NITROGEN SURPLUS AS INDICATOR OF AGRICULTURAL POLLUTION IMPACT IN THE VENICE LAGOON WATERSHED.

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ABSTRACT
During 2001 a survey has been carried out in 36 arable farms of the Venice Lagoon Watershed, VLW (NE Italy), to investigate on the adopted agricultural practices and estimate their environmental impacts. Farmers cultivated field crops, 23 out of the 36 farms had livestock rearing plants. Given the relevance of the nitrate problem for the Venice Lagoon ecosystem, in this paper, the potentials of the “N-surplus index” at the farm level are presented in view of providing a concise representative impact indicator of the farming systems at the territorial scale. The N-surplus indicator was compared with the N-leaching of each one of the 36 farms estimated with the NLEAP model and the correlation between N-surplus and N-leaching is presented. The highest N-surplus values have been found for the livestock-farms, with an average value of 364 kg $ha^{1}year^{-1}$, while the average value for crop farms is 72 kg $ha^{-1}year^{-1}$. Intensive animal farms produce great amounts of manure and slurry, which are totally or mainly spread within the "farm gate" even if they exceed both the crop removal and the legislative limit. Moreover, additional chemical fertilizers are applied. The N-surplus index has been then applied to census data at the municipal level, to explore the feasibility of calculating a synthetic impact indicator at the watershed. For the VLW's areas where rearing plants are geographically referenced, a GIS technique is presented in order to better define the N-surplus indicator

Keywords: impact indicator, water pollution, nitrogen, farm survey

INTRODUCTION
The Venice Lagoon Watershed (VLW) is a portion of the alluvial plain of the Veneto Region, Italy, with a surface of about 1850 km^2. Around 65 % of the VLW surface area is under cultivation. The predominant crop is maize which is grown over 56% of the cultivated lands.

The VLW is considered by the national legislation a sensitive area for the protection of water against pollution (D.Lgs.n°152/99). Despite that, an agriculture with high level of fertilization is practised and livestock production is characterized by an intensive farming system. Agriculture has high input of fertilization and the livestock production is very intensive and scarcely integrated with crop production.

High nutrient discharges in the VLW surface waters have been responsible during the 1980's and the 1990's of a severe eutrophication of the Venice Lagoon (Sfriso *et. al*,1988; Sfriso *et. al*, 1990). While municipal and industrial discharges has been reduced during the past decade by the construction of treatment plants, the nutrient (nitrogen in particular) loads from agriculture and animal rearing activities have still to be reduced in order to restore a stable mesotrophic condition for the Lagoon (Bendoricchio et al., 1999). According to the estimate of the Government of the Veneto Region (Regione Veneto, 2000), nitrogen from agricultural and animal farming sources accounts for about the 65% of the nitrogen generated in VLW which is esteemed to be around 9200 tons per average year, while after point source treatment about two third are still loading the Lagoon.

Extensive monitoring activities were launched in recent years to acquire detailed assessments of chemical loads to the Lagoon from its watershed. Several studies are also in progress to acquire in depth understanding of the mechanisms linking human activities located in the sub-basins of the VLW to the ecological status of surface and ground-water resources of the area and of the Venice Lagoon water body. It is expected that in a reasonable time reliable distributed hydrologic and chemical models, linked to data provided by the monitoring information system could allow accurate assessment of the main pollution phenomena and estimation of their environmental impacts. Nevertheless, to date the estimation of contributions of the various sources of pollutants to the overall impacts on the VLW water resources is far from being feasible with the necessary temporal and spatial accuracy that policy makers would like to have, for designing effective and efficient environmental measures for the area, which is managed by ad hoc special legislation (at the national and regional levels) targeted to the preservation of the city of Venice, its Lagoon and its watershed (VL+VLW). The assessment of location and spatial distribution of those activities potentially responsible for generating impacts on the VL+VLW is a basic requirement for the design of any policy measure aiming at the preservation of water resources quality.

Diffuse sources of pollution are usually those most difficult to identify and describe. Diffuse pollution phenomena from agricultural sources are usually the most challenging not only for the difficulties inherent in their monitoring and assessment, but also for those related to the design of effective policies and regulations.

One aspect which contributes dramatically to such problems is the complexity of the agricultural production system, which is characterised by spatially distributed environmental driving forces (soils, climate), interacting with diversified human activities (crops, livestock, etc.), managed by a multitude of agents – the farmers.

