Energy flow analysis of irrigated pistachio production in Aegina, Greece

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Abstract
Efficient use of energy and its resources is pivotal to the sustainable development of agriculture and subsequent reduction of associated GHG emissions. In this context, an energy flow analysis was performed to evaluate energy performance of irrigated pistachio (*Pistachia vera.* L) production in Greece and identify the highest energy consuming phases. Detailed data from on-site surveys and questionnaires were collected from 36 pistachio orchards located in Aegina island during the period 2013-2016. Irrigation water requirements were fully covered by private wells for all orchards studied.

The obtained results showed that the total input energy used for irrigated pistachio production was 41,897 MJ ha^{-1}, whereas the ratios of energy use efficiency and energy productivity were estimated as 0.70 and 0.06 kg MJ $^{-1}$, respectively. Pistachio orchards with an area greater than 0.4 ha (~1 acre) were more successful in energy performance. Nutrient management (chemical and organic fertilizers), irrigation and use of machinery for agricultural operations were the most critical inputs for pistachio production in terms of energy consumption. Additionally, results of econometric analysis indicated that among exogenous inputs analysed in this study in terms of energy performance, fertilizers and machinery had statistically significant positive effects and contributed most to increased yield of in-shell pistachios. Based on the overall results of this study, several opportunities for improving energy efficiency and mitigating GHG emissions could be identified, including reduction or/and efficient application of chemical fertilizers, water savings, proper use of agricultural machinery, reuse of crop residues for compost and biochar production and shifting from fossil fuels to renewable sources of energy.

Introduction
Irregular use of energy in agriculture to achieve higher crop yield, is largely responsible for several environmental impacts including depletion of non-renewable energy resources, destruction of biodiversity and increase of GHG emissions (Nemecek *et al.* 2011). Energy efficiency is an important indicator of sustainability since it links energy performance directly with environmental impacts and several economic features such as cost of energy and loss of productivity. Therefore, monitoring the energy performance of irrigated cultivation systems is fundamental for providing guidelines and adopting eco-efficient management strategies toward achieving the optimum energy resources use along with sustaining socioeconomic growth at farm level (Ghisellini *et al.* 2016). Currently, energy flow (input–output) analysis is a well-recognized assessment method suitable to investigate the energy use efficiency of energy-based cultivation systems and determine the environmental aspects of inefficient energy consumption as well as the degree of their reliance on non-renewable energy resources i.e. fossil fuels (Deligios *et al.* 2017).

So far, very few studies have evaluated the energy performance of pistachio production, which are limited mostly to rainfed cultivations located in the Middle-East region and Turkey (Kulekci and Aksoy, 2013). Moreover, to the best of our knowledge, there has been no similar study available in literature for assessing energy use efficiency of pistachio production under irrigated conditions in Europe. Accordingly, the objectives of this study were to: (a) determine the energy performance of irrigated pistachio (*Pistachia vera.* L) production in Aegina, Greece (b) quantify wasteful uses of energy and identify the target processes that offer promise in reducing non-renewable energy requirements and (c) fill an important gap and propose guidelines for developing eco-friendlier and goal-oriented sustainable strategies for these cultivation systems in a small island with limited water resources.

Study area and Methodology
Aegina island is located approximately 16.5 miles southward from Piraeus port and covers a total surface area of 87 km^2. Aegina is among the top three pistachio producing regions in Greece and is world known for its pedoclimatic conditions that yield the production of high quality Protected Designation of Origin (PDO) pistachios. It is characterized by semi-arid Mediterranean climate, with a mean annual precipitation of 234 mm and a mean annual air temperature of 18.3°C (NOA, 2017).

In this study, the main inventory data (agronomic inputs-outputs) needed for energy analysis were provided via an integrated on-site survey campaign conducted in 36 pistachio orchards located in the study area during the period 2013-2016. Secondary data were retrieved from various energy-related sources and databases,

while appropriate references to fill data gaps were also used where required. Energy inputs for pistachio production included human labor, chemical and organic fertilizers, pesticides, diesel fuel, electricity, irrigation water and agricultural machinery whereas yield of in-shell pistachios was considered as the only output variable. Embodied energy needed to produce each input or the energy required to perform a process was calculated by multiplying each input/process by its respective energy indicator. A selected set of indicators was then calculated and adapted in this study to evaluate energy performance including energy use efficiency, net energy, specific energy and energy productivity. Econometric analysis using Cobb–Douglas production function was also used to determine the statistical relation between energy inputs and pistachio yield.

Results and discussion

The total energy input for pistachio production in Aegina ranged from 19,256 to 53,842 MJ ha^{-1} with its median value estimated as 41,897 MJ ha^{-1}. On a process basis, nutrient management (chemical and organic fertilizers) with a share of 40% was the most energy consuming phase followed by machinery use operations (25%), energy used for pumping groundwater (17%) and post-harvest operations (14%) (Fig.1). More specifically, chemical nitrogen fertilization accounted for 79% of the total energy consumption associated to nutrient management, thus indicating that pistachio production in Greece is fully relied on this highly energy intensive input due to its manufacture process.

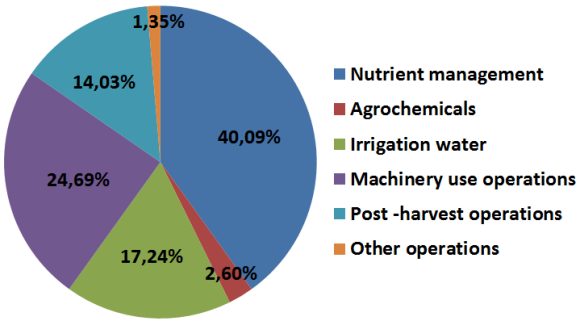

Figure 1. Breakdown of energy consumption for irrigated pistachio production in Aegina

Comparison of energy balance based on the size of pistachio orchards showed that holdings above 0.4 ha were more successful in terms of energy use efficiency and energy productivity because of higher yield and better management of the inputs used. Overall, the estimated energy use efficiency and energy productivity ratios were 0.70 and 0.06 kg MJ^{-1}, respectively. On average, the non-renewable energy and indirect energy accounted for 80% and 67% of the total energy input consumed for the pistachio production, respectively. Finally, Cobb-Douglas regression results showed the significant impact of fertilizers and machinery energy inputs on pistachio yield.

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