AGRICULTURAL SEWAGE SLUDGE REUSE POTENTIAL IN APULIA (ITALY): ANALYSIS OF DIFFERENT SCENARIOS FOR THE SUPPORT OF LEGISLATIVE DECISIONS

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Abstract

Agricultural use is one of the best options for sewage sludge management, whenever sludge quality is suitable with respect to established law limits and if local situations (field availability, climate, specific constraints) are favourable. This practice is recognized to be the most economical one and allows recovering nutrients and organic matter with benefits to crops and land.

Beside general rules issued at European level (Directive 86/278/EEC) and transposed in Italy with D.Lgs. 99/1992, regional authorities can establish other restrictions to better protect environment, preserve population from nuisance and defend specific areas.

Through GIS elaborations, we have analysed different scenarios, computing available land in Apulia region with present and new revised constraints and evaluating sludge quantities to be potentially recovered for land application in the light of current legislative limits, nitrogen requirements by crops and cultivation cycles.

This study has showed that available land can face the total sludge production in the area even in the most conservative hypothesis. The used methodology represents a powerful tool to move the focus of political decisions from general law constraints towards specific ones closely related to the environmental and agricultural context and to plan new investments to completely satisfy sludge disposal needs.

Keywords

agricultural sludge use, GIS analysis, sludge disposal management, strategic planning

Introduction

Sewage sludge disposal represents one of the most urgent environmental issues nowadays, as, while on the one hand the different disposal routes are becoming less feasible (see for example landfill), on the other hand huger amounts of sludge are produced as a result of the implementation of Directive 91/271/EEC.

According to the figures provided to the European Commission for the period 2003-2006, about 10 million tons of dry matter (DM) of sewage sludge were annually produced in the European Union (8.7 million t DM in the EU-15 and further 1.2 million t DM for the 12 new Member States), a value which is probably even underestimated (Milieu Ltd et al. 2010).

Figure 1 shows mean annual sewage sludge production in Europe in the period 1996 - 2007, based on Eurostat data. As Italy is one of the states with wider amounts of sludge yearly generated, the correct evaluation of sludge production and quality, along with current outlet available routes and disposable quantities, is necessary for an effective planning of sludge management strategies to avoid future emergencies.

