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# UNIVERSITÀ DEGLI STUDI DI TORINO

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

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

3

#### 4 Abstract

5 Regionally mandated budgets often ignore important sub-regional differences. To help identify hot-6 spots, where environmental pressures and agricultural activities combine and heighten the need to 7 optimise farming strategies, we recommend using detailed spatial target analysis. 8 In this paper, we propose a methodology for identifying different agro-environments, test that 9 method in a case-study territory in the western Po River plain (the largest and most intensive 10 agricultural area in Italy), and then calculate the nutrient budget indicators of these defined agro-11 environments as a means to assess environmental sustainability. 12 We identified five Macro Land Units (MLUs) representing five different agro-environments from 13 official datasets and territorial surveys, detected and quantified land use, crop productivity, and 14 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<sup>-1</sup> for N, 15 16 P, and K, respectively) were detected in the most intensely managed area. N surpluses were 17 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<sup>-1</sup> threshold; at the crop scale, maize showed the 18 19 least-optimised fertilisation management. 20 This work suggests that GIS-based analysis of environmental pressures of agricultural activities at a 21 sub-regional level is useful for identifying areas and crops for which fertilization must be well 22 managed. The proposed methodology depends on accurate collection and collation of farm data into 23 GIS databases; public authorities should promote investment in planning and managing data 24 collection in agriculture.

26 Key-words: Agro-environmental indicators, fertilisation management, GIS-based spatial analysis,

27 gross nutrient balance, Po river plain, territorial scale.

28

## 29 **Definitions**

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

32 area of 2,100 ha.

- 33 Province: According to EUROSTAT (1059/2003/EEC), it corresponds to the NUTS-3 territorial
- 34 level. In the Piemonte region there are 8 provinces, ranging from 91,000 to 690,000 ha.
- 35 Region: According to EUROSTAT (1059/2003/EEC), it corresponds to the NUTS-2 territorial
- 36 level. The Piemonte region covers 2,540,753 ha.

#### 38 1. Introduction

39 European agriculture contributes 30% to 80% of nitrogen (N) and 20% to 70% of phosphorus (P) 40 loads to water bodies (OECD, 2008). The Water Framework Directive (2000/60/CE) states that 41 protection of water resources can be achieved only through a reduction of pollution from all 42 agricultural sources—both potential (nutrient loads from fertilisation) and actual (measurable 43 pollutants reaching water bodies). This focus makes diagnosis of the environmental impact of 44 farming systems the primary step in the process of assessing agricultural sustainability (Payraudeau 45 and van der Werf, 2005). 46 Agro-environmental indicators (AEIs) are key tools for assessing the environmental impact of 47 agriculture (Stein et al., 2001). Among the AEIs used for fertilisation management, nutrient budget 48 is the most common (Langeveld et al., 2007). Its versatility is well-documented; it can serve as an 49 analytical instrument (Isermann and Isermann, 1998), performance indicator (e.g.: Folmer et al., 50 1998; Bassanino et al., 2007a), or legislative threshold (Oenema et al., 2003) in the field (Kutra and 51 Aksomaitiene, 2003; Sieling and Kage, 2006), on the farm (Bockstaller et al., 1997; Brouwer, 52 1998), or at the scale of the territory (Sacco et al., 2003; Kimura and Hatano, 2007). Nutrient budget 53 analyses have most often focused on N, and to a lesser degree on P, even though agriculture can 54 contribute large amounts of P inputs to water ecosystems leading to eutrophication (Chardon and 55 Withers, 2003). Potassium (K) balances are often altogether ignored. Generally, K is not a limiting 56 element for water system quality, but Öborn et al. (2005) finds agronomic value in determining K 57 budgets for long-term soil sustainability, crop quality, and grassland yield purposes. Furthermore, a 58 general interest in P and K optimisation exists due to the fact that these fertilisers come from 59 limited, non-renewable resources. The largest and most intensive agricultural area in Italy is the Po River catchment; 70,700 km<sup>2</sup> host 60 61 75% of the livestock and 36% of the Utilized Agricultural Area (UAA) at the national scale

