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Life cycle assessment of cultivating lettuce and escarole in Spain

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ABSTRACT

Exportation of fresh vegetable products, especially to northern European countries, have expanded significantly in recent years in Spain in response to the demand of developed countries for fresh and high-quality products all year round. Many of these products are produced intensively in protected or semi-protected (mulched) cropping systems. The methodology selected for the environmental study was Life Cycle Assessment (LCA). The cropping systems were unheated greenhouse (GH), plastic mulch combined with fleece (PM + F), plastic mulch (PM) and open field (OF). The effects of different nitrogen fertiliser application rates (0%, 25%, 50%, 100%, 125% and 150% of an optimum rate) were evaluated for each system. The aim of this analysis was to identify and study the main environmental problems of producing lettuce and escarole in Spain under different production systems and at different N management application levels.

The LCA methodology proved to be a useful tool to evaluate the environmental burdens of producing two leafy crops in Spain. The environmental results were very similar for two crops, but the escarole crop produced a major contribution in all impact categories due to lower commercial yields. The main burdens in the production systems were structure, auxiliary equipment and fertilisers. GH was the production system with the largest environmental impact in all categories and crops due to the greenhouse structure. Improving design of the greenhouse structure and the irrigation system and using recycled materials could produce significant impact reduction. The reduction and optimising of N fertiliser application should be considered a priority to improve the environmental impact of the different cultivation systems.

1. Introduction

Sustainable food production and consumption is currently one of the main concerns of consumers and governments. Due to the growing environmental consciousness of consumers in numerous countries worldwide, further knowledge is needed related to the environmental impacts of agricultural activities (Mourad et al., 2007). In recent years, the area covered by protected vegetable cropping systems has expanded (plastic mulch, plastic tunnels and plastic greenhouses) in response to the demand from developed countries for fresh products all year round (Castilla, 2007). The climate control possible with these structures enables extended crop production periods and increased production levels. Different climates in different regions of Spain have had a strong influence on the technological and economic development of protected and semi-protected horticulture. For example, in favourable climate conditions of southern and eastern Spain, semi-protected and open-field systems are commonly used for production of lettuce and escarole. In contrast, in cold-winter climates (North Spain), these two crop growing cycles are completed with protected systems in greenhouses, as they are in northern Europe. With the improvement of communications between north and south Europe due to the construction of motorway networks, it has become more economic to produce vegetable crops in south-east Spain (and even in Morocco) and transport them to northern Europe, than to use energy to heat greenhouses in colder climates. Previous studies have been carried out on the environmental impacts of protected crops in greenhouses under Mediterranean climatic conditions (Stanhill, 1980; Antón, 2004; Torrellas et al., 2012a,b) comparing greenhouse production to traditional open field cultivation (Muñoz et al., 2007; Nuñez et al., 2008; Romero-Gámez et al., 2012). The use of plastic mulching and fertigation in horticultural crops is increasing due to its agronomic and environmental benefits (Robledo and Martin, 1981; Benoit, 1994; Farias-Larios and Orozco-Santos, 1997; Suárez-Rey et al., 2008a). Some of the reported beneficial effects of plastic mulches are an increase in crop yield,

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modification of the soil thermal regime, reduced weed competition and conservation of soil moisture (Tarara, 2000). Also, a decrease in nitrate leaching through the reduction of drainage (Benoit, 1994; Romic et al., 2003) and nitrate concentration in the drainage water (Romic et al., 2003), have been reported. The advantages of using fleece have also been documented as an inexpensive means to improve the crop micro-environmental conditions (Giménez et al., 2002; Hernández et al., 2004).

In Spain, lettuce and escarole can be grown all year round in all systems (Maroto et al., 2000; Sádaba et al., 2010). Lettuce is one of the most important leafy vegetable crops with a global production of 22.5 million tonnes in 2010 (FAOSTAT, 2011). Spain is one of the largest producers in the world, with 809 thousand tonnes in 2010 (with an average yield of 31.5 t ha^{-1} in greenhouse conditions and 42.7 t ha^{-1} in open field) (MARM, 2011) of which 56% were exported. Specific applications of Life Cycle Assessment (LCA) to lettuce grown in greenhouses have been used to evaluate deposition and residues (Sevigné et al., 2012) or seasonality in consumption (Hospido et al., 2009). The escarole total production in Spain was 59.8 thousand tonnes in 2010 (with an average yield of 32 t ha^{-1} in greenhouse and 38.5 t ha^{-1} in open field) (MARM, 2011) of which 38% were exported.