The international literature is rich of methodological proposals for modelling the fate of agro-chemicals at the various scales: field, farm, whole watershed. Of greatest importance for the VL+VLW ecosystems is understanding and the assessment of those phenomena related to nutrient balances (nitrogen and phosphorus) in the agro-ecosystems. With such aims several experimental studies and simulation modelling were carried out in the area in recent years (Borin et al., 1997; Morari and Giupponi, 1997; Giupponi and Rosato, 1999; Bendoricchio et al., 1999; Bendoricchio, 2000), providing insights in the orders of magnitude of the phenomena and in the main driving forces. Nevertheless, as previously stated, a comprehensive distributed hydrologic and chemical model for diffuse pollution phenomena is not yet available for the estimation of nutrient loads generated within the watershed in terms of nitrogen and phosphorus losses in leaching and runoff losses from agricultural lands.

In this paper the potentials of the nitrogen surplus index are presented for identifying most sensitive areas within the VLW where targeting future efforts for the mitigation of impacts on water quality from diffuse pollution from agricultural sources. The study sparks off from the result of a farm survey carried out during 2001 in 36 arable farms of the VLW to investigate on the adopted agricultural practices and estimate their environmental impacts. Farmers cultivated field crops, and in particular: maize, winter wheat, soybean, sugar beet and alfalfa; 23 out of the 36 farms had livestock rearing plants.

METHODS

Environmental impact indicators were calculated at the field scale in a previous work by Giupponi et al. (2001), by means of calculation routines and models provided by the Planetor software (Giupponi and Klair, 1996), allowing the estimation of: soil loss by erosion, nitrogen in leaching, phosphorus loss index, indices of pesticide losses in leaching and runoff and a farmer's risk index related to the toxicity of the pesticides used.

Given the relevance of the nitrate problem for the Venice Lagoon ecosystem, the nitrogen surplus, defined as the algebraic value obtained by the difference between the N-inputs to the soil and the N-output with crops products, ("N-surplus index") was adopted for providing a concise impact index of agricultural activities. Calculations of the N-surplus index at the farm level were used to derive coefficients expressed as N-surplus per hectare, associated to the main crops cultivated in the study area and used to produce maps of potential impacts of the farming systems at the territorial scale.

The N-surplus index was first compared with the simulated potential nitrogen leached. The N-leaching of each one of the 36 farms was estimated by the Planetor software with the NLEAP model. The results of simulations were evaluated with respect to available local experimental records and with evidences acquired from the international literature and the correlation between N-surplus and N-leaching is presented. The N-surplus index has been then applied to census data at the municipal level in order to calculate a synthetic impact indicator for the whole VLW. The result is a map based on municipal administrative boundaries which provides a first estimate of the potential risk of nitrogen losses. Since such municipal aggregation doesn't take into account neither the geographical distribution of the rearing plant nor the distribution of the cultivated land, it can result in a smoothing of the value of surplus index. A more spatially detailed approach is proposed for the Vela Catchment, which is a sub-basin of the VLW for which both a land cover map (source ARPAV and Regione Veneto) and georeferened rearing plants are available.

Nitrogen surplus at a farm level

N-surplus is defined as the algebraic value obtained from the soil surface balance by the difference between the N-inputs to the soil and the N-output with crops products and it is expressed as a quantity unit per hectare per year. N-surplus can be intended as the amount of nitrogen that is lost from the production and can be either accumulated in the soil or loss to the environment. The loss to the environment consist of leaching and runoff of nitrate, volatilization of ammonia and denitrification to nitrogen gas and nitrous oxide. The accumulation of nitrogen cannot be considered a permanent outlet since after a while an equilibrium between immobilization and mineralization will be established.

