M., 2004. An integrated non-point source model-GIS system for selecting criteria of best management practices in the Po Valley, North Italy. Agric. Ecosys. Environ. 102, 247-262.

Öborn, I., Andrist-Rangel, Y., Askegaard, M., Grant, C.A., Watson, C.A., Edwards, A.C., 2005. Critical aspects of potassium management in agricultural systems. Soil Use Manag. 21, 102-112.

OECD, 2001. Environmental indicators for agriculture: methods and results. OECD Ed., Paris, France.

OECD, 2008. Environmental performance of agriculture in OECD countries since 1990. OECD Ed., Paris, France.

Oenema, O., Kros, H., de Vries, W., 2003. Approaches and uncertainties in nutrient budgets: implications for nutrient management and environmental policies. Eur. J. Agron. 20, 3-16.

Parris, K., 1998. Agricultural nutrient balances as agro-environmental indicators: an OECD perspective. Environ. Pollut. 102 (S1), 219-225.

Payraudeau, S., van der Werf, H.M.G., 2005. Environmental impact assessment for a farming region: a review of methods. Agric. Ecosys. Environ. 107, 1-19.

Petersen, J.E., 2004. Development of farm management indicators in the EU. Work under the EU's IRENA operation. Proceedings of the OECD Expert Meeting "Farm management indicators and the environment", 8-12 march 2004, Palmerston, New Zealand.

Regione Piemonte, 2000. Piano di sviluppo Rurale 2000-2006. Parte I: Aspetti generali. DGR 118-704, 31/07/2000 (in Italian).

Regione Piemonte, 2008a. Banca dati agrometeorologica. Database available online at www.sistemapiemonte.it/agricoltura/agrometeo (verified 26/03/2010) (in Italian).

Regione Piemonte, 2008b. Carta dei suoli 1:250.000. Database available online at www.regione.piemonte.it/agri /suoli_terreni/index.htm (verified 26/03/2010) (in Italian).

Regione Piemonte, 2008c. Sistema Informativo Territoriale Ambientale Diffuso. Database available online at www.sistemapiemonte.it/serviziositad/index.shtml (verified 26/03/2010) (in Italian).

Saam, H., Powell, J.M., Jackson-Smith, D.B., Bland, W.L., Posner, J.L., 2005. Use of animal density to estimate manure nutrient recycling ability of Wisconsin dairy farms. Agric. Sys. 84 (3), 343-357.

Sacco, D., Bassanino, M., Grignani, C., 2003. Developing a regional agronomic information system for estimating nutrient balances at a larger scale. Eur. J. Agron. 20 (1–2), 199–210.

Sacco, D., Zavattaro, L., Grignani, C., 2006. Regional-scale prediction of agricultural N losses in an area with a high livestock density. It. J. Agron. 4, 689–703.

Schröder, J.J., Neeteson J.J., Oenema, O., Struik, P.C., 2000. Does the crop or the soil indicate how to save nitrogen in maize production? Reviewing the state of the art. Field Crops Res. 66 (2), 151-164.

Sieling, K., Kage, H., 2006. N balance as an indicator of N leaching in an oilseed rape–winter wheat–winter barley rotation. Agric. Ecosys. Environ. 115, 261–269.

Silva, J.F., Farinas, M.R., Felfili, J.M., Klink, C.A., 2006. Spatial heterogeneity, land use and conservation in the cerrado region of Brazil. J. Biogeography 33, 536-548.

Sleutels, S., de Neve, S., Hofman, G., 2007. Assessing causes of recent organic carbon losses from cropland soils by means of regional-scale input balances for the case of Flanders (Belgium). Nutr. Cycl. Agroecosys. 78, 265-278.

Stein, A., Riley, J., Halberg, N., 2001. Issues of scale for environmental indicators. Agric. Ecosys. Environ. 87, 215-232.

van Beek, C.L., Brouwer, L., Oenema, O., 2003. The use of farmgate balances as estimator for nitrogen leaching to surface waters. Nutr. Cycl. Agroecosys., 67, 233–244.

van der Molen, D.T., Breeuwsma, A., Boers, P.C.M., 1998. Agricultural nutrient losses to surface waters in The Netherlands: impacts, strategies and perspectives. J. Environ. Qual. 27, 4–11.

van Eerdt, M.M., Fong, P.K.N., 1998. The monitoring of nitrogen surpluses from agriculture. Environ. Pollut. 102 (S1), 227-233.

