Regional assessment of waste flow eco-synergy in food production: using compost and polluted ground water in Mediterranean horticulture crops

Julia Martínez-Blanco[1,*], Pere Muñoz[2], Joan Rieradevall[1,3], Juan I Montero[2], Assumpció Antón[2,4]

[1]Universitat Autònoma de Barcelona, Institute of Environmental Science and Technology, SosteniPrA, 08193 Barcelona, Spain.

[2]Intitute of Research and Technology in the AgriFood sector, Environmental Horticulture. SosteniPrA, 08348 Barcelona, Spain.

[3]Universitat Autònoma de Barcelona, Chemical Engineering Department, 08193 Barcelona, Spain.

[4] Departament d'Enginyeria Quimica, Universitat Rovira i Virgili, 43007 Tarragona, Spain.

[*]Julia.Martinez@uab.cat

Abstract The potential eco-synergetic effects of using two waste flows for the substitution of mineral fertilizers is assessed from nutrient and environmental points of view. The two wastes are: composted organic municipal waste (slow release of nutrients) and nitrate polluted water (rapid nitrogen release). Catalonia is selected as a representative Mediterranean area of study. Macro-data at county level was used for the calculations, geographic information system, for the illustrations, and IPCC impact factors, for the environmental quantification. Compost and polluted water are able to supply 35-50% of the nutrient demand of Catalan horticulture production (330,000 tons of horticulture products per year), leading to reduction of 46% of the global warming potential of mineral fertilizers production. More mineral fertilizers are saved in urban and agriculture intensive areas.

1 Introduction

Intensive horticulture has produced increasing economic and social benefits and a more efficient use of resources; nevertheless, the increase of inputs has had bad consequences for the environment. Two of the main problems derived from the high use of mineral fertilizers are the loss of nutrients and the resulting pollution of aquifers. Most intensive horticulture areas in Europe have been declared

regions vulnerable to nitrate pollution [1]. Mild winter climates concentrate a major vegetable crops production, because weather is generally more favourable.

On the other side, the European Directive 2006/12/EC [2] on waste settled that the Member States should take measures for the treatment of their waste in line with the waste hierarchy, which considers recycling as one of the priority options. Therefore it is necessary to reduce the amount of the organic fraction of the municipal solid waste (OFMSW) being dumped, in order to minimise environmental impacts, and also the loss of organic resources.

Composting is one of the most broadly used OFMSW treatments in Europe and in the world [3]. However, composting plant managers usually came across with the rejection of farmers to apply the organic product in their fields. One reason is that nutrients from compost are not immediately available for the plant after compost application in soils, but they are slowly released in the long term, besides, there is a lack of training in its application. It could lead to shortage of nutrients during plant growth and, therefore, lower yields.

Nevertheless, an adequate use of composted products, together with a readily available nitrogen supplementation, have proved to reach similar yields as conventional fertilization [4-7], saving a part of the economic and environmental costs of produce and use inorganic fertilizers. Highly nitrate polluted water may be a potential source of rapid nitrogen, apart from mineral fertilizers, and its use could mean a decrease in the concentration of contaminants.

Fertilization decisions are extremely relevant, as fertilization production has been reported as one of the determining factors for the environmental performance of horticulture products, particularly for those with low energy consumption [7,8].

Taking into account the principles of the industrial ecology, the aim of this paper is to study the potential eco-synergetic effects of using two waste flows, composted organic municipal waste and nitrate polluted water, which are slow and rapid sources of nutrients, respectively. We assess the maximum compost production in the area of study and state its potential use for supplying, together with the nitrogen in ground water, the nutrient demand of the horticulture sector. The results include the balance of nutrients and the global warming avoided due to mineral fertilizers savings. The area of study, Catalonia, was selected as representative of other Mediterranean regions due to the high population density, and therefore, large production of wastes; because it has firmly committed for composting as the major treatment for OFMSW [9]; because it has an annual production of almost 330,000 tons of horticulture products [10]; and because it presents relevant levels of nitrates in ground water.