It has been calculated for the 36 farms surveyed by Giupponi et al. (2001) with data derived form the application of the Planetor software.
The annual nitrogen input entering the soil has been obtained by the sum of the amounts of:

- inorganic nitrogen fertilizers applied (obtained from farms accounts)
- nitrogen applied as livestock manure, in the case of livestock farms. It has been estimated from the total number of live animals in terms of different categories according to species, purpose (e.g. beef cattle, milk cow), age multiplied by respective mean coefficients (source CNR-REFLUI) of the quantity of nitrogen contained in manure excreted per animal per year net of nitrogen loss during storage and application. In the cases that a livestock farm transfer part of the manure out of the farm, it is considered just the percentage of the manure spread on the farm's agricultural surface.
- nitrogen atmospheric deposition, estimated according to local studies as 20 kg ha^{-1} $year^{-1}$ (Degetto, 1997; CVN, 1988)

The annual nitrogen output with crops products have been calculated multiplying, crop by crop except for legumes, the actual harvested yields (without crop residues), by standard nutrient concentrations obtained from literature (Giardini, 1992). In order to take into account the biological nitrogen fixation, according to Giardini and Giupponi (1987) has been assumed for the legumes a default value of nitrogen surplus of 40 kg/ha for soybean and 100 kg/ha for alfalfa.

Nitrogen surplus at the watershed level

Nitrogen surplus from chemical fertilisers at the municipal scale has been calculated from statistical and census information considering as nitrogen input nitrogen from mineral fertilizers and atmospheric deposition. The origin data (from the national statistic agency - ISTAT) are referred to the sales of nitrogen fertilisers at a provincial aggregation level which comprise various municipalities. In order to obtain an estimate of the amount of mineral nitrogen sold in each municipality a disaggregation based on crop distribution of the values referred to each one of the three province of the VLW has been made as follows: for each province, an average value of mineral nitrogen application has been assigned to the main crops of the VLW as function of local practices and yield and multiplied by the surface occupied by the respective crop in the province (census source: ISTAT, 2001). The ratio between the crop by crop sum of the obtained values and the actual nitrogen fertilizers sales has been utilized as coefficient to adjust the value initially proposed for each crop mineral nitrogen application. The adjusted value found for each crop has been then multiplied by the surface of the relative crop in the various municipality in order to get the estimated mineral nitrogen applied in each municipality.

Nitrogen from manure at the municipal scale was calculated by multiplying the number of heads of livestock (from census data), grouped by species and age or weight classes, by the average amount of nitrogen excreted per year, and considering as 40% of the total, the nitrogen loss occurring during storage and application (Giardini, 1999; Granstedt, 2000). Evidences from farm surveys suggest that the integration of nitrogen available from manure in the fertilization plan is usually marginal, thus a simple summation of the two sources of nitrogen to estimate total input is not far from the reality.

Nitrogen surplus at a sub-watershed (Vela Catchment) level

Nitrogen surplus from chemical fertilisers on a field-by-field basis was calculated by means of a look up table in which the N-surplus indices per crop class previously calculated were assigned to the classes of the land cover map of the VLW.
Nitrogen from manure on a farm-by-farm basis was implemented in the GIS by attributing the whole net annual potential production of nitrogen in manure to the location of the livestock rearing plants and then applying an interpolation routine based upon the inverse distance to the power algorithm, thus providing a proxy of a probabilistic surface of livestock manure spreading on cultivated fields. Within the Idrisi32 GIS software a macro was developed for obtaining an interpolated surface, over cultivated fields only, and expressed in terms of kilograms of nitrogen per hectare per year. The interpolation algorithm included a rescaling routine to make the total amount for the whole catchment equalling the total available nitrogen from local livestock rearing plants.

The interpolated map of manure loads is clearly not at all intended to provide a picture of the real word in terms of where and how much manure is applied annually, first of all because it does not take into account the land property and formal spreading rights of livestock farmers. Nevertheless, at the geographical scale it is not far from a "realistic" picture of the situation because it takes into account the main criterion adopted by farmers for manure spreading, which is based upon the minimisation of transport and application costs rather than on the integration of manure in the fertilization plan.
The total nitrogen loads were calculated by additive overlaying mapping of the layers of N-surplus from mineral fertilisers, N from manure and a uniform atmospheric deposition input of 20 kg ha^{-1} $year^{-1}$.

RESULTS AND DISCUSSION

Simulations at the farm scale

Remarkably different N-surplus values have been found in dependence of farm type: the highest N-surpluses have been found for the livestock-farms, with an average value of 364 kg $ha^{-1}year^{-1}$, while the average N-surplus for crop farms is 72 kg $ha^{-1}year^{-1}$. Intensive animal farms produce great amounts of manure and slurry, which are totally or mainly spread within the "farm gate" even if they exceed both the crop removal and the legislative limit. The national legislation (D.Lgs.n°155/99), in fact, considers the VLW, a sensitive area for the protection of waters against pollution where the limit for the spreading of livestock effluent is fixed at 170 kg/ha. Despite the legislative limit, in the livestock farm, the amount of organic nitrogen applied over maize fields is on average 320 kg/ha. Moreover additional chemical fertilizers are applied. The amount of nitrogen applied with chemical fertilizers doesn't change considerably among crop and livestock farms pointing out that manure is treated more as a waste that has to be dispose somehow instead as a source of fertilizer.

