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Life cycle analysis of pistachio production in Greece

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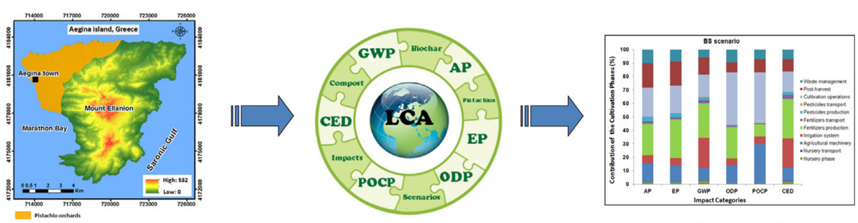
HIGHLIGHTS

- The environmental impacts of pistachio production in Aegina were assessed.
- Two alternative scenarios for improving environmental profile were analyzed.
- Partial use of compost and biochar indicate noticeable environmental benefits.
- Fertilizers, irrigation and cultivation operations are the most impactful phases.
- Scenario and contribution analyses suggest actions towards eco-friendly cultivation.

GRAPHICAL ABSTRACT



Pistacia vera L. cultivation

Contribution analysis

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ABSTRACT

In the present paper, a life cycle assessment (LCA) study regarding pistachio (*Pistacia vera* L.) cultivation in Aegina island, Greece, was performed to evaluate the energy use footprint and the associated environmental impacts. In this context, a detailed life cycle inventory was created based on site-survey data and used for a holistic cradle-to-farm gate LCA analysis using the GaBi 6.5 software. The main impact categories assessed were acidification potential (AP), eutrophication potential (EP), global warming potential (GWP), ozone depletion potential (ODP), photochemical ozone creation potential (POCP) and cumulative energy demand (CED). In order to reveal the main environmental concerns pertinent to pistachio production and in turn propose measures for the reduction of environmental and energetic impacts, three scenarios were compared, namely the Baseline scenario (BS) that involves current cultivation practices, the Green Energy (GE) scenario that involves the use of biological fertilizers i.e. compost, and the Waste Utilization (WU) scenario that involves the production of biochar from pistachio and other agricultural wastes and its subsequent soil application to promote carbon sequestration and improve soil quality. Based on the results of this study, the use of compost for fertilization (GE scenario), which results in approximately 9% savings in terms of energy consumption and the five environmental impact categories studied compared to BS scenario, is considered a promising alternative cultivation strategy. Slightly higher savings (10% on average) in terms of the five calculated environmental impact categories, compared to the BS scenario, were indicated when the WU scenario was considered. Regarding energy consumption, the WU scenario results in minor increase, 3%, compared to the BS scenario. Results of uncertainty analysis performed using the Monte Carlo technique and contribution analysis showed that GE and WU scenarios offer reliable and significant eco-profile improvements for pistachio production in the study area compared to the current situation.

1. Introduction

Pistachios are, among the tree nuts, the richest source of heart-healthy fatty-acids, metals, phytosterols, phenolic and other compounds and therefore their consumption has become increasingly

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popular over the past decade (Dreher, 2012). The pistachio nut tree, *Pistacia vera* L., is a dioecious and deciduous native species that grows in the Mediterranean countries and the Middle East; now is expanded and is commercially grown throughout the world, from Australia to USA (California). At global scale, the pistachio production has increased from 348 kt in 1994 to 856 kt in 2014 (FAOSTAT, 2014). In terms of production share, Iran is the largest producer (416 kt) followed by USA (233 kt) and Turkey (80 kt). Among the EU-28 countries, Greece has the largest production (6 kt) followed by Italy (4 kt). In Greece, pistachios are mainly produced in the regions of Attica (Aegina island and Megara), Central Greece (Phthiotis, Viotia and Euboea), Thessaly (Almyros) and North Greece (Chalkidiki). The island of Aegina is characterized by specific pedoclimatic characteristics that promote the production of high quality Protected Designation of Origin (PDO) pistachios with premium pricing in the EU market, due to their particular organoleptic characteristics, excellent flavor and appeal. Currently, 120,000 pistachio trees are cultivated in Aegina over a total area of 3500 acres, accounting for 11% of the total pistachio production in the country (HSA, 2012). Pistachio production is of considerable importance for Aegina's economy as it is estimated that approximately 1500 families are traditionally associated with it.

Harvested pistachio nuts are covered with organic outer pericarps (hulls) and endocarps (shells) which are removed during the processes of de-hulling and shelling, respectively. Both of these pistachio waste streams account for >75% of the harvested crop and in Greece around 7000 tons are disposed annually (Komnitsas et al., 2015). At country level, pistachio waste is mainly subjected to open burning and dumping without any treatment. Both options may cause serious environmental problems and thus the need for the development of alternative and eco-friendly waste management practices is a major concern within the pistachio sector. To this end, production of compost and biochar from pistachio wastes has gained considerable attention over the last decade as emerged strategy for improving soil quality and productivity, sequestering carbon in soil and mitigating GHG emissions (Lazcano et al., 2014; Mohammadi et al., 2016). In fact, reuse and recycling of agricultural residues not only reduces the environmental footprint of the harvested crop but also provides an additional income to farmers since higher yields are achieved (Bartzas et al., 2015).