Withers, P.J.A., Haygarth, P.M., 2005. Agriculture, phosphorus and eutrophication: a European perspective. Soil Use Manag. 23 (Suppl. 1), 1–4.

Yli-Viikari, A., Lemola, R., 2004. Usability of management indicators – considerations from a Finnish perspective. Proceedings of the OECD Expert Meeting "Farm management indicators and the environment", 8-12 march 2004, Palmerston, New Zealand.

Yli-Viikari, A., Vietala-Koivu, R., Huusela-Veistola, E., Hyvönen, T., Perälä, P., Turtola, E., 2007. Evaluating agro-environmental indicators (AEIs) – Use and limitations of international indicators at national level. Ecolog. Indic. 7, 150-163.

Zavattaro, L., Romani, M., Sacco, D., Bassanino, M., Grignani, C., 2006. Fertilization management of paddy fields in Piedmont (NW Italy) and its effect on the soil and water quality. Paddy Water Env. 4, 61-66.

Zavattaro, L., Romani, M., Sacco, D., Bassanino, M., Grignani, C., 2008. Fertilization management of paddy fields in Piedmont (NW Italy). It. J. Agron. 3(3): 201-212.

Table 1 – Overview of data sets used for delineation of the Agronomic Land Units (ALU).

Data	**Source**	**Detail**	**Derived information**
Climate	Regione Piemonte, 2008a	Map 1:250.000	Climatic areas
Soil type	Regione Piemonte, 2008b	Map 1:250.000	Soil homogeneous areas
Land use	Census of Agriculture (ISTAT, 2000)	Municipality	Crop frequency (% UAA)
Crop yield	Specific territorial survey	Map 1:250.000	Yield (t DM ha^{-1})
Cadastral map	Regione Piemonte, 2008c	Cadastral Units	Cadastral unit borders

Table 2 – Crop frequency (% Utilized Agricultural Area) in the five Macro Land Units (MLU) identified in the study area.

	MLU					
	1	**2**	**3**	**4**	**5**	**All the MLUs**
maize for grain	12.9	19.1	37.0	16.6	17.1	**25.5**
leys and meadows	13.7	11.9	26.7	43.3	2.5	**22.0**
rice	1.3	0.3	0.6	0.7	69.2	**15.0**
winter wheat	26.1	33.6	9.0	11.5	1.0	**11.7**
soybean. bean and pea	1.4	1.1	4.6	3.9	4.4	**3.8**
vineyards	18.7	2.7	2.4	5.2	0.3	**3.7**
other winter cereals	6.8	5.0	3.4	4.3	1.2	**3.5**
maize for silage	0.2	0.5	6.4	3.2	0.7	**3.5**
poplar trees	3.8	2.9	3.5	2.4	2.3	**3.0**
fruit trees	0.9	0.8	4.1	5.6	0.0	**2.9**
rapeseed and sunflower	8.8	5.8	0.8	1.3	0.7	**2.0**
sugar beet	3.7	11.7	0.2	0.8	0.4	**1.8**
vegetables	1.6	4.7	1.2	1.1	0.3	**1.4**
total	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**
UAA (ha)	**44,482**	**63,564**	**255,051**	**105,518**	**124,358**	**592,973**

Table 3 – Main characteristics of the farming systems in the five Macro Land Units (MLUs) identified in the study area.

		MLU					
		1	**2**	**3**	**4**	**5**	**All MLUs**
Farms	n.	6,269	4,894	24,189	14,860	3,877	**54,089**
Livestock farms	% total	7.9	7.8	31.3	30.7	7.5	**24.6**
Stocking rate							
in livestock farms	t l.w. ha^{-1}	0.7	0.7	2.7	1.6	7.2	**2.3**
in the whole MLU		0.1	0.2	0.9	0.6	0.1	**0.5**
Farm land	UAA ha $farm^{-1}$	7.7	14.1	10.8	7.3	39.0	**11.8**
Irrigated	% UAA	7	31	65	32	81	**47**
Covered during winter		17	16	24	37	6	**25**
Ploughed every year		63	82	63	44	95	**68**
Biologically fixing N		5	7	4	5	4	**5**

Table 4 – Yield (tons of DM ha^{-1}, grain only) of the main crops in the five Macro Land Units (MLU) identified in the study area.