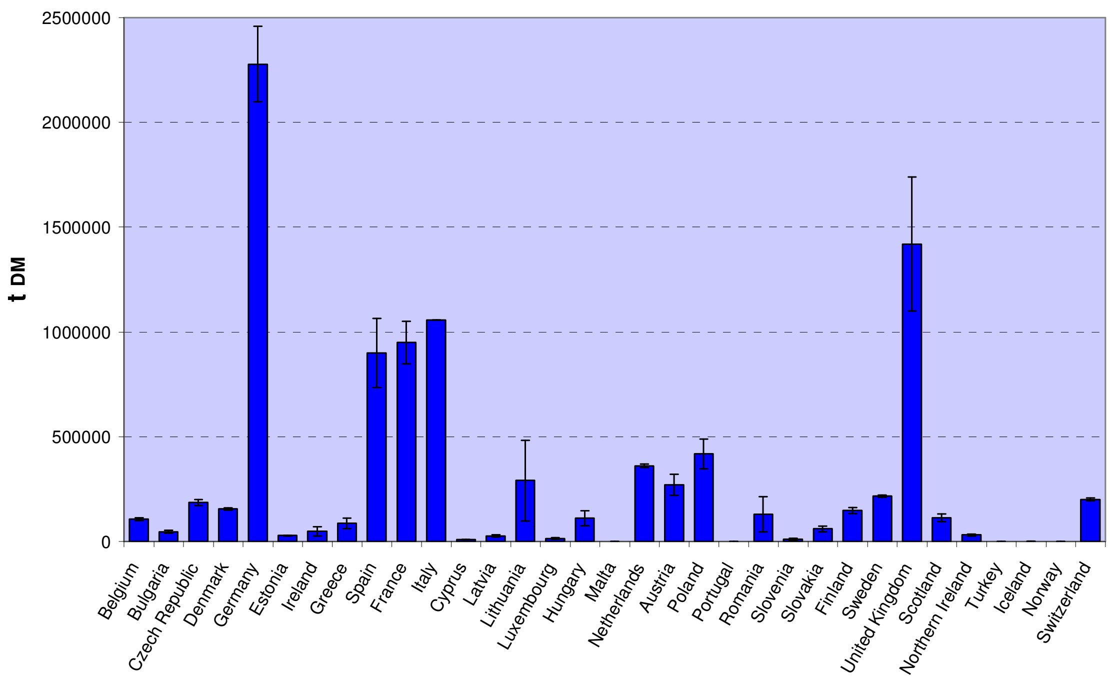

Figure 1: **Annual sludge production in Europe (mean values relative to the period 1996 – 2007, Eurostat)**

The common options for sludge outlet are agricultural sludge use (direct or as compost), landfilling and incineration. Other routes, such as innovative thermal treatments, land reclamation or incorporation in building materials (Meeroff and Bloetscher 1999, Monzò et al. 1999, Weng et al. 2003), play only a marginal role. Figure 2 shows the incidence of every disposal route in Europe for the period 1996 - 2007, on the base of Eurostat data.

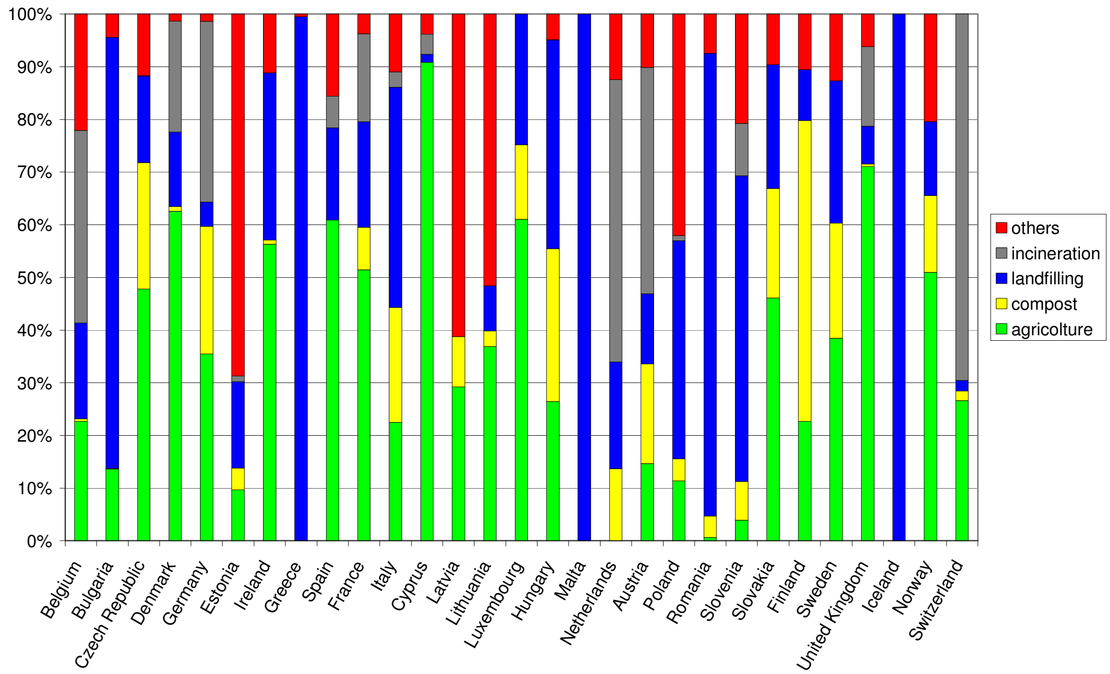

Figure 2: Sewage sludge disposal routes in Europe (mean values relative to the period 1996 – 2007, Eurostat)