62 (ISTAT, 2000). Cropping system inputs in this area are often very high (e.g.: Bassanino et al.,

63 2007a). Commensurate with the poor water quality of the Adriatic Sea, into which the Po River

64	collects, the European Commission has asked Italy to extend the Nitrate Vulnerable Zones (now								
65	covering 50% of the Po plain) to the entire river catchment (ADAS and NIVA, 2004). Such an								
66	extension would fail to consider the very different agro-environments that co-exist in this expanse								
67	stocking and stockless, irrigated and non-irrigated, intensive and extensive farming systems								
68	(AdBPo, 2006). According to Parris (1998), regional-scale budgets mask important sub-regional								
69	differences; hence, national values need to be interpreted with caution (OECD, 2008). A detailed								
70	spatial targeting analysis has been recommended (EEA, 2006) to start identifying "hot-spots,"								
71	where the environmental pressures of agricultural activities are magnified and the need for farming								
72	strategy optimisation is urgent.								
73	The western part of the Po river plain is a site where nutrient budgets can be applied at a sub-								
74	regional level to spatially define local agricultural pressure. The coexistence of different cropping								
75	systems makes analysis of sustainability scenarios complex, but informs us of the specifics that								
76	each agro-environment plays in the regional scale budget. In this paper, we have three objectives:								
77	a) to develop a methodology for the geographical delineation of different agro-environments								
78	using existing databases and local data, and then test it in a case-study territory;								
79	b) to assess the sustainability of previously defined agro-environments according to some								
80	nutrient budget indicators;								
81	c) to verify the feasibility and effectiveness of the adopted indicators.								
82									
83	2. Materials and methods								
84	2.1 The study area								
85	The study focused on northwest Italy in the Piemonte region, between $44^{\circ}20'$ and $45^{\circ}50'$ N and								
86	7°20' and 8°50' E, covering 35% of the Po River catchment. The climate is temperate sub-								
87	continental, with an annual mean precipitation of 850 mm (spring and autumn are the main rainy								
88	periods) and an annual mean temperature of 12°C. The total area of Piemonte is 2,540,000 ha; the								
89	Utilized Agricultural Area (UAA) accounts for 1,075,000 ha only, due to wide mountain areas.								

90 According to Regione Piemonte (2000), agriculture takes place on the plain (41% of UAA), mainly 91 with maize-based systems, and on the hills (31% of UAA), mainly with vineyards and winter 92 cereals. Irrigation ranges from less than 10% (southeast hilly provinces) to more than 70% 93 (northeast paddy area) of the UAA. Livestock farms account for 25% of all farms. The livestock density averages 1.0 livestock unit (LU) ha<sup>-1</sup>, reaching 2.0 LU ha<sup>-1</sup> in the central-southern 94 provinces. At the scale of the farm, as many as 2.5-5.0 LU ha<sup>-1</sup> are not uncommon due to intensive 95 96 breeding systems of both swine and bovine livestock (Bassanino et al., 2007a). 97 This work focuses only on the plain, where agro-environments are defined mainly by land use, and 98 are influenced by the role of livestock husbandry activities and by crop yield as a function of water 99 availability for irrigation. Although it is easy to describe agro-environmental characteristics, their 100 territorial boundaries are difficult to identify in a scientific way. Nevertheless, spatially targeted

101 data are needed to assess the agro-environmental sustainability of a territory.

#### 102 2.2 Data collection

103 According to Eswaran et al. (2000), an agro-environment is a geographic unit characterized by 104 homogeneous agricultural use and land qualities. To do so required that we identify the different 105 agro-environments in the study area on the basis of the soil, climate, land use and farming systems 106 characteristics, delineate their spatial boundaries, and then characterize them through averaging 107 spatially-distributed parameters (crop frequency, farming systems, yields). First, we defined 108 working units at a more detailed scale and collected data for each. These units were homogeneous 109 in climate, soil type, land use, and crop productivity, and were spatially delineated as follows. 110 Official datasets provided data about climate (Regione Piemonte, 2008a), soil (Regione Piemonte, 111 2008b) and land use (ISTAT, 2000). Crop productivity data, on the other hand, were neither 112 available at the desired level of detail, nor were they geo-referenced (Grignani et al., 2003). Given 113 the lack of data, we were forced to use experts or educational extension technical literature as viable 114 information sources (van Eerdt and Fong, 1998). As has been done in other studies (e.g.: Bindraban 115 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).