This paper provides also a good example of the potentialities of the joint use of geographical information systems and life cycle assessment.

2 Methods and area of study

Area of study, data sources and considerations for the calculations and tools used for the assessment are briefly explained below. The information was processed at county level.

2.1 Area of study

Catalonia is an autonomous region located at the north-east of Spain and with a total area of about 32,000 km^2. It borders on France to the north and on Mediterranean Sea to the south. At the beginnings of 2011, it had more than 7.5 million of inhabitants. The region of study is divided into 41 counties of 145-1,785 km^2.

2.1.1 Horticultural production and nutrient demand

The productions and areas cultivated per horticulture crop (for instance, tomato, onion, lettuce, etc.) and per county are obtained for 2008 [10].
Regarding the calculation of nutrient demand (nitrogen, phosphorus and potassium), fertilization recommendations for integrated cultivation management are used [11,12].

2.1.2 Potential nutrients from OFMSW compost

The total amount of organic waste from households, restaurants, caterers and retail premises generated (source-separated or collected with the bulky waste) in Catalonia is calculated at county level, using the following data: total municipal solid waste generation per county in 2009 [13] and average content of organic waste in the municipal solid waste for Catalonia, which is 36% [9]. We consider a 10% of OFMSW non-composted due to likely technical, geographical and social difficulties for the whole source-separated collection.
Catalan average mass reduction during composting is 78% [14]. The average nutrient supply of compost the first year was calculated using analysis from Huerta et al. [14] and considering the mineralization rates of 14% (N), 37% (P) and 78% (K), from several compost reviews.

2.1.3 Potential nutrients from ground water

The available data from the Catalan quality controlling net is used [15]. Average nitrate content per county and for the last 5 years is calculated. In order to do calculations we have assumed the total irrigation water (6,500 m^3/ha·year) coming from ground water, which is supplemented with rainfall water. Total nitrogen applied with irrigation water is calculated multiplying nitrate content by the total amount of water used in each county. Supply of phosphorus or potassium is not taken into account as the concentrations in water are negligible.

2.2 Comparison scenarios

The nutrient savings and environmental improvement of the assessed eco-synergy scenario, which considers the use of nutrients coming from compost and polluted ground water, are calculated from the initial or current scenario. The maximum amount of compost per county depends on the potential compost production and is restricted to do not apply more than 170 kgN/ha·year from organic sources [16]. The rest of nutrients are supplied by mineral fertilizers.
The initial scenario, considers that the entire nutrient demand from horticulture is supplied by mineral fertilizers and the slender compost applied to soils is not substituting inorganic fertilization. Nowadays, less than 15% of the OFMSW generated in Catalonia is being applied to soils as compost [9,17].

2.3 Geographic information system

The spatial information generated was presented with a geographic information system (GIS) software, MiraMon$^{(R)}$ v7, allowing data processing and visualization.

2.4 Global warming potential

For the global warming potential (GWP) calculation, impact factors from IPCC 2007 were used and only classification and characterisation steps, applied.
For the impact saving calculation only the avoided manufacture of mineral fertilizers is taken into account. Neither pumping station nor OFMSW management options nor transport of fertilizers are being included. The

environmental data related to mineral fertilizers production was obtained from Boldrin et al. [3].

3 Results

3.1 Nutrient demand and potential supply

The nutrient demand from horticulture sector and potential supply from compost and ground water for Catalonia region, at county level, are presented in this section. Nitrogen demand and supply are showed in Fig. 1 and 2, respectively.
The total amount of required nutrients from horticulture crops, which is calculated following section 2.1.1, is about 1,900 tons of N, 300 tons of P and 2,150 tons of K per year. Nitrogen demand per county is represented in Fig. 1. Coastal counties and 4 and 5 are the ones with higher demand of N and, therefore, higher horticulture production.