Among the different approaches, agricultural sludge reuse can be considered the best option whenever sludge quality is sufficiently high. Not only it represents the most economic solution, with a total cost of 150 – 400 €/t DM (Hall 1999), but this choice also allows recovering nutrients for crops. Beneficial outcomes of this process would be the reduction of the spread of inorganic fertilizers on lands and the improvement of soil physical properties (soil structure, bulk density, soil moisture, compaction and aeration) through the addition of organic matter, thereby eventually helping to fight soil desertification (Epstein 2003).
Moreover, sludge contains macronutrients (such as calcium, potassium and sulphur) and micronutrients (copper and zinc), useful for the growth of cultures (Milieu Ltd et al. 2010).
Despite the indubitable aforementioned advantages, sludge agricultural use is often opposed due to the possible presence of toxic elements, e.g. heavy metals and organic contaminants, or pathogens, which would pose a potential threat to human health and environment and possible contamination of food (milk). Even though there is no evidence suggesting the possible harmfulness of this practice, such concerns have even led to the total ban of sludge use in agriculture in some states, such as Switzerland (Milieu Ltd et al. 2010).
Nevertheless, it is worth to observe that if sludge is applied according to law prescriptions as to sludge quality and spreading rules, this solution is the optimal one, as it combines benefits with low costs. As stated in Art. 14 of Directive 91/271/EEC, “sludge arising from waste water treatment shall be re-used whenever appropriate”, giving a clear priority to agricultural sludge use, if requirements concerning sludge quality are met. Additionally, the European Commission encourages this option since it represents a long-term solution, provided that the sludge quality is compatible with public health and environmental protection (Magoarou 1999).

Sludge recycling in agriculture is regulated in Europe by Directive 86/278/EEC, transposed in Italy by D. Lgs. 99/1992. According to this national law, regional authorities are responsible for the definition of further limits, conditions and prescriptions. Hence, over the past years, numerous different regulations have been issued by the Italian regional authorities, some of which encompassing new limits and constraints proposed in the Working Document on Sludge, known as 3rd draft (European Commission, 2000).

Local authorities of Apulia Region are now considering the opportunity of revising regional legislation on sludge agricultural reuse and introducing new rules. For a right evaluation of the potential sewage sludge agricultural use in Apulia, we have computed the disposable quantities taking into account the legislative regional and national framework. Then, we have hypothesised different scenarios in order to verify how variations in the regulative framework might affect potential agricultural sludge use. The results show that a different approach in political decisions could be introduced, shifting the focus from general law constraints towards more specific ones that take into account the actual local environmental and agricultural context.

Regulative framework

European Legislation: Directive 86/278/EEC

Directive 86/278/EEC tries to encourage the application of sewage sludge in agriculture and to regulate its use in such a way as to prevent harmful effects on soil, vegetation, animals and man. In order to pursue such a goal, sludge has to be treated before land application, undergoing "biological, chemical or heat treatment, long-term storage or any other appropriate process so as to significantly reduce its fermentability and the health hazards resulting from its use". Maximum concentration values of heavy metals in soil and sludge, together with the maximum annual dose of heavy metals brought to soil, are fixed as well.

Furthermore, areas in which sludge application is totally banned or allowed only for limited periods are indicated to reduce health risks, namely grassland or forage crops, soil in which fruit and vegetable crops are growing (with the exception of fruit trees) or ground intended for the cultivation of fruit and vegetable crops normally in direct contact with the soil and normally eaten raw.

Agricultural sludge reuse should not be merely conceived as a disposal activity, but has to be considered essentially as an agricultural practice as "sludge shall be used in such a way that account is taken of the nutrient needs of the plants".

Italian Legislation: Decreto Legislativo 99/1992

Directive 86/278/EEC has been transposed in Italy by D.Lgs. 99/1992.

According to the Italian law, both urban sewage sludge and industrial sludge of similar characteristics can be regarded as sludge usable in agriculture. More specifically, it is stated that sludge has to produce a fertilizing effect and/or act as a soil conditioner. Furthermore the use of sludge containing toxic and noxious substances and/or persisting ones and/or bio-accumulating ones in such a concentration to result harmful to soil, cultures, animals, men and environment is prohibited.

Limits in heavy metal contents in soil and sludge are set, reporting values included in the range indicated in the European Directive for soil and the lower value of the intervals for sludge (only mercury content in sludge is reduced). In addition to this, a maximum value for pathogens (Salmonella) is introduced.
Maximum applicable rates, in terms of tons of dry matter per hectare over a period of three years, are laid down, referring to soil characteristics (pH and cationic exchange capacity), as reported in Table 1.

