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A spatial analysis model to assess the feasibility of short rotation forestry fertigated with urban wastewater: Basilicata region case study

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ABSTRACT

The large-scale cultivation of energy crops irrigated with non-conventional water resources could reduce the negative impacts of fossil fuel use, while still saving potable supplies and decreasing pollution in surface water, particularly in water-deficient environments, like the Mediterranean region. Energy planning is a complex process involving multiple decision makers and criteria. Given the spatial nature of the problem, the research proposes a spatial analysis model to assess the agronomic and economic feasibility of vegetation filter systems in Basilicata region, southern Italy. The model chosen for land suitability analysis is the ordered weighted averaging (OWA) with the use of linguistic quantifiers. The suitability map obtained from the OWA model was used as input in the spatial analysis functions to quantify the productivity and irrigation needs of the species, the potential irrigable service area of the wastewater treatment plants (WWTPs), as well as the distances between them and SRF, which are all key elements in the economic evaluation. The results show that the distance is the main element that influences the feasibility: only 25 out of 163 WWTPs are cost-effective and can actually irrigate 864 ha of SRF. The research demonstrates that there is a great potential for bio-energy development in the region with significant economic advantages; in fact, there is a large number of sites with positive NPV up to 50,876.43 €/ha and payback period between 3 and 10 years. The implementation of vegetation filter systems could create chains with a high number of local actors (farmers, intermediaries, forest nurseries, etc.) and contribute to promoting territorial development and employment.

1. Introduction

Bioenergy has a significant potential to mitigate greenhouse gases (GHGs), provided that sustainable strategies are adopted to develop resources, and efficient bioenergy systems are used (Styles and Jones, 2007; IPCC, 2011). Considered as the most promising renewable resource in the short and medium term (Hoogwijk et al., 2003), bioenergy is expected to play an increasing role in Europe, in view of achieving the targets recently established by the European Union on energy supply security and in compliance with international agreements on emission reductions. Within this context the biomass produced on agricultural soils will play an important role (Bernetti et al., 2004; EEA, 2013), related in particular to short-rotation forestry (SRF) (Dornburg et al., 2008, 2010; Romano et al., 2013a,b). Actually, following the IPCC report on renewable energies (IPCC, 2011), it would be possible to obtain up to 700 EJ/year from dedicated biomass crops grown on abandoned lands and/or on soils not planted with food crops. In the Basilicata Region, southern Italy, marginal farmland areas are being increasingly abandoned due to their low productivity in terms of output and product type, and as a result of the major reforms of the EU Common Agricultural Policy (Romano and Cozzi, 2008). It follows that there is a large availability of soils suitable for bioenergy crops, but there is still a need to convince farmers of the cost effectiveness of growing bioenergy crops. Several studies show that the gross margin for SRF cultivation is positive only if biomass production is >9 tDM/ha × year (Rosenqvist and Dawson, 2005a; Dimitriou and Rosenqvist, 2011; IEA Bioenergy, 2011). In Italy the yield values of SRF vary from

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North–South, mostly as related to the existing precipitation levels; surveys conducted in southern Italy (Bergante et al., 2013) report yield levels ranging between 5.6 and 6.1 tDM/ha × year, respectively, for poplar and willow, against values ranged between 7–10 and 14–16 tDM/ha × year for poplar and willow in northern Italy (Bergante and Facciotto, 2006; Facciotto et al., 2012). Irrigation and the application of fertilizers become, thus, necessary to achieve high productivity levels, especially in Mediterranean environments, characterized by water deficits notably in summer (Barbera et al., 2009). In those environments, the use of unconventional water resources is an excellent strategy to reduce the use of fresh water resources in agriculture while still supplying crops with water and nutrients (FAO, 2010); actually the European Union is stimulating and encouraging the spread of such a practice (European Commission, 2012).

The implementation of multifunctional SRF plantations has, thus, become a sound alternative to conventional SRF for the considerable economic and environmental benefits associated with them (Rosenqvist and Dawson, 2005b; Berndes et al., 2008; Ericsson et al., 2009; Dimitriou and Rosenqvist, 2011). These plantations, irrigated with wastewater and consisting of species such as willows (*Salix* spp.) and poplars (*Populus* spp.), are defined "*vegetation filter systems*" and are intended for the production of energy biomasses and phytoremediation (Guidi et al., 2008). Wastewater supplies plants with water and nutrients, notably nitrogen and phosphorus, thus favouring crop growth; the plants, characterised by high transpiration rates, clean water by uptaking the dissolved elements, including heavy metals (e.g., cadmium) (BIOPROS, 2008).