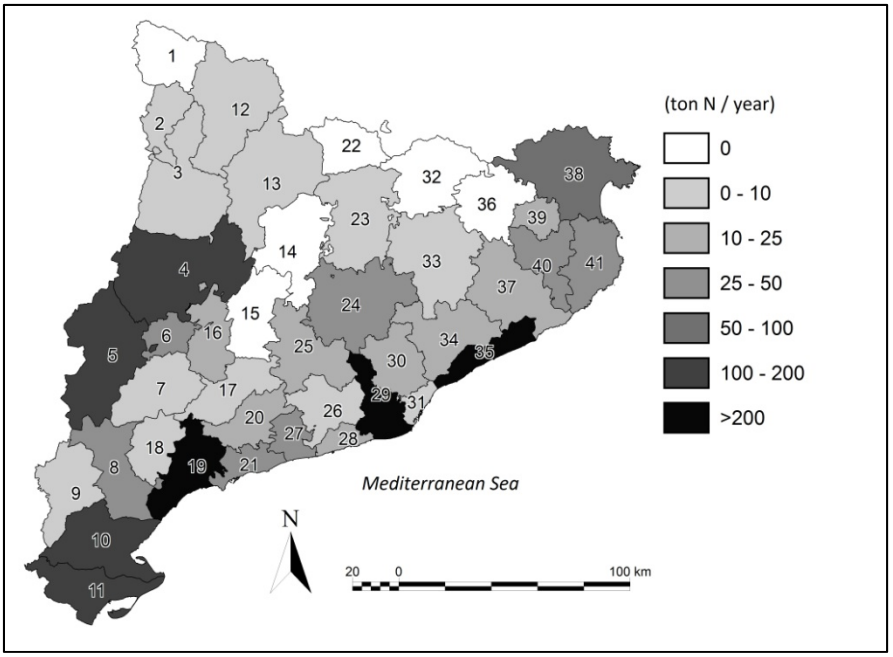

Fig.1: Nitrogen demand from the Catalan horticulture sector

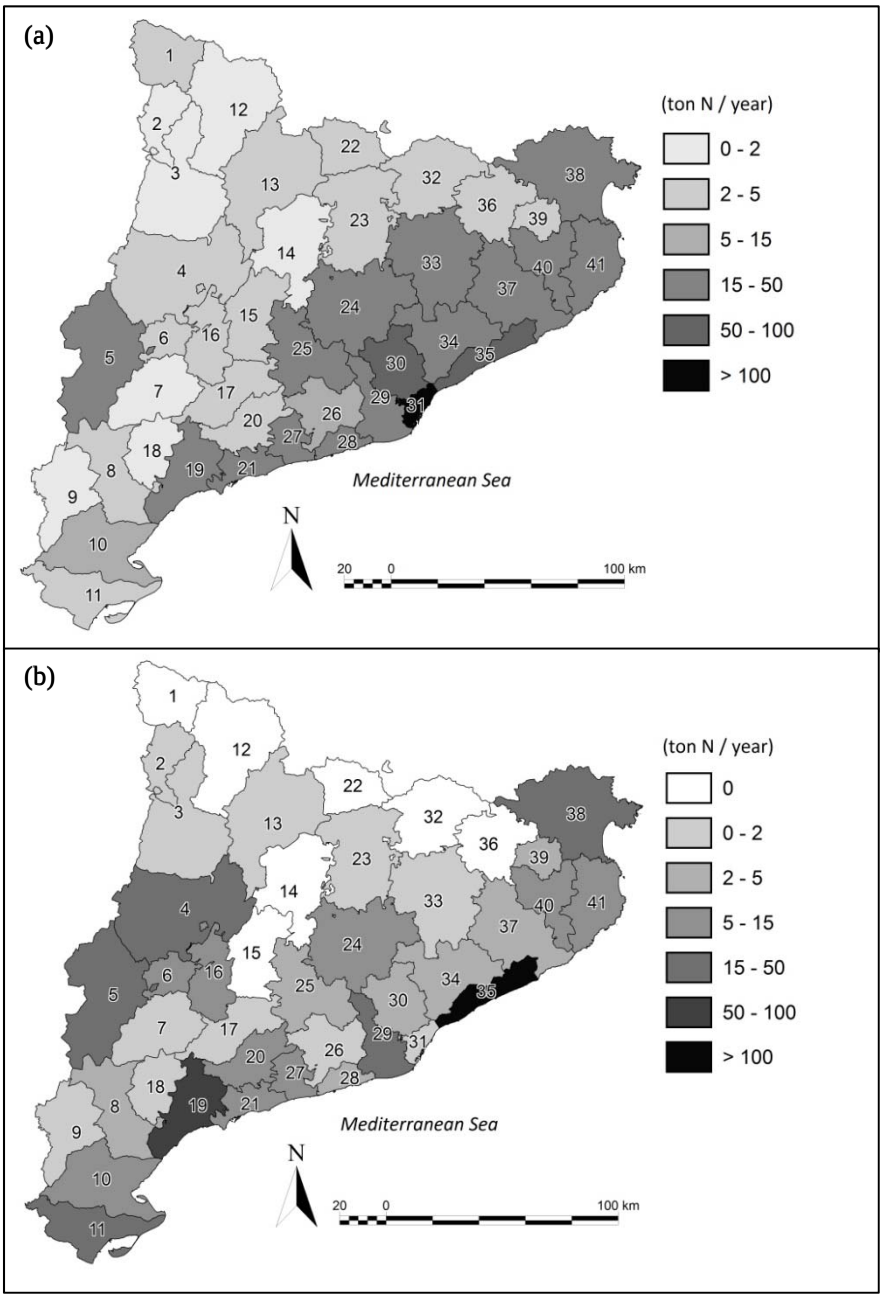

Fig.2: Nitrogen offer from the two wastes. (a) Potential nitrogen available the first year from OFMSW composted. (b) Potential nitrogen available from ground water irrigation

Fig. 2a shows the amounts of nitrogen available (in the short term) from the Catalan OFMSW generation if 90% of it is composted (see section 2.1.2). Counties with higher populations obviously have upper amounts of OFMSW to manage. Catalan population is mainly concentrated in coastal counties, being Barcelona city (county 31) and its surroundings the higher populated and the major generators of waste. County 31 has a generation of nearly 600 thousand tons of OFMSW per year, which represents almost half of the total Catalan generation (1,450 thousand tons). The potential nutrient supply from compost is about 950 tons of N, 450 tons of P and 2,050 tons of K per year

Upper nitrogen concentrations in ground water are measured in those counties with a major dedication to agriculture or stockbreeding: 4, 5, 6, 15, 19 have concentration above 50 mg NO_3/l and 33 and 35 have levels above 75 mg [15]. These areas are under regional regulation [16], in accordance with the Directive 2006/118/EC [1], for the protection of water against nitrate pollution from agricultural sources. Fig. 2b shows the amount of nitrogen supplied by ground water according to the irrigation demand of each county (section 2.1.3). The potential amount of nitrogen coming from irrigation water for Catalonia is almost 500 tons per year.