Table 1: Maximum applicable sludge quantities, on the grounds of soil characteristics

pH	Cationic exchange capacity (C.E.C.) [meq/100 g]	Maximum sludge applicable quantity [t_{DM}/ha in 3 years]
< 5	any	not allowed
any	< 8	not allowed
> 5	8 – 15	7.5
5 - 6	> 8	7.5
6 – 7.5	> 15	15
> 7.5	> 8	22.5

Besides the aforementioned restrictions already recommended in Directive 86/278/EEC, agricultural sludge reuse is also banned on wet lands, flooded or marshy areas, frozen or snow-covered grounds, landslides and on sloping lands (with slope higher than 15% if the dry matter content is less than 30%) in order to reduce the possible contamination by erosion and run-off.

Apulian regional legislation

Alongside the national and European directives, several regional laws and regulations affect agricultural sludge reuse, in particular those forbidding sludge disposal in buffer zones around built-up areas, streets, drinkable and not drinkable water wells, rivers, strand, etc. In addition, application is banned in natural parks, pastures, vegetable crops, groundwater protection areas, areas under hydrogeological protection and areas with organic substance content higher than 5%.
Further limitations in applicable quantities are introduced when soil is shallow.

Analysis of different scenarios

Evaluation of agricultural sewage sludge potential in Apulia has been carried out with the help of the commercial software Esri® ArcGIS® 9.2.
GIS elaborations are very useful to political authorities to take proper decisions on issues related to environmental protection, as they enable the evaluation of the impact and sustainability of each new prescription.
Firstly, we have defined the areas in which sludge application is prohibited pursuant to limitations presently in force and we have subtracted them from the total regional surface (Figure 3).

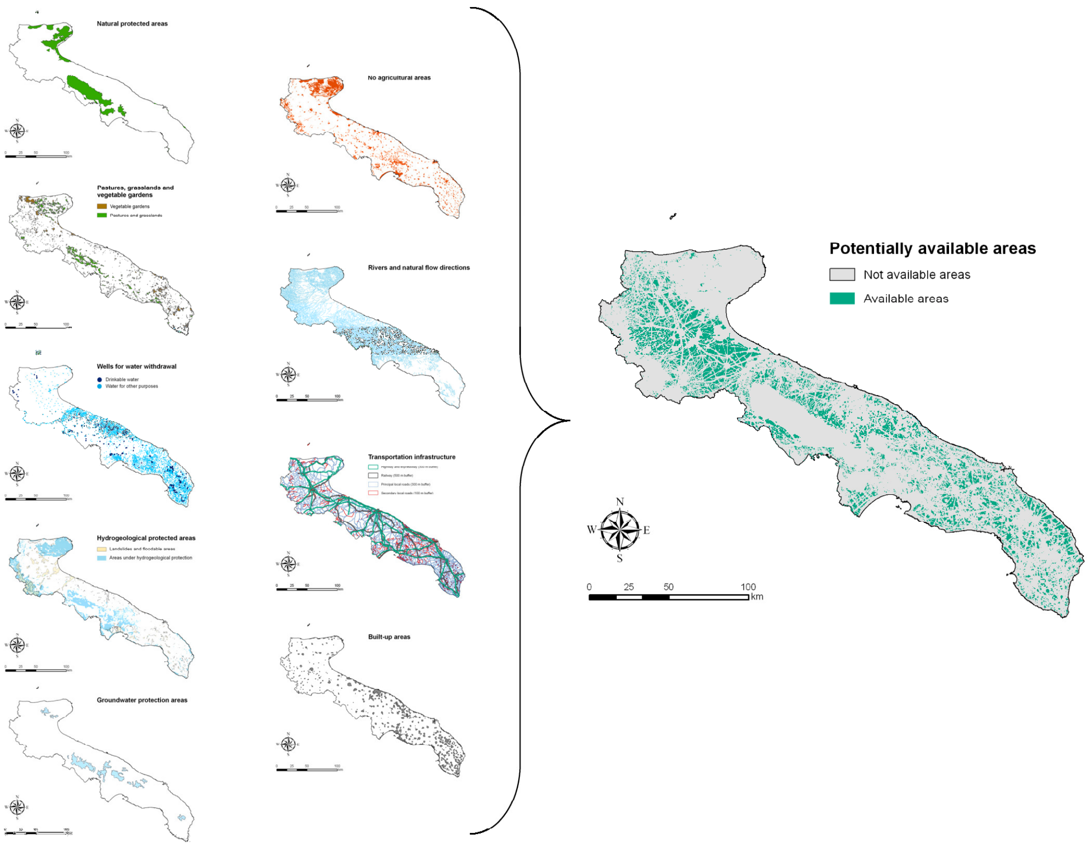

Figure 3: Superposition of prohibition areas in order to obtain potentially available areas for agricultural sludge reuse