121 2.3 Spatial analysis

122 In order to select the proper spatial units for data collection, a digital intersection of the available

123 data (Table 1), similar to Folmer et al. (1998), was done by means of a geographical information

124 system (GIS). Data combination, also reported in Bassanino et al. (2006), allowed the identification

125 of 125 land units (Agronomic Land Units, ALUs) defined by homogeneous climate, soil type, land

126 cover, and crop productivity.

127 ALUs were outlined according to the cadastral borders (Regione Piemonte, 2008c) to allow for

128 further joining with other datasets. We integrated ALU information with the animal stocking rate

129 official dataset (ISTAT, 2000), available at the municipality level. We coupled the stocking rates to

130 the NPK excretion coefficients adopted for Italian application of the Nitrate Directive (D. Lgs.

131 152/2006) to calculate the manure input per municipality and per ALU.

132 ALUs represent the smallest homogeneous units of land that can be identified at the working scale,

133 and they can differ only for very specific aspects. They are too detailed to be regarded as agro-

134 environments of the study region. In order to aggregate units into a higher hierarchical level, ALUs

135 were grouped using a cluster analysis procedure (Leeson et al., 1999; Silva et al., 2006) applied to

136 land use variables. Land use was sufficient to separate clusters because it condensed soil and

137 climate characteristics, as it depends on them. Euclidean distance was used as the separation

138 method. The cluster analysis produced a higher-scale set of units for the study territory and allowed

139 us to identify a clear spatial structure at the aggregated level that identified five separate areas, that

140 we called Macro Land Units (MLUs). As these areas were different in terms of agricultural use and

141 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.

147 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).

153 Since the year 2000, the IRENA (Indicator Reporting on the Integration of Environmental Concerns

154 into Agriculture Policy) European Project coordinated by the European Environmental Agency

155 (COM, 2000) selected and identified 35 AEIs, including two nutrient budget indicators: Gross

156 Nitrogen Balance (GNB, IRENA 18.1) and Gross Phosphorus Balance (GPB, IRENA 18.2).

157 IRENA indicators are intended specifically to help target agro-environmental measures and they

158 provide information concerning agro-ecosystems in the European Union (EEA, 2006). As the

159 IRENA gross nutrient budgets are the most recent set of indicators for an interregional comparison

160 of agro-environmental performance, we tested them in a territorial case study, in part to evaluate

161 their feasibility and effectiveness.

162 Gross balances were calculated for N (GNB), P (GPB), and K (GKB) according to the following

163 equation contained in the IRENA operation sheets:

 $164 \quad GB = fertilisers + manures + others - harvested,$ 

165 where fertilisers represents N, P, or K in applied mineral fertilisers; manures represents N, P, or K

166 in manure inputs; others equals N from wet and dry atmospheric depositions and legume crop

7

(1)

167 symbiotic fixation; harvested represents N, P, or K collected from the field through grain, straw,

and forage.

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

170 As the K balance is not included in the IRENA indicators, we computed the GKB indicator in a

- 171 similar way to the GPB indicator.
- 172 2.5 Calculation of nutrient budgets
- 173 According to the methodology described in Figure 1, we calculated N, P, and K nutrient budgets for

174 each ALU. We calculated crop nutrient removal through the average yield described by the

175 territorial survey within each ALU as well as the average NPK content of kernel and straw collected

176 by local experimental data (Grignani et al., 2003).

177 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

179 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

181 fertilisation technique per each crop and ALU.