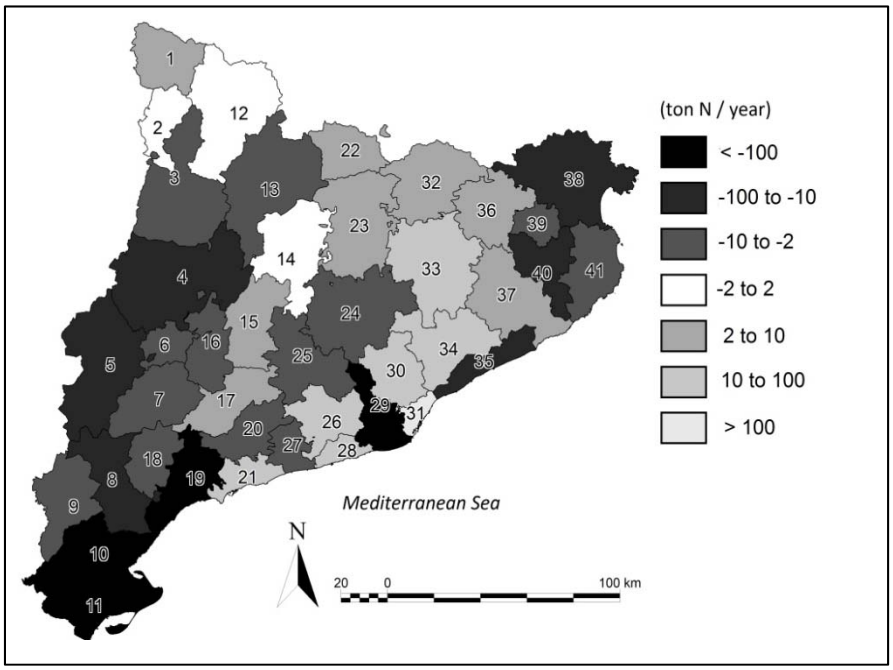

Fig.3: Balance of nitrogen for the eco-synergy scenario (negative values show shortage, positive values show surplus)

3.2 Nutrients balance for compost scenario

According to the abovementioned amounts of nitrogen required by Catalan horticulture sector and supplied by compost and ground water (Fig. 1 and 2), Fig. 3 shows the balance of nitrogen at county level. Most coastal and west counties have shortage of nitrogen, whereas the rest have too much compost generation for their consumption.

Fig. 4 illustrates the potential contributions from compost and ground water in the eco-synergy substitution of fertilizer. Almost 50% of mineral fertilizers are saved for N and P, half using compost and half using irrigation water, for the former, and using only compost, for the latter. Regarding potassium, compost supplies 35% of the demand.

However, the total amounts of truly saved mineral fertilizers by compost differ considerably from the potential nutrient supply for the entire Catalonia. According to section 3.1 and Fig. 4, 41% of the potential nitrogen from compost is used, 30% of the P and 37% of the K. It is as a consequence of conflicts with places where compost is produced and places where nutrients are required (Fig. 3), and because maximum amount of compost applied per hectare is limited [16].

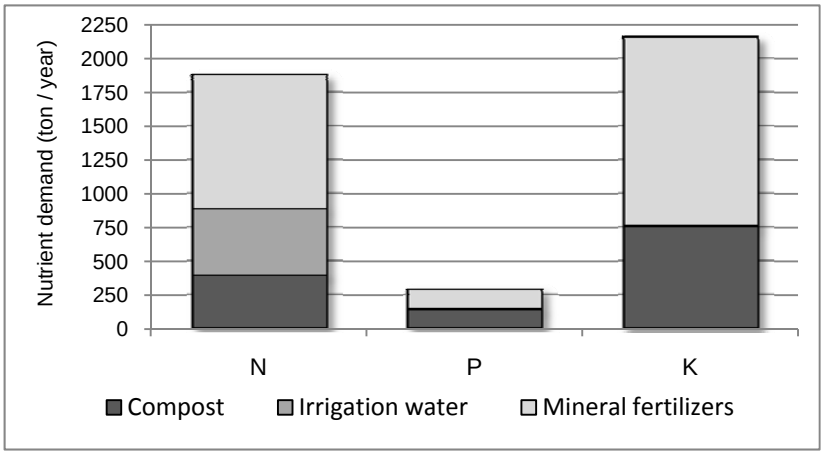

Fig.4: Contribution of the three sources of nutrients to the total demand of nutrients of Catalan horticulture sector in the eco-synergy scenario

3.3 Environmental impact savings

The GWP of the mineral fertilizers saved, thanks to nutrient contribution of the eco-synergy compost and ground water, is presented in Fig.5. More than 9,000

tons of CO_2 equivalents, 46% of the current emissions from mineral fertilizers manufacture, are saved for the whole Catalonia.
Major GWP is avoided where there is high generation of OFMSW (i.e. population), high nitrate content in ground water and, specially, high demand of nutrients (i.e. horticulture production), for instance, county 35, 5 and 19.