As a second step, maps of organic substance content, pH and cationic exchange capacity have been drawn through interpolation based on the inverse weighted method, using punctually distributed data, in order to classify potentially available lands according to the maximum disposable quantities showed in Table 1 (Figure 4).

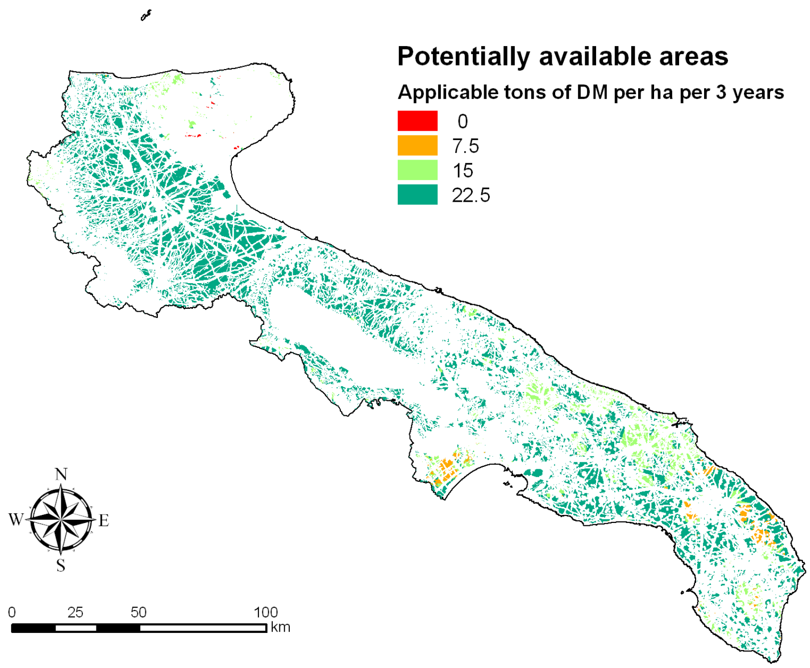

Figure 4: Potentially available areas classified in relation to maximum applicable tons of dry matter per hectare per three years

Next, disposable capacity has been computed in terms of a security factor (SF), defined as the ratio between the total amount of sludge that can be used in agriculture in three years and the sludge produced in five years. The calculation covers a five years period to take into account the prohibition to apply sludge for a period longer than three consecutive years and the need to suspend application for the two successive years. In our analysis, all the produced sludge is assumed to be sufficiently good to be recycled in agriculture, which implies an overestimation of the real quantities that can be disposed in such a way.

Sludge production has been evaluated assuming a contribution of 20 kg DM per year per population equivalent. A future projection can be made considering an increased production of 25 kg DM per year per population equivalent (Milieu Ltd et al. 2010). Population equivalents have been fixed in 4,700,000 and 6,000,000 respectively for present and future situation, as deduced from regional planning documents.

Agricultural sludge application cannot prescind from soil depth and cultivation practices that are locally employed for each cultivation type. Hence, potentially available lands have been classified on the grounds of the type of cultivation present and soil depth (Figure 5).

Different scenarios have been hypothesized as summarized in Figure 6, in order to estimate the effect of the environmental and agricultural context on disposable quantities.