The N-leaching of each one of the 36 farms was estimated by Planetor software with NLEAP model and the N-surplus index was compared with the simulated potential nitrogen leached. In figure 1 simulated leaching losses are plotted against calculated N-surplus. N-leaching increases linearly as the N-surplus increases with a R^2=0.84. The linearity of the regression is mainly due to the saturation of the buffer capacity of the soil.Even if the absolute value of N-leaching obtained with the model might be not reliable, the use of the model results for such comparative evaluation is acceptable.

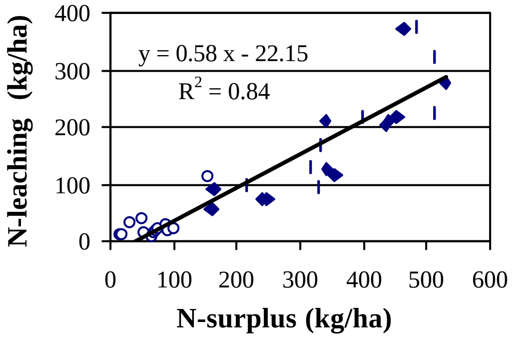

Figure 1: Simulated N-leaching plotted against N-surplus for the 36 farms. Crop farms are represented with white circles, livestock farms with black squares.

The good regression found corroborates the validity of N-surplus as concise impact indicator of the nitrogen potentially available for leaching and it justify and support an application at a larger scale in the VLW with the purpose of identifying the most sensitive areas for N-leaching. Nevertheless, it has to be specify, in accordance with other authors (e.g. Kengni et al.,1994; Bechman et al., 1998; Grignani and Zavattaro, 2000;), that N-surplus is an unsuitable tool for predicting N-leaching since it disregards many determinant factors such as between year variability of precipitations, soil characteristics (nutrient storage capacities, retention periods) and tillage operations.

Simulations at the watershed scale

Figure 2c displays the distribution of N-surplus index obtained with the simulations at the watershed scale showing an evident variability among municipality.

Variability is not marked when considering only mineral N-surplus (fig. 2a). This is partially a consequence of the estimation method of the nitrogen input from mineral fertilizers which is based on crop distribution that doesn't remarkably change between municipalities. Conversely the distribution of nitrogen from livestock manure (fig.2b) is not homogeneous over the municipalities and is determinant for the definition of the municipalities with higher total N-surplus.

Since this approach disregards the spatial distribution of the rearing plants inside the municipalities, the obtained N-surplus values are smoothed over each municipality.

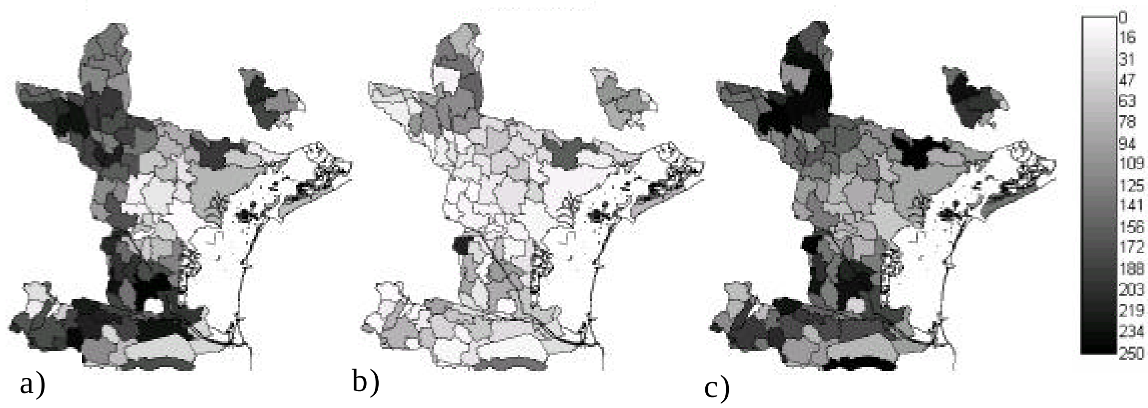

Figure 2: *VLW, which is extended over 1850 km² and comprise 119 municipalities.* ***a)*** *N-surplus from chemical fertilizers ($kg*ha^{-1}*year^{-1}$);* ***b)*** *Nitrogen in manure ($kg*ha^{-1}*year^{-1}$);* ***c)*** *N-surplus ($kg*ha^{-1}*year^{-1}$).*