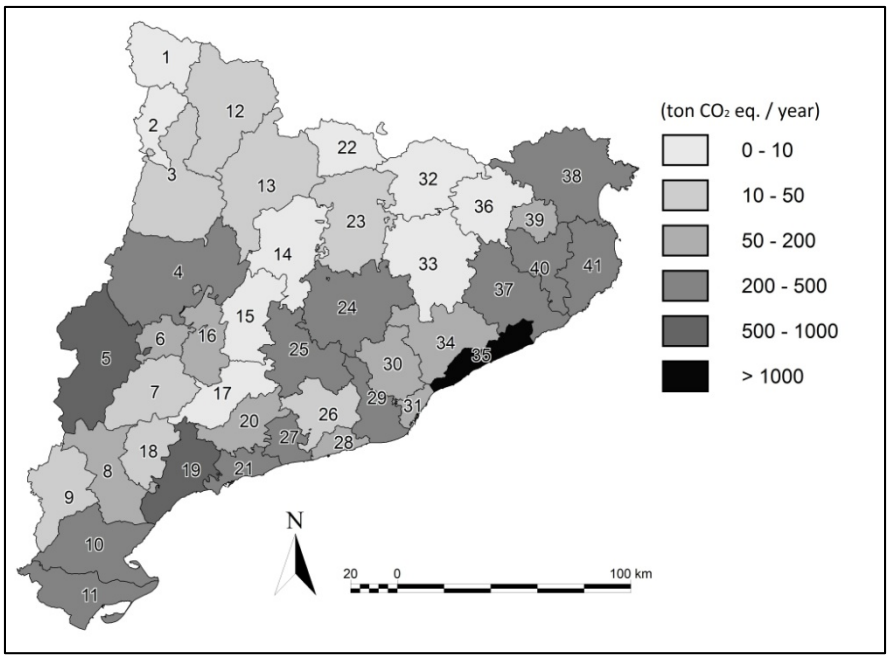

Fig.6: Global warming savings for the eco-synergy scenario

4 Discussion and conclusions

The total amount of required nutrients from horticulture crops in Catalonia is about 1,900 tons of N, 300 tons of P and 2,150 tons of K per year. From them, the compost and polluted water eco-synergy combination is able to supply between 35-50% of the demand of nitrogen, phosphorus and potassium. Polluted water supplies rapid available nitrogen to the crops, while compost nitrogen and other nutrients are slowly released, providing a source of nutrients in the long term.
Two waste flows, that before were problematic, become a way to reduce inorganic fertilizers consumption. The potential reduction would lead to avoid 46% of the current emissions from mineral fertilizers manufacture. Furthermore, other environmental savings would take place due to reduction in the amount of

OFMSW going to landfill, decrease in the nitrate content of nitrates in ground water, thanks to bio-filtration effects, and effects of organic matter in the health of soils and plants.
Higher substitution rates, and therefore larger impact savings, with the eco-synergy of the two wastes are achieved in urban and agriculture intensive areas. It is consequence of major pollution of aquifers, major generation of organic waste and major demand of nutrients.
Taking into account the possibility of transporting compost from one county to another, it could increase even more the savings. Moreover, less than 41% of the nutrients of the potential production of compost would be used by horticulture sector; therefore other agriculture sectors could take profit of this surplus.
From the results of this paper, the joint use of the tools LCA and GIS inside the framework of industrial ecology appears a valuable strategy for territorial planning and decision taking.

5 Further research and points of concern

Aiming to build a more realistic model and to obtain more comprehensive results it is necessary to stress in several of the suppositions and data used throughout the paper. Further research would be focus on:

- Consider real values of OFMSW generation per county or municipality.
- Add other irrigated crops apart from horticulture ones.
- Take into account the residual effects of nutrient release from compost in the long term.
- Assess the potential higher savings if transport of compost between counties is considered.
- Assess the loads of a excessive application of P and K applied with compost.
- Add other impact categories apart from GWP, as eutrophication and acidification potential, relevant for the water pollution.

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