	MLU					
	1	**2**	**3**	**4**	**5**	**All MLUs**
maize	7.1	8.0	10.2	8.6	8.8	**9.4**
leys and meadows	8.8	9.4	9.1	8.9	9.3	**9.1**
rice	6.1	6.1	5.6	6.0	5.8	**5.8**
winter wheat	3.9	4.4	4.5	4.0	4.5	**4.3**

Table 5 – Annual inputs, outputs and nutrient surpluses for the five Macro Land Units (MLUs) identified in the study area. Standard deviation represents the variability between different ALUs in each MLU. MLU averages were tested using Kruskal Wallis H test.

	fertilisers	manure	others	harvested	*GNB*	
MLU	kg N ha^{-1} yr^{-1}				*Avg.*	*SD*
1	89	14	40	95	**49**	*3.8*
2	140	16	38	121	**74**	*11.2*
3	127	94	43	161	**103**	*37.2*
4	81	60	52	140	**53**	*41.2*
5	137	14	32	128	**56**	*40.7*
Total	**120**	**57**	**42**	**141**	**77**	***43.1***
Sig.	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	

	fertilizers	manure	harvested	*GPB*	
MLU	kg P ha^{-1} yr^{-1}			*Avg.*	*SD*
1	25	7	19	**12**	*4.5*
2	33	7	22	**18**	*6.4*
3	26	43	31	**39**	*17.4*
4	22	28	27	**22**	*10.6*
5	22	7	27	**2**	*17.6*
Total	**25**	**26**	**27**	**24**	***20.7***
Sig.	*0.000*	*0.000*	*0.000*	*0.000*	

	fertilizers	manure	harvested	*GKB*	
MLU	kg K ha^{-1} yr^{-1}			*Avg.*	*SD*
1	75	17	71	**20**	*13.8*
2	75	20	75	**20**	*18.9*
3	91	110	106	**95**	*46.5*
4	62	72	116	**19**	*40.2*
5	116	15	65	**65**	*48.1*
Total	**88**	**67**	**93**	**62**	***50.7***
Sig.	*0.000*	*0.000*	*0.000*	*0.000*	

Table 6 – Nutrient budget results for the main crops in each of the five Macro Land Units (MLUs) identified in the study area.

	MLU	Maize for grain	Maize for silage	Leys and meadows	Rice*	Winter wheat**
GNB						
(kg N ha^{-1} yr^{-1})	1	103	67	-40	116	82
	2	131	47	-24	118	99
	3	175	88	-11	161	148
	4	130	27	-9	157	115
	5	150	98	4	43	10
GPB						
(kg P ha^{-1} yr^{-1})	1	28	20	6	-7	10
	2	24	-17	9	-6	16
	3	52	35	22	25	37
	4	36	17	13	14	27
	5	12	-6	-8	0	-2
GKB						
(kg K ha^{-1} yr^{-1})	1	58	-27	-69	92	47
	2	54	-123	-100	95	58
	3	180	18	-50	174	172
	4	114	-30	-73	146	110
	5	44	-54	-116	87	-18

* The straw is removed, buried or burnt according to local strategies; this information was spatially elaborated in order to calculate different NPK removals per each ALU.

** The straw is always removed from the field.

Table 7– Mineral N fertilization management for the main crops in each of the five Macro Land Units (MLUs) identified in the study area.

	MLU	**Maize for grain**	**Maize for silage**	**Leys and meadows**	**Rice**	**Winter wheat**
Mineral input (kg N ha^{-1} yr^{-1})	1	158	157	47	194	130
	2	221	191	87	190	154
	3	218	218	27	150	128
	4	184	173	43	189	112
	5	270	270	83	121	123
Top dressing* (% mineral input)	1	0.81	0.81	0.93	n.a.	1.00
	2	0.84	0.96	1.00	n.a.	0.98
	3	0.73	0.73	1.00	n.a.	0.87
	4	0.75	0.72	1.00	n.a.	0.88
	5	0.65	0.65	1.00	0.51	0.42

* Information about top dressing on rice was spatially elaborated only for the paddy area (MLU5), where almost all the rice is cultivated.

Figure 1 – Inputs and outputs (kg NPK ha^{-1}) for calculation of the nutrient budget at the Agronomic Land Unit (ALU) scale.

Figure 2 – Delineation of the five Macro Land Units (MLUs) as an aggregation of the Agronomic Land Units (ALUs) by means of cluster analysis in the Piemonte Region, NW Italy.