Simulations at Vela Catchment scale

When, as in the case of Vela Catchment, both the spatial distribution of the cultivated land and the distribution of the rearing plants are considered, a higher level of spatial detail is obtained. In figure 3a, N-surplus from mineral fertilizers is shown on a field by field basis. As it has been confirmed with the farm survey, while some crops, maize in particular, receive high input of fertilization resulting in high N-surplus values, other crops receive low nitrogen input (that in the case of sugar-beet are even smaller than the nitrogen withdrawals with yield) because they exploit part of the nitrogen applied to the previous crops. Since the land cover map is the representation of one single year it doesn't take into account crop rotations and the map of N-surplus results in an accentuated variability from field to field. In figure 3b the map of organic nitrogen from livestock farms is presented. Although it is just an hypothetical distribution of the manure spread based on the assumption of a decreasing organic load with the increasing distance from the rearing plans, it can be considered a reasonable tool for the identification of the specific organic nitrogen loads and of the areas where organic nitrogen is distributed.

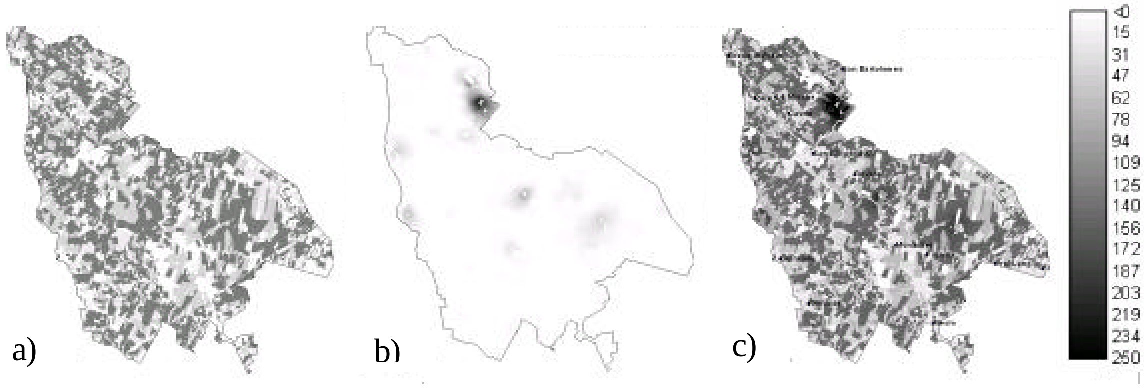

Figure 3: Vela Catchment, which is the isolated NE portion of the VLW. **a)** N-surplus from chemical fertilizers (kg*ha^{-1}*year^{-1}); **b)** Nitrogen in manure (kg*ha^{-1}*year^{-1}); **c)** N-surplus (kg*ha^{-1}*year^{-1}).

CONCLUSIONS

The present study is carried out using the results of a survey in 36 farms of the VLW. The good regression found in between leaching and surplus of nitrogen at a farm scale suggest the reliability of surplus as indicator of agricultural impact on surface water. Even if the N-leaching values have been obtained with a non calibrated model their use for a comparative evaluation is reliable when the main purpose is planning the interventions and not the evaluation of critical loads.

In addition, N-surplus index from census data, which has the worth of being rather easy and feasible to calculate also when only a limited database is available, represents an adequate tool for the policy makers for the identification of the spatial distribution of the most sensitive areas within the VLW where targeting the efforts for the mitigation of impacts on water quality from diffuse pollution from agricultural sources.

The implementation of hydrologic and chemical models is nevertheless to be carried out in order to have a more accurate assessment of the pollutants loads at the watershed scale. That will enable to understand how far the diffuse pollution abatement has to be pushed in order to reach the required by law maximum nitrogen load for the VL which is fixed, according to the Piano Direttore 2000 (Regione Veneto, 2000), at 3000 tons per year.

The always increasing availability of georeferenced data will allow better simulations based on GIS techniques also at the entire VLW.

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