Scientia Horticulturae 162 (2013) 380–386

Contents lists available at ScienceDirect

Scientia Horticulturae

journal homepage: www.elsevier.com/locate/scihorti

Alternative management for olive orchards grown in semi-arid environments: An energy, economic and environmental analysis

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ARTICLE INFO

Article history:
Received 6 June 2012
Received in revised form 29 July 2013
Accepted 21 August 2013

Keywords:
Olea europaea L.
Sustainability
Energy analysis
LCA
Economic analysis
Wastewater management

ABSTRACT

The objective of this study was to test a more productive and sustainable system compared to the traditional approach to manage olive orchards at risk of abandonment placed on hilly and mountainous areas of semi-arid environments. The main sustainable features include the use of treated urban wastewater for drip irrigation and the exploitation of environmentally friendly techniques aimed to preserve/maintain soil quality, to increase the atmospheric carbon storage in the soil, to correctly use natural resources. The comparison between the two management systems, sustainable – SS′ and conventional – CS′, was carried out through an energy, economic and environmental analysis. The data used in this paper refer to averages for the period 2001–2008. Energy values were calculated by multiplying the amount of farm inputs by the related energy conversion factors. The total input energy per kg of olives was 4.43 and 2.80 MJ in the SS and CS, respectively. The economic analysis showed that the gross profit of the SS was considerably higher (6276 €ha^{-1}) than the CS (1517 €ha^{-1}). The environmental analysis was carried out according to the Life Cycle Assessment (LCA) methodology using SimaPro7.2 software. Emissions of CO_2 eq per kg of olives, in SS were 0.08 kg, while in the conventional olive orchard were equal to 0.11 kg. Under our experimental conditions, although the SS was the most energy-consuming system, its greater productivity enabled a more 'sustainable' kg of olives to be produced, at least regarding CO_2 eq emissions, and it seemed to be a much more effective management model in terms of productivity and profitability. The combined use of various methodologies (LCA, energy and economic analysis) could provide critical information for policy makers and producers and help them in making strategic choices.

1. Introduction

Traditional olive cultivation systems are typical of hilly and mountainous areas of producing countries in the Mediterranean Basin. Conventional olive orchards are generally grown under rainfed conditions on low fertile soils often tilled. Furthermore, they are characterized by low-density planting and their soils are frequently exposed to erosion as the slopes are left without vegetation during autumn–winter rains. The productivity of such systems is very low because of the above mentioned reasons. Other limiting factors, such as the old-age and large-size of the olive trees, and the low inputs of labour and materials, lie behind their low productivity. As a consequence, their agronomical management can be hardly sustained from an economic point of view, particularly because traditional systems are frequently associated with small or very small farms (Duarte et al., 2008). All these factors are leading to the abandonment of traditional olive orchards with serious consequences on the socio-economic structure and landscape of local rural areas, and negative effects on the environment at a basin level.

At the same time, olive tree cultivation and the extraction of olive oil can cause resource consumption and detrimental emissions into the air, water and soil, all having a great impact on the environment (Salomone and Ioppolo, 2012).

Crop production, food processing and product marketing, all generate greenhouse gases (GHGs), contributing to global climate change, and consume large amounts of conventional water and energy (Dyer et al., 2010; Pimentel, 1992; WHO, 2006). On the other hand, developing renewable energy sources; combating desertification and mitigating the effects of climate change; improving the quality of inland and coastal waters; reducing emissions of greenhouse gases, all represent EU strategic objectives.

Increasing anthropogenic GHG emissions have been changing the Earth's climate (Ruddiman, 2003; IPCC, 2006). As Gan et al. (2011) noted, policy-makers, the general public and farmers are

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http://dx.doi.org/10.1016/j.scienta.2013.08.031

concerned about climate change and this is driving the development and adoption of effective measures to reduce GHG emissions from all sectors.

A growing interest is recorded also in searching for alternative irrigation water resources. Some countries in the world (i.e. Israel, California) use systematically reclaimed urban wastewater as supply option in agriculture to overcome water scarcity issues associated with population increase, deterioration of surface water quality, groundwater depletion and climate change (WHO, 2006; Chen et al., 2012). In addition, the use of wastewater in agriculture can allow the achievement of two among the Millenium Development Goals (Goal 1: Eliminate the extreme poverty and hunger; Goal 7: Ensure environmental sustainability) adopted by the United Nations General Assembly in 2000 (WHO, 2006). Non-conventional water resources represent a challenge for both Mediterranean and continental Europe, which are equally affected by recurrent seasonal water shortages. Within the last document produced by the European Commission ‘A Blueprint to Safeguard Europe’s Water Resources’ (EC, 2012), it is emphasized the necessity to seriously consider the water re-use as a convenient supply option for irrigation and to encourage the application of this practice – which is not commonly used in European Union – by opportune instrument and strategies to be provided by EC in the near future.