182 We assumed that the manure produced within a municipality to be homogeneously spread to all

183 crops in the municipality. This simplified assumption, also adopted by de Koening et al. (1997) and

184 Saam et al. (2005), was formed from two considerations. First, data from farmers of single crop

185 manure applications are often incomplete, inconsistent, or unreliable, as reported in Piemonte

186 (Grignani and Zavattaro, 1999) and other European regions (Oenema et al., 2003; Bechini and

187 Castoldi, 2006). Some authors (e.g.: Lesschen et al., 2007) used to estimate the manure spread

188 according to crop requirements, but we now know that farmers often neglect organic input in their

189 fertilisation planning, accounting for mineral fertilisers only. The second consideration stems from

190 legislation in Piemonte today requiring farmers to delocalise excess farm manure to surrounding

191 neighbourhoods to better balance manure N load at the territorial scale. This practice effectively

192 makes manured cropland match the total amount of available cropland (Sacco et al., 2003).

- 193 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.
- 196 Due to the lack of official data, we estimated the wet and dry N depositions based on local data
- 197 collected at an experimental monitoring station (Grignani et al., 2003). This input value (26 kg N
- ha<sup>-1</sup>) is slightly higher than the national average (20 kg N ha<sup>-1</sup>, according to the law D.M. 7 aprile

199 2006).

- 200 All crop management data obtained at the ALU scale were weighted within each MLU based on
- 201 relative UAA in order to account for crop area and frequency.
- 202

203 **3. Results** 

#### 204 3.1 Geographical identification of the agro-environments

205 Cluster analysis of ALU data allowed geographical identification of five MLUs (Figure 2)

206 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

208 identify an agro-environment.

209 Livestock husbandry set apart two MLUs. While more than 30% of the farms in each contained

210 livestock, MLU3 was a widely irrigated, highly productive maize-based area and MLU4 was a

- 211 scarcely irrigated, but productive grass-based area. Conversely, the other MLUs conducted little
- 212 livestock husbandry—less than 10% of the farms housed animals. Among these three areas, MLU5

213 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

215 productive winter wheat-based area.

216 Of the two MLUs with high livestock levels, MLU3, covering 43% of the total UAA, showed a

217 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.

231 MLU1 and MLU2 were stockless areas. Here, the lack of water for irrigation had traditionally 232 limited the presence of maize and grass, the most common forage crops. Soils were silt loam, silt, or 233 silty clay loam, sub-alkaline, with a poor content of organic matter and a normal content of Olsen P. 234 Due to the fine soil texture, fields were usually ploughed in autumn and left bare during the winter. 235 In MLU2, farm size was slightly larger than the regional average, and crop productivity was good 236 thanks to farmers' technical skills. In MLU1, where irrigation was rare, winter cereals and 237 vineyards were the prevailing crops. Farms were smaller and crop productivity was much lower 238 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 intensivelymanaged, yielding a very high farm livestock density.

#### 244 3.2 Assessment of the agro-environmental performances

245 Table 5 reports the N, P, and K budget results for each MLU. Statistically significant differences 246 were found for both indicators and nutrient budget components (P<0.000) among the MLUs. 247 MLU3 was the most intensively managed of the agro-environments as shown by its highest crop 248 productivity (161 kg N ha<sup>-1</sup>), high mineral inputs (127 kg N ha<sup>-1</sup>) and large water supply. MLU3 also ranked highest in net nutrient surpluses. Even though surpluses (103 kg ha<sup>-1</sup> for N, 39 for P, 249 250 and 95 for K, respectively) were principally driven by the quantity of manure spread, reflecting the 251 high livestock density, mineral fertiliser management still played an important role in determining 252 the surpluses. The manure input, combined with N natural sources, covered 85%, 139%, and 104% 253 of the harvested N, P, and K, respectively; therefore, the mineral input added to manure could easily 254 be reduced. MLU2 showed the second highest level of nutrient surpluses: 74, 18, and 20 kg ha<sup>-1</sup> for N, P, and K, 255 256 respectively. This agro-environment was characterized by a reduced availability of water; 257 nonetheless, it showed some elements of intensive farming including high crop productivity (121 kg 258 N harvested per each hectare) and high fertiliser inputs (140 kg N ha<sup>-1</sup> were applied). 259 The other three agro-environments yielded lower nutrient surpluses. In the case of the paddy rice 260 area (MLU5), a detailed agro-environmental study has been presented by Zavattaro et al. (2006 and 261 2008). 262 On average, the entire territory, based on all the MLUs combined, reported surpluses of 77, 24, and 263 65 kg ha<sup>-1</sup> for N, P, and K, respectively. To better explain the results obtained at the territorial scale, 264 further analysis at the crop level was helpful. To this end, we calculated an MLU-specific soil-265 surface balance for N, P, and K for the main crops (named in Table 4) according to equation 1, and 266 reported the results in Table 6. In general, farmers tended to overestimate the nutrient requirements 267 for maize and grain and underestimate it for grass surfaces. Although this result might be biased by 268 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).