There are areas in Spain classified as "vulnerable zones to nitrate contamination from agricultural use and exploitation" according to European Union regulations, following the directives on protective measures against aquifer contamination by fertilisers (CEC, 1991). This directive contains mandatory measures relating to agricultural practices to reduce groundwater and surface water pollution by high nitrate contents. In leafy vegetables, an additional disadvantage of excessive fertilisation is the increase of nitrates in the edible plant organs. Since 1990 the surplus nitrogen has increased in Spain, mainly due to inadequate irrigation and fertilisation management (EEA, 2006). Maximum levels for nitrate in lettuce are established by the European Commission Regulation (EC, 1881/2006). Lettuces harvested between October and March, have a limit of 4500 mg NO_3 kg^{-1} (under cover) and 4000 mg NO_3 kg^{-1} (in the open air), whereas lettuces harvested between April and September, 3500 mg NO_3 kg^{-1} (under cover) and 2500 mg NO_3 kg^{-1} (in the open air). Maximum levels for iceberg type lettuce are 2500 NO_3 kg^{-1} grown under cover and 2000 NO_3 kg^{-1} grown in the open air. This regulation does not establish maximum levels for escarole, but this plant is physiologically very similar to lettuce.

Research in nitrogen assimilation and use of alternative agricultural techniques have been carried out to reduce the environmental impact of nitrogen fertilisation while maintaining crop yield, especially in these vulnerable areas. Characterisation of growth and quality parameters and nitrate accumulation in crops such as lettuce and escarole (Suárez-Rey et al., 2008a,b), tomato (Vázquez et al., 2006) or garlic (Suárez-Rey et al., 2009) with different covering techniques (plastic mulch and fleece) have been investigated. Studies have also been conducted to address the effect of using different nitrogen levels on crops, e.g. lettuce (Acar et al., 2008; Rickie et al., 2008, etc.) and studies of environmental impact of rates on N in wheat grain, oilseed rape and potatoes (Williams et al., 2010). In order to have a representation of most relevant types of protected and semi-protected horticulture, it was considered that developments and assessments should be studied under alternative systems in the different climatic conditions in Spain. Thus, four representative systems of agricultural practices in Spain were selected, focussing on two leafy crops (lettuce and escarole) and six N fertiliser rates.

The aim of the study was to identify the main environmental problems of different lettuce and escarole production systems in Spain at different N applications. Thus, the objective for each production system and N dose was to evaluate the associated impacts and to select and improve the cultivation techniques, equipment and structures by trying to minimise their impact on the surroundings and natural resources. In this study, a detailed description of representative lettuce and escarole crop production systems will help in evaluating the most efficient solutions to improve the sustainability of agricultural practices. This study is the first involving environmental aspects for the different production systems for green leafy vegetables existing in Spain.

2. Materials and methods

2.1. Goal and scope definition

The main objective of the study was to analyse the environmental burdens of lettuce and escarole crop production methods on farms at a national level in Spain and to select and improve the cultivation techniques, equipment and structures by trying to minimise their impact on the surroundings and natural resources. The main components affecting the environmental impacts were identified with respect to the resource inputs.

The production burdens associated to these crops were calculated by the LCA methodology using the system model "Cranfield Arable and Horticultural Life Cycle Inventory" (Williams et al., 2006). This inventory quantifies the input data, solid residues, atmospheric emissions and emissions to water (more recent work looks at water footprints of crops). The effects of other factors, e.g. changing nitrogen fertiliser application rates, were also analysed.

The research focused on four systems representative of the actual situation of the production of lettuce and escarole in Spain:

plastic greenhouse in northern Spain (GH)
plastic mulch combined with fleece in southern Spain (PM + F)
plastic mulch in southern Spain (PM)
open-field in southern Spain (OF)

at different N fertiliser rates (0%, 25%, 50%, 100%, 125% and 150% of an optimum rate).

The scope of this study is limited to crop production, considering all the input and output flows of materials and energy up to the farm gate in Spain. Packaging and transport to market are considered the same for the functional unit.

The base system is the crop produced in open field conditions. The functional unit (FU) is defined as 1 tonne of Class 1 marketable fresh weight of each crop, from which all the data have been normalised, since the main objective of agricultural systems is food production (Audsley et al., 1997). We assume the nitrogen content of the crop is not a significant market factor. All other lettuce that is not marketable and is organic waste, is ploughed into the soil.

The system boundary includes from the raw material extraction to farm gate. The same approach was used to model both crops. The main sources of agricultural burdens for these crops were machinery and buildings manufacture, transport of materials, manufacturing of pesticides and fertilisers, diesel for cultivation, emissions of contaminating compounds due to fertilisation, water and energy consumed by the irrigation systems, energy consumed by the controlled climate systems and management and transport of the wastes generated. Fig. 1 shows a general flow diagram for the four production systems considered. In order to simplify the LCA study, some aspects of the analysed treatments were excluded: transport of fertilisers and pesticides, containers and packaging used in the supply of fertilisers and other farming materials. It is assumed that the aspects excluded would have a low environmental impact compared to those that were included (Antón, 2004).