Another recent topical subject is the energy use in the agricultural sector which depends on the size of the population engaged in agriculture, the amount of arable land, the level of mechanization (Ozkan et al., 2004), the type of fertilizers and pesticides used. As Kaltsas et al. (2007) referred, conventional agricultural production is characterized by a high input of fossil energy which is directly consumed by fuel used on the farm, and indirectly in the manufacturing of fertilizers, plant protection products, machines, etc. So, an energy analysis can indicate the ways to decrease energy inputs and increase energy efficiency. Recently, there has been renewed interest in the control of energy consumption according to a sustainable approach in agriculture, and many studies have been performed to deeply know the food systems and thus identify the weakest stages of the whole chain (Hendrickson, 1994). At the same time, low energy inputs production systems are not well accepted by farmers who are interested in economic benefits rather than in energy productivity (Kaltsas et al., 2007). As a matter of fact, minimizing energy inputs is necessary but not sufficient to obtain an economic benefit. Therefore, a combination of economic, environmental and energy analysis of a production system may be more useful for the application of the best management strategies (Bowers, 1992; Pimentel, 1992; Pimentel et al., 2005; Reganold et al., 2001).

In the last decade the use of the life cycle assessment (LCA) methodology on food-processing has increased (Clasadonte et al., 2010) in order to identify and pursue sustainable food production and consumption systems (Salomone and Ioppolo, 2012). A very large number of articles have been published, which vary from studies that focalise attention on environmental emergencies of the system analyzed to studies comparing two or more case studies or giving an overview of the principal results of different case studies from particular countries. So, many authors have carried out literature reviews on LCA applied to agricultural and food products, as can be seen in Hayashi et al. (2005), Hospido et al. (2010), Roy et al. (2009), and Shau and Fet (2008). A summary of specific articles containing LCA studies applied to the olive oil industry can be found in Salomone et al. (2010) and Salomone and Ioppolo (2012).

A sustainable and profitable model to manage traditional olive orchards aimed to induce olive growers to continue their cultivation and to act as controllers of the surrounding environment was proposed by Palese et al. (2013). Such sustainable system was tested in a semi-arid marginal area of Southern Italy and provides essentially the reuse of urban wastewater by drip irrigation and the use of soil management techniques based on the recycling of polygenic carbon sources produced within the olive orchard (cover crops, pruning material). By comparing such model with the traditional one (defined as conventional), Palese et al. (2013) found, under their experimental conditions, that the alternative management was more socially sustainable and more environmentally friendly, more productive and profitable, able to ensure a constant annual production characterized by a superior quality which allowed an annual and significant income to the farmer. In order to eventually confirm or not such findings, a further data analysis of the two management systems was performed to assess their energy-consuming patterns and environmental impacts according to the LCA methodology.

2. Materials and methods

2.1. Orchard management systems and data collection

The trial was performed in Ferrandina (Basilicata – Southern Italy, 40°29′ N, 16°28′ E). The site is characterised by a semi-arid climate with an annual precipitation of around 561 mm (mean 1976–2006) and an average annual temperature ranging from 15 to 17 °C. The experimental field was a mature olive orchard (*Olea europaea* L. – cv Maiatica), roughly 1.3 ha, planted on a sandy loam classified as a *Haplic Calcisol* (FAO, WRB, 1998) and characterized by a low organic carbon content ($7.0 \pm 3.8\,\mathrm{g\,kg^{-1}}$ – mean of 0–0.60 m layer ± standard deviation).

In 2000 the olive orchard was split into two parts and subjected to different management systems (Table 1). One plot, indicated as conventional system – CS, was managed according to the traditional horticultural techniques of the area which were: tillage performed 2–3 times per year, and empirical soil fertilization performed without considering the plant needs and their partitioning along the various phenological phases of the annual vegetative cycle, heavy pruning performed every two years during the winter after a productive year (a so-called ‘on’ year), pruning residues removed from the field and burned. The other plot, the sustainable system – SS, was microirrigated with urban treated wastewater reclaimed according to simplified treatment schemes which allowed to recover N, P and K and use them as fertilizing substances (Lopez et al., 2006; Palese et al., 2009). In addition, the favourable position of the wastewater treatment plant – upstream the experimental olive orchard – allowed to distribute the reclaimed wastewater by gravity without any pumping energy costs. The seasonal volume was equal to $3425\,\mathrm{m^3\,ha^{-1}\,year^{-1}}$ (mean 2000–2008). The soil was not tilled and covered by spontaneous weeds which were mowed at least twice a year. Irrigated trees were lightly pruned each year. Pruning material was cut and left on the ground as mulch together with crop residues. The fertilization plan was designed each year according to the nutrient balance approach (Palese et al., 2012) which took into account the chemical composition of the treated wastewater, soil nutrients pool, olive tree requirements along the vegetative season, pruning material and crop residues management. Treated wastewater were able to distribute, on an average, an annual amount of N, P and K equal to 63.0, 3.0 and $58.0\,\mathrm{kg\,ha^{-1}}$, respectively (2000–2008). These amounts together with the nutrient supply coming from the pruning material recycling, allowed a significant fertilizer save. Particularly, with respect to N, olive tree needs were fully satisfied by integrative N fertirrigations (about $40.0\,\mathrm{kg\,ha^{-1}\,year^{-1}}$ versus about $120.0\,\mathrm{kg\,ha^{-1}\,year^{-1}}$ as total N need for olive trees).

Throughout the considered period, thanks to irrigation and to the better agriculture practices, SS showed a remarkable shift from an alternate to a yearly production, and an increase in both the quantity and quality of olive production (Table 2) (Palese et al.,