271 With regard to fertilisation management, since the mineral inputs play a part in defining surpluses, 272 we also explored the role of top dressing for N mineral fertilisation. Results are reported in Table 7. 273 Although the spreading strategy for maize is more uniform, a wide difference is shown with regard 274 to winter wheat, suggesting the possibility that a large improvement in farm fertilisation technique 275 results in nutrient surplus reduction. No differences between stockless and stocking farms were 276 detected with regard to quantity of mineral fertiliser spread each year, or spread timing. As farmers 277 tend to ignore the nutritional role of farm manures, especially for P and K, they prefer to spread a 278 mineral quota plus the manure, the so-called "insurance N" of Schröder et al. (2000), often setting 279 the farm fertilisation beyond crop needs. Therefore, it seems possible to reduce mineral inputs 280 without decreasing the crop productivity in order to lower the NPK surpluses at the MLU scale.

281

#### 282 **4. Discussion**

#### 283 4.1 Are the studied agro-environments sustainable?

284 The calculation of selected nutrient budget indicators suggests that Piemonte farming systems 285 generally display a net surplus for all the main nutrients. However, within that general tendency, 286 substantial differences among different agro-environments exist. Although the Po plain is usually 287 treated as a uniform geographical entity (as in ADAS and NIVA, 2004), we were able to 288 geographically identify different agricultural systems by highlighting wide differences in land use, 289 input amounts (e.g. fertilisers and water), and surpluses. 290 Several attributes should be considered when assessing farming system pressure on the 291 environment. A given crop or farming system is not dangerous *per se*, but can be more or less 292 harmful according to specific operations and/or management choices (Bechini and Castoldi, 2006). 293 Maize (the most diffuse crop in the Po valley) was the most frequently over-fertilised crop. Yet, not 294 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 rainfed 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).

299 Crop utilisation type is also crucial. Our survey results revealed that maize is often fertilized with 300 large amounts of manure and fertiliser, independent of the product collected from the field (kernel 301 only, kernel and straw, silage), therefore the fate of straw has a great impact on the nutrient surplus. 302 According to data obtained at both the territorial and crop scales in the studied agro-environments, 303 NPK surpluses could be lowered to near zero at the MLU scale mainly through mineral input 304 reduction since manure spread alone often satisfies crop needs. Some authors (e.g.: Killingsback 305 and Hansen, 2007) have reported that crops utilize the commercial fertiliser N better than manure 306 organic N because of greater gaseous losses in the latter. Moreover, mineral fertilisers are managed 307 more easily and are without constraints associated with livestock husbandry. In fact, the N in 308 mineral fertilisers has been shown to be equally prone to loss as the N is in organic fertilisers (e.g. 309 Sacco et al., 2006). A reduction in mineral inputs, in the interest of a wider use of well-managed 310 organic wastes, could be a sound solution for improving territorial agro-environmental 311 sustainability.

312 4.2 Are the adopted indicators feasible?