Despite the many economic and environmental benefits proved by experimentation conducted in North-Central Europe countries (Rosenqvist and Dawson, 2005a,b; Börjesson and Berndes, 2006; BIOPROS, 2008; Dimitroiu and Aronsson, 2011; Dimitriou and Rosenqvist, 2011; Holm and Heinsoo, 2013) and although the Italian legislation allows the use of wastewater in agriculture1, the applications in Italy of multifunctional SRF for the production of biomasses and water purification are limited (BIOPROS, 2008; Guidi et al., 2008).

This work has as its main objective the development and application of a GIS-based spatial analysis model aimed at identifying areas potentially suitable for creating vegetation filter systems. Based on the existing wastewater treatment plants (WWTPs) in a given area, the use of a large scale land analysis model would enable public and private decision-makers to make targeted investments (Cozzi et al., 2013). The above model has been applied to the Basilicata region, characterized by a typically Mediterranean climate with summer water deficits that justify the use of unconventional water resources for irrigation for not undermining drinking water supply in urban areas. The idea stems from the research conducted at the University of Basilicata that has developed a system for urban wastewater treatment based on "conventional activated sludge"; this system enables the production of water with a varying load of organic carbon, nitrogen and phosphorus, so as to adapt water to the needs of irrigated crops, thus reducing the treatment costs by about 20–30% (Lopez et al., 2006; Masi et al., 2008).

The whole model has been designed to focus not only on environmental sustainability (proper use of wastewater, exclusion of nitrate-vulnerable zones) but also on the cost effectiveness of growing SRF fertigated with urban wastewater, all core potential elements for the spreading of these systems.

2. Potentials of vegetation filter systems

Most studies on vegetation filter systems have focused on their environmental and economic impacts and have shown that they are viable only if the use and management of urban wastewater is safe for the environment (minimum leaching of nutrients in ground water), if the purification efficiency of these systems is equal to that of other treatment methods and if it is allowed by the national legislation (Dimitriou and Rosenqvist, 2011). It has been demonstrated that the treatment efficiency may be even higher than that of conventional treatments (Hasselgren, 2003), with retention up to 96% for nitrogen and 94% for phosphorus (Dimitroiu and Aronsson, 2011), whereas leaching processes depend on the load of nutrients contained in wastewater more than on irrigation flow rates (Dimitroiu and Aronsson, 2004; Rosenqvist and Dawson, 2005b). Hence, the pretreatment of water (Aronsson, 2000; Carlander and Stenström, 2001) and the calculation of crop irrigation requirements (Guidi et al., 2008) can ensure high efficiency of these water treatment systems without any risk for the environment. At the same time, the application of water rich in nutrients results in a substantial increase of crop yields. If 100% yield increases have been recorded in north Europe countries (Börjesson and Berndes, 2006), more sustained increases have been observed in Mediterranean environments. In a study conducted in Italy, yield values are reported to increase from 6.6 to about 64 tDM/ha for willow and from about 9 to 44.4 tDM/ha for poplar, when crops are irrigated with wastewater (Guidi et al., 2008). These results are due to the higher evapotranspiration rate observed in arid climates, where large volumes of wastewater may be actually treated. This produces economic benefits both for farmers who can rely on higher returns related to higher crop yields and a 25–30% cut of production costs, and for the companies working in urban wastewater treatment that can largely reduce purification costsby using the vegetation filter systems as an alternative to conventional treatments (Rosenqvist and Dawson, 2005b; Börjesson and Berndes, 2006; Dimitriou and Rosenqvist, 2011).

Despite the many experiences, which prove the considerable economic and environmental benefits, the spread of SRF fertigated with wastewater is limited. Different literature studies have proposed GIS-based land use suitability models for identifying the most potentially suitable soils for SRF (Salvati et al., 2007; Romano et al., 2013a), but none of them has produced a model specifically targeted to identify the WWTPs that can be used for the fertigation of those soils. The use of this large scale analysis model would facilitate public and/or private decision-making for the establishment and spreading of vegetation filter systems.

For building the spatial analysis model wholly developed using GIS, this work has focused on the following practical aspects that impact directly on the real potential of vegetation filter systems (BIOPROS, 2008; Guidi et al., 2008):

1. Use of urban wastewater for fertigation in agriculture allowed by law.
2. Land suitability for SRF plantations.
3. Local availability of urban wastewater.
4. Short distances of treatment plants from SRF plantations, so as to reduce the investment costs of the conveyance pipeline.
5. Benefits resulting from multifunctional SRF plantations for farmers, society and the environment.

An additional economic aspect needs to be taken into account to minimize the investment costs of fertigation system: SRF planted areas should be located downstream of treatment plants to reduce water pumping costs.

The Italian legislation (see footnote 1) allows for the reuse of wastewater in agriculture, provided that the legal limits are complied with; in this work wastewater is assumed to be pretreated by the "conventional activated sludge" systemto make it compliant with legal limits and to meet crop requirements.