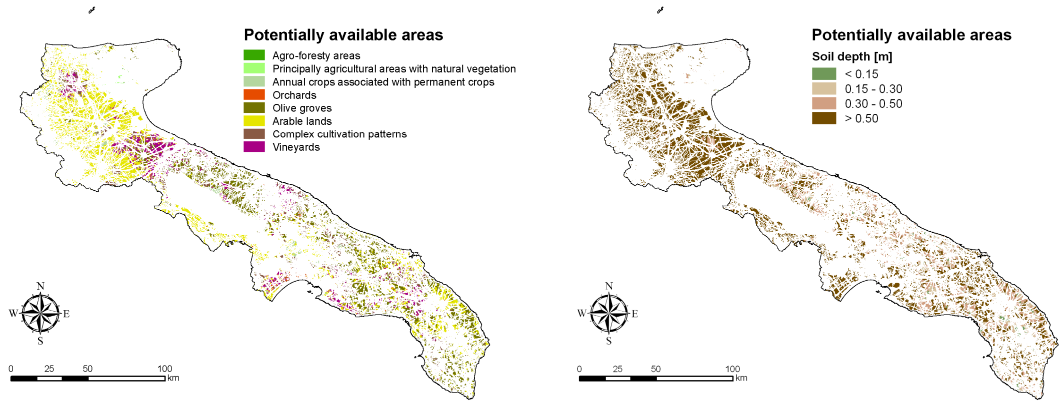

Figure 5: Potentially available areas classified in relation to cultivation types and soil depth

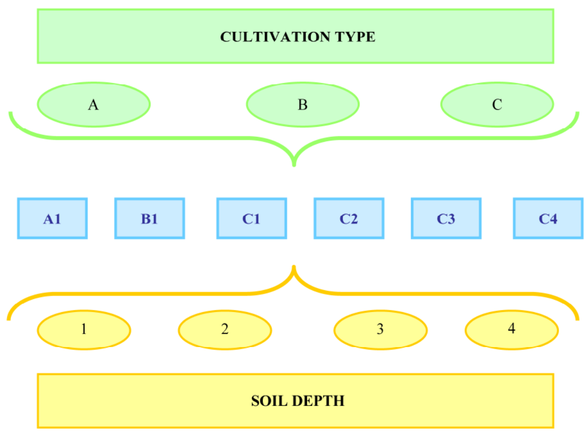

Figure 6: Schematic representation of the different scenarios analysed referring to type of cultivation and soil depth

In particular, three scenarios have been considered for cultivation types, so as to take into account crop rotation, possible presence of vegetables and the coexistence of natural areas:

A. total availability of all areas (100%);
B. reduced availability of non-irrigated arable lands and permanently irrigated lands (50%) and complete availability of all the other areas (100%);
C. reduced availability of principally agricultural areas with natural vegetation, agro-foresty areas and complex cultivation patterns (75%), annual crops associated with permanent crops (50%), non-irrigated arable lands and permanently irrigated lands (33%).

To take into account soil depth, as we did not have soil texture data necessary to correctly evaluate the reduction of sludge applicable quantities, we have fixed some reduction coefficients, defining four scenarios as reported in Table 2.

Table 2: Reduction coefficients applied to take into account soil depth

Scenario	Soil depth d < 0.15 m	Soil depth 0.15 m < d < 0.3 m	Soil depth 0.3 m < d < 0.5 m
1	0.25	0.5	0.75
2	0.167	0.333	0.556
3	0	0	0.5
4	0	0	0

The analysis of the regional legislation currently in force has revealed the opportunity to introduce some modifications in order to homogenize all the limits imposed by the laws that during the years have affected agricultural sludge reuse and to better stress the agricultural value of this practice in the specific local context.
In fact, some "objective limits" (i.e. those areas in which sludge application is totally banned, especially on the grounds of bonds on distances from streets and rivers), appear to be excessively restrictive, even in the light of lower values reported in the European Communities - Good Agricultural Practice for Protection of Waters - Regulations 2009 (Directive 91/676/EEC). As a consequence of the application of these "relaxed" constraints, new available areas can be gained (Figure 7).