With growing environmental awareness and demand for sustainable cultivation along with proper waste management, decision-makers and other interested stakeholders are increasingly aware of the need for the development of feasible approaches to improve the eco-profile of harvested crops in the future. Among other assessment tools, life cycle assessment (LCA) is considered the best available approach to identify, quantify and evaluate the potential environmental, human health and resource scarcity impacts of any product or process over its entire life cycle, from raw material acquisition to production, use, end-of-life treatment, recycling and/or ultimate disposal. To date, LCA has been extensively used to identify improvement opportunities or compare alternative farm management scenarios at farm or regional level (Bartzas et al., 2015; Kendall et al., 2015).

Despite the perceived necessity towards a less GHG-intensive agriculture, very little attention has been paid in the literature to the impacts of the pistachio cultivation systems. Because of their long-lived nature, cultivation of pistachios differs from that of annual crops in several aspects, including notable changes of the marketable yields, temporal variation of farm management practices as well as application of raw materials (e.g. fertilizers, irrigation water, pesticides) over the whole lifetime of the orchards (Bessou et al., 2013). As a result, the estimation of their environmental impacts is a difficult and volatile task, which requires long-term data persistence, consideration of time-changing and more detailed models for calculating direct and indirect GHG emissions and use of certain assumptions pertinent to the most site specific factors that interact with climate and resource availability.

To this context, this LCA study attempts to (i) analyze the life cycle of the pistachio production in the island of Aegina, (ii) explore two alternative scenarios, namely the Green Energy (GE) and the Waste Utilization (WU) to minimize impacts and improve environmental performance, and (iii) identify critical processes that are energy intensive and cause most environmental impacts. To the best of our knowledge, no similar LCA studies are available in literature regarding pistachio cultivation in the Mediterranean region, thus this study aims to fill an important gap and propose guidelines for developing eco-friendlier and goal-oriented sustainable strategies for these cultivation systems.

2. Study area and methodology

2.1. Study area

Aegina is located approximately 16.5 miles south of Athens and is the second largest island of the Saronic Gulf (after Salamis) with a total surface area of 87 km^2 (Fig. 1). Aegina is a Plio-Pleistocene volcanic island with two geomorphological settings: a permeable region (34% of the total surface of the island) located in the north and covered by Neogene lacustrine along with shallow marine sediments and a less permeable region (66%) covered by andesitic lava flows, plugs and necks, as well as by large volcanoclastic dacitic flows (van Hinsbergen et al., 2004). The geological basement comprises mainly of Permian to Upper Cretaceous limestones, covered by flysch and ophiolitic thrust sheets. From a hydrogeological point of view, the mountains of the Aegina island (mainly the Mount Ellanion) form four major water basins (catchment areas of Skoteini, Viros, Mesagros and Glyfada). In the rest of the island there are no significant water catchment areas or basins. Aquifer permeability increases towards the coast due to the major karstic development, while the groundwater table usually fluctuates between 10 and 60 m.

The island of Aegina is characterized by semi-arid Mediterranean climate, with a mean annual temperature of 19 °C and an annual rainfall of 295 mm. Almost 80% of annual rainfall is recorded in the wet period (November–April), while summers are usually dry (NOA, 2016). The dominant soils in the study area are shallow Cambisols and Leptosols according to the soil taxonomy of FAO (FAO, 2014). The north part of the study area is intensively cultivated and the major land uses include family orchards with pistachio trees planted in the fields and house gardens (Fig. 2). Approximately 32% of the cultivated land is irrigated while the rest is rainfed or dry (CLC, 2012). The main cultivations in the irrigated land are pistachios 63%, olive trees 20%, almonds 7%, lemon trees 4%, vineyards 2% and others 4%. Over the last three decades, agricultural activities and urban development have led to soil erosion and desertification, depletion of underground water resources availability, deterioration of irrigation water quality due to sea intrusion and significant decline in the water table of the available aquifer systems. It is estimated that the total annual groundwater abstraction in Aegina island is about 1 hm^3 covering 53% of the total water supply needs, while the remaining quantity is transferred daily from Attica, mainland Greece, via tanker ships (Doula et al., 2013). Most groundwater is pumped from wells, mainly privately owned, which are located at the Kipseli area; the average discharge rate is >10 $m^3\ h^{-1}$ and corresponds to about 65% of the total groundwater abstraction in the study area. However, there exist additional abstraction points which are not recorded and used occasionally for the irrigation of pistachio orchards the period April to September.

2.2. LCA methodology

The LCA study was carried out to determine the consumption of raw materials i.e. fertilizers, pesticides, irrigation and processing water, energy and agricultural waste, as well as to calculate emissions of pollutants (CO_2, CH_4, VOCs, NO_x, SO_2 etc.) to air, water and soil. The study was carried out according to the guidelines and specific requirements of the International Organization for Standardization (ISO) 14040–14044 standard series (ISO, 2006a, 2006b). Special emphasis was