313 According to Yli-Viikari and Lemola (2004), an indicator is deemed feasibly "good" when input 314 data are readily available. This case study has highlighted several data availability problems: a) the 315 high cost of data collection which leads to few updates; b) heterogeneity of the available data 316 relative to scale and source; and c) little crop scale data on manure spread which forces 317 simplifications in the balance methodology adopted. In this case study, the simplification might 318 have introduced a bias that would underestimate manure inputs to summer crops, and overestimate 319 them to winter crops. Manure might also have been exchanged between MLUs, but such an 320 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

328 IRENA nutrient budgets were developed to be applied at NUTS 2/3 levels. Even though this scale is 329 administrative, and thus very different from the system-related scale adopted in this study, the 330 applied methodology is shown to be flexible and adaptive to available datasets. Clearly, data 331 collection on a smaller scale is required for environmentally meaningful results (Petersen, 2004), 332 but generally, a GIS-based approach allows broad use of adopted indicators. They could, for 333 instance, be used for practical application of spatial analyses within the context of agricultural 334 policy-making across different scales, from the sub-region to the whole of Europe.

335 4

#### 4.3 Are the adopted indicators useful?

336 If spatial and temporal boundaries of the study are properly defined, the adopted indicators can

asily be used for insight into agricultural management in both intensive and extensive

338 environments across different scales.

339 For example, the GNB indicator calculated for the entire study area (77 kg N ha<sup>-1</sup>) varied

340 considerably from those reported by OECD (2008) by nation in 2002-2004. GNB was 83 kg ha<sup>-1</sup> for

341 EU-15 ranging from 39 kg ha<sup>-1</sup> for Italy and 229 kg ha<sup>-1</sup> for the Netherlands. Only the Netherlands

342 and Belgium reported national manure rates higher than the threshold of 170 kg N ha<sup>-1</sup> specified by

343 the Nitrate Directive, whereas manure rates for Italy were approximately 40 kg N ha<sup>-1</sup>. This study

344 showed an average manure input of 57 kg N ha<sup>-1</sup> for the Piemonte plain, ranging from 14 kg N ha<sup>-1</sup>

in MLU1 and MLU5 to 94 kg N ha<sup>-1</sup> in MLU3. Even at the sub-regional scale, the manure N

346	applied in Piemonte was far below the 170 kg N ha <sup>-1</sup> threshold, suggesting that local farmers
347	understood better the role of mineral fertilisers in increasing the N surplus.
348	Another application of the adopted indicators was recently performed in Piemonte with regard to P.
349	According to Withers and Haygarth (2005), a high P content in the topsoil increases the risk of
350	losses to the environment. Due to the accumulation of P in farmed soils and its slow transport time,
351	high concentrations in water could persist, even as P surpluses diminish. In Italy, the local
352	application of agro-environmental measures has led to a general decrease in the use of P mineral
353	fertilisers (-26% in the last 15 years, according to OECD, 2008). However, in some areas of
354	Piemonte the amount of soil P has continued to increase (Bourlot et al., 2007). A geo-referenced
355	analysis of more than 18.000 soil analytical data points available in the Regional Soil Analysis
356	database (Menardo et al., 2006) has shown that soil P is increasing in MLUs characterized by the
357	highest P budget surpluses and manure inputs, thus stressing the need for local regulation of manure
358	P crop inputs.
359	It should be remembered, however, that nutrient budgets are indicators of potential environmental
360	impact and unsustainable resource use. The real nutrient loss in any specific year and site cannot be
361	calculated through the use of soil-surface balances. Territorial data analysis therefore, can be of help
362	in evaluating the temporal changes in the amount of inputs and outputs (e.g.: Liu et al., 2007) or
363	highlight the spatial differences among areas (so-called hot spots) where an improved application of
364	the legislation may be more effective.
365	
366	5. Conclusions