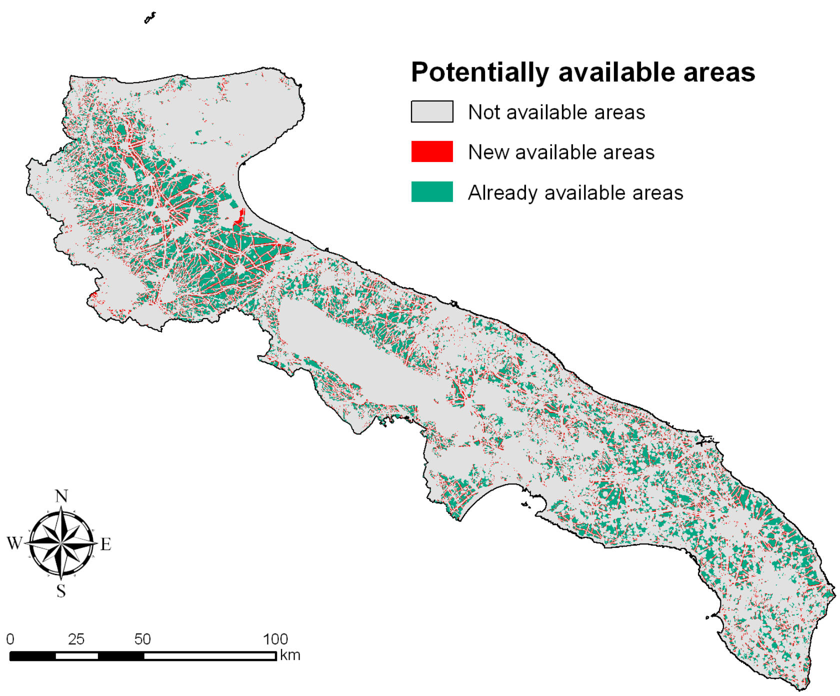

Figure 7: New potentially available areas regained by the introduction of new relaxed limits

On the contrary, the maximum applicable quantities seem too high when considering the nitrogen supplied to soil, given that Apulian sludge usually contains huge amounts of nitrogen, i.e. a mean value of 5%. As a consequence, the dumping of the highest quantity of sludge set by law will result in the application of about 400 kg of nitrogen per hectare per year, a value 3-4 times higher than nitrogen required by the typical regional crops. However, it should be considered that not all the nitrogen applied can be absorbed by vegetation and that nitrogen

availability depends on the type of sludge and largely varies even within the same sludge type (European Communities 2001).
Even if Directive 86/278/EEC explicitly highlights the necessity to take into account plants nutrient needs when applying sludge, no reference to this topic is present in Italian legislation. Therefore, a second modification in regional rules can be proposed, linking maximum applicable quantities to nitrogen needs for each cultivation type.
In order to assess the impact of the suggested revisions in regional legislation, reduced applicable quantities referred to nitrogen needs have been calculated considering a mean content of nitrogen of 5% and an average nitrogen availability of 70% in three years. Such an analysis yields the following values:

- 8,6 t_{DM}/ha in three years for non-irrigated arable lands and permanently irrigated lands, annual crops associated with permanent crops, complex cultivation patterns, principally agricultural areas with natural vegetation, agro-foresty areas;
- 11,6 t_{DM}/ha in three years for vineyards;
- 11,1 t_{DM}/ha in three years for orchards;
- 12 t_{DM}/ha in three years for olive groves.

Table 3 compares the security factors computed with present restrictions and maximum law applicable quantities with those based simultaneously on the relaxation of the over-restrictive bonds and on the actual nitrogen requirements of vegetation. To get a comprehensive view of the feasibility of our proposal, the analysis has been carried out for all the scenarios reported in Figure 6.

Table 3: Security factors (ratio between disposable and produced sludge) with present and new limits considering present and future sludge production

	Scenario	Disposable sludge [t DM]	Present SF	Future SF
Present limits	A1	6,411,933	13,64	8,55
	B1	4,896,064	10,42	6,53
	C1	4,114,997	8,76	5,49
	C2	3,875,708	8,25	5,17
	C3	3,570,413	7,60	4,76
	C4	3,258,504	6,93	4,34
New limits	A1	4,148,236	8,83	5,53
	B1	3,303,201	7,03	4,40
	C1	2,852,294	6,07	3,80
	C2	2,678,884	5,70	3,57
	C3	2,457,908	5,23	3,28
	C4	2,231,387	4,75	2,98

As evident, the soil availability appears sufficiently high even in the future projection for the worst scenario (C4) with new limits linked to nitrogen requirements.
A further reduction of the disposable quantities could result from the exclusion of olive groves and vineyards: in fact, on the one hand the nutrients needs of olive groves can be already satisfied by olive oil mill effluents, while, on the other hand, sludge application in vineyards can be difficult for operational reasons. Our estimate of the reduction of the security factors after

the elimination of olive groves and vineyards from available areas with current sludge production is reported in Figure 8.