Figure 1

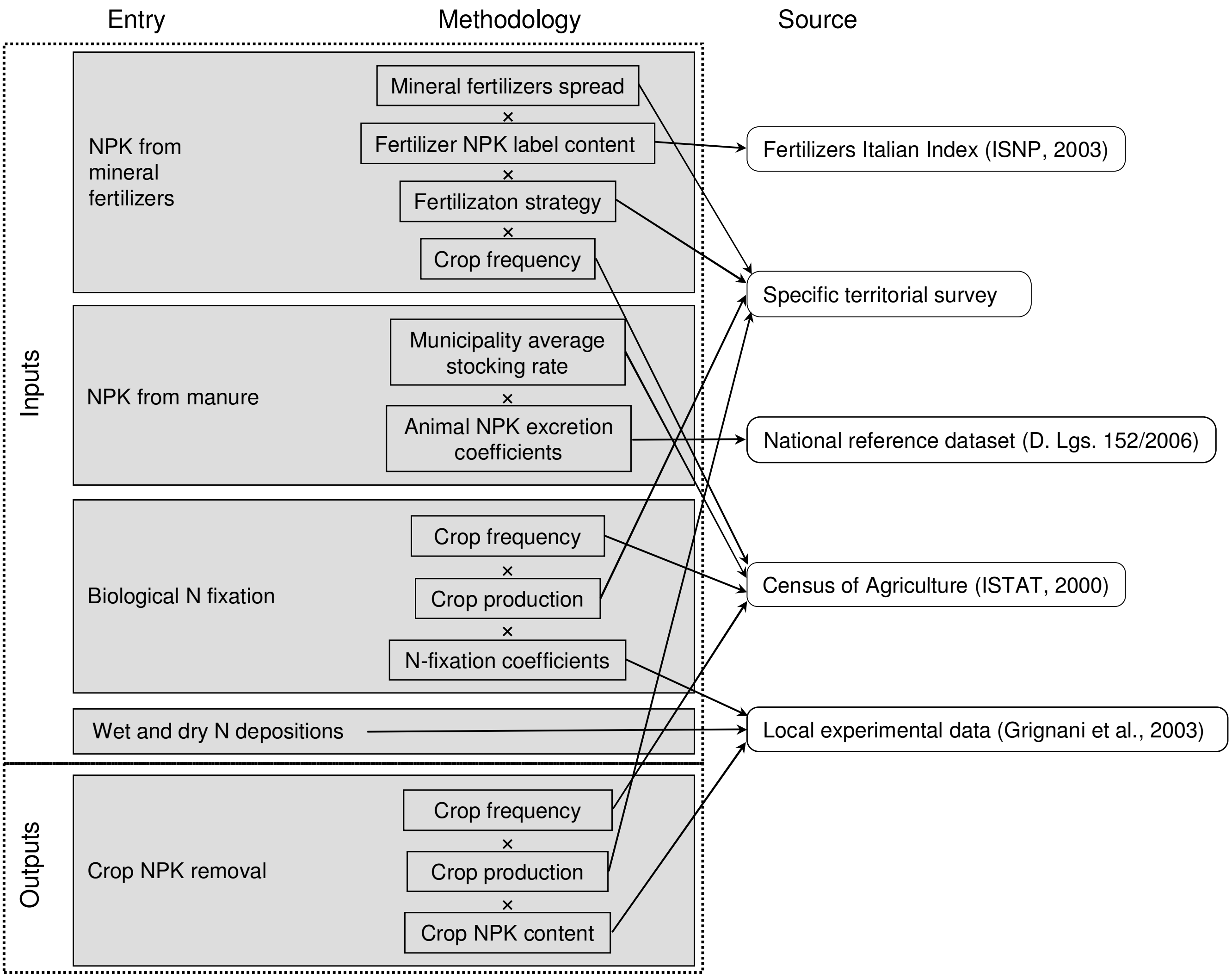
Entry
Methodology
Source
Inputs
NPK from mineral fertilizers
Mineral fertilizers spread
×
Fertilizer NPK label content
×
Fertilizaton strategy
×
Crop frequency
NPK from manure
Municipality average stocking rate
×
Animal NPK excretion coefficients
Biological N fixation
Crop frequency
×
Crop production
×
N-fixation coefficients
Wet and dry N depositions
Outputs
Crop NPK removal
Crop frequency
×
Crop production
×
Crop NPK content
Fertilizers Italian Index (ISNP, 2003)
Specific territorial survey
National reference dataset (D. Lgs. 152/2006)
Census of Agriculture (ISTAT, 2000)
Local experimental data (Grignani et al., 2003)

Figure 2