We have developed a geographically-based process for the spatial delineation of different agroenvironments, 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. 371 The process utilised calculated nutrient budgets in defined agro-environments as indicators of the 372 environmental pressures caused by agricultural activities at the sub-regional and crop levels. These 373 indicators allowed quick assessment of the relative importance of different inputs in surplus 374 determination, thereby enhancing the potential for improved management techniques. 375 Our work stressed the possibility of a general lowering of mineral fertilisers spread on crops in the 376 study area. The adoption of best practices for fertiliser management could significantly reduce 377 environmental pressures and help reach the 2020 goals to reduce the N, P, and K surpluses by 25 %, 378 70 %, and 57 %, respectively (EEA, 2005). The concentration of stocking activities in only one out 379 of five studied agro-environments enhances the availability of manure for territorial redistribution. 380 A strategy that moves manure excesses to meet the fertilizer needs of stockless areas would also 381 result in a beneficial increase in the soil organic matter. 382 The inputs and outputs we relied on to calculate nutrient budgets are simple, consistent with the 383 spatial scale of available data, and widely used for similar agro-environmental studies (e.g.: Folmer 384 et al., 1998; Lesschen et al., 2007, Sleutels et al., 2007). The strength of the nutrient balance 385 approach lies in regular monitoring of related data sets (de Koening et al., 1997; Bechini and 386 Castoldi, 2006). If officially recorded data are not easily manipulated, then costs become a hurdle 387 and updates are difficult and infrequent. Enhancement in the level of detail and in the ease of data 388 recording will lead to wider scientific significance of the described indicators. For instance, in Italy, 389 the availability of all fertilisation-related information is slowly increasing due to the Action 390 Programmes applied locally according to the Nitrate Directive. The creation of a data warehouse 391 aimed at organising both farm-scale and territorial-scale information would be a powerful tool for 392 the evaluation of different sustainability scenarios. 393

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

Data	Source	Detail	<b>Derived information</b>
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 <sup>-1</sup> )
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. 7 8

		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	4 1 1 <sup>-1</sup>	0.7	0.7	2.7	1.6	7.2	2.3
in the whole MLU	t I.w. na	0.1	0.2	0.9	0.6	0.1	0.5
Farm land	UAA ha farm <sup>-1</sup>	7.7	14.1	10.8	7.3	39.0	11.8
Irrigated		7	31	65	32	81	47
Covered during winter		17	16	24	37	6	25
Ploughed every year	% UAA	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. 18 19

	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	
					Avg.	SD
MLU			kg N ha⁻¹	yr <sup>-1</sup>		
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	40.2
Total	120	57	42	141	77	<i>43</i> .
Sig.	0.000	0.000	0.000	0.000	0.000	
	fertilizers	manure		harvested	GPB	
					Avg.	SD
MLU			kg P ha⁻¹	yr <sup>-1</sup>	Ū	
1	25	7		19	12	4
2	33	7		22	18	6.4
3	26	43		31	39	17.4
4	22	28		27	22	10.
5	22	7		27	2	17.
Fotal	25	26		27	24	20.
Sig.	0.000	0.000		0.000	0.000	
	fertilizers	manure		harvested	GKB	
MLU			kg K ha <sup>-1</sup>	vr <sup>-1</sup>	Avg.	SD
1	75	17	0	<u>,</u> 71	20	13 8
2	75	20		75	20	18
3	91	110		106	 95	46
4	62	72		116	19	40.
5	116	15		65	65	48.
Total	88	67		93	62	50.
Sig.	0.000	0.000		0.000	0.000	200

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

identified in the study area. 

	MIT	Maize	Maize	Leys and	Rice*	Winter
	WILU	for grain	for silage	meadows		wheat**
GNB						
$(\text{kg N ha}^{-1} \text{ yr}^{-1})$	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						
$(\text{kg P ha}^{-1} \text{ yr}^{-1})$	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						
$(\text{kg K ha}^{-1} \text{ yr}^{-1})$	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. 

32

35 Table 7- Mineral N fertilization management for the main crops in each of the five Macro Land

36 Units (MLUs) identified in the study area.

37

	MLU	Maize for grain	Maize for silage	Leys and meadows	Rice	Winter wheat
Mineral input						
$(\text{kg N ha}^{-1} \text{yr}^{-1})$	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

38 39 \* Information about top dressing on rice was spatially elaborated only for the paddy area (MLU5), where almost all the

rice is cultivated.

- 1 Figure 1 Inputs and outputs (kg NPK ha<sup>-1</sup>) for calculation of the nutrient budget at the Agronomic
- 2 Land Unit (ALU) scale.
- 3
- 4 Figure 2 Delineation of the five Macro Land Units (MLUs) as an aggregation of the Agronomic
- 5 Land Units (ALUs) by means of cluster analysis in the Piemonte Region, NW Italy.

## Figure 1