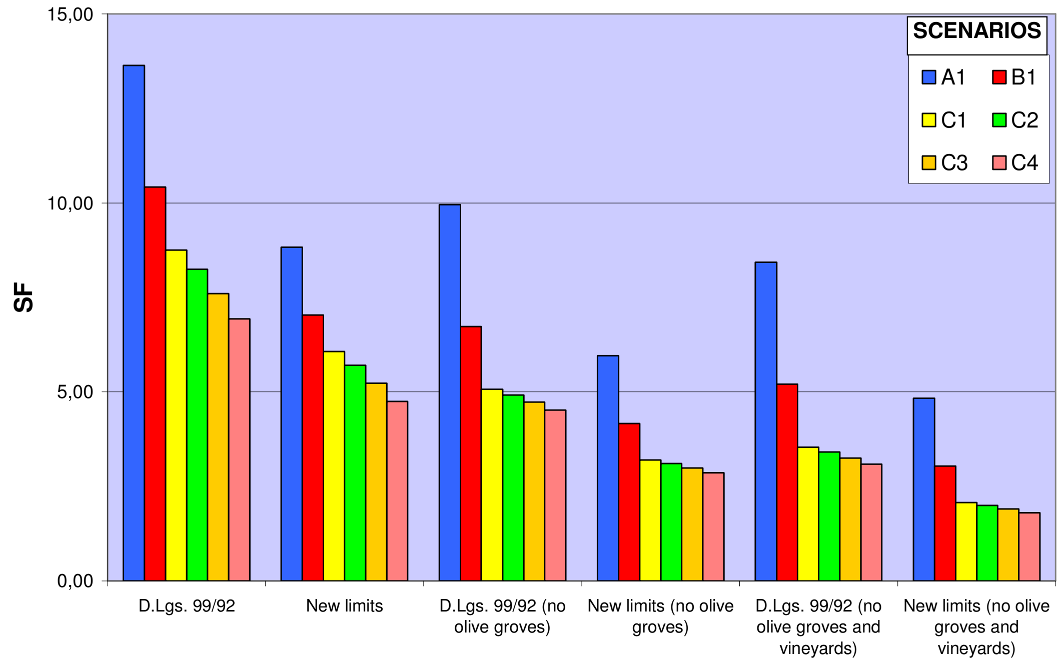

Figure 8: Reduction of security factors with current sludge production when considering olive groves and vineyards as not available areas

It is worth to note that even in this case potentially available areas are completely sufficient for facing the entire sludge production, as security factors are always higher than 1 both with present and new revised limits.

Conclusions

On the grounds of our analyses taking into account multiple possible scenarios, the following conclusions can be drawn:

1. Potentially available areas for agricultural sludge reuse in Apulia in view of current law limits are wide enough to tackle the outlet of both the present and expected future sludge production; security factors are very high even when introducing some limitations to applicable quantities in order to take into account agricultural cycles, soil depth and actual availability of some areas (i.e. olive groves and vineyards). The worst security factors obtained show that potentially available areas would be able to handle a sludge production three or two times higher than the present and expected production respectively.
2. A detailed analysis of the regulatory framework advises to introduce some modifications in regional laws with the aim to enlarge the types and location of areas to be potentially considered eligible for sludge application and to conversely restrict the maximum applicable quantities per hectare to meet crop nitrogen requirements. The calculations with these modifications show sufficient reuse potential even in the most conservative hypothesis, as security factors are never less than one.

3. The proposed analysis would suggest moving the focus of political decisions from general but in many cases generic law constraints towards specific ones closely related to the environmental and agricultural local practices and standards (cultivation cycles, crop rotations, high olive mill effluent production, etc.).
4. Furthermore, the maps we realised can be used to plan a strategic upgrading of wastewater treatment plants, aimed to improve sludge quality in those plants located in areas suitable for sludge agricultural use or to detect different disposal routes for those plants for which these areas are scarce.

Acknowledgments

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