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Original article

Energy flow analysis in agriculture; the case of irrigated pistachio production in Greece

Georgios Bartzas[a,*], Kostas Komnitsas[b]

[a] School of Mining and Metallurgical Engineering, National Technical University of Athens, Zografos Campus, Athens 15780, Greece
[b] School of Mineral Resources Engineering, Technical University of Crete, Chania, Crete 73100, Greece

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ABSTRACT

Pistachios (*Pistacia vera* L.) are among the most energy intensive crops. Therefore, in this study an energy flow analysis was performed to evaluate energy performance of irrigated pistachio production in Greece and identify the most energy consuming phases. Detailed data from on-site surveys were collected from 36 pistachio orchards located in Aegina island during the period 2012–2016. Results showed that the total input energy used for irrigated pistachio production was 41.9 GJ ha^{-1}, whereas the ratios of energy use efficiency and energy productivity were estimated as 70% and 0.06 kg MJ^{-1}, respectively. Nutrient management, 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 terms of energy performance, fertilizers and machinery had statistically significant positive effects and contributed most to increased yield of pistachios. Based on the overall results of this study, several opportunities for improving energy efficiency and conservation can be identified, including reduction or/and efficient application of chemical fertilizers, water savings, proper use of agricultural machinery, reuse of crop residues for compost production and shifting from fossil fuels to renewable sources of energy.

Introduction

Irregular use of energy in agriculture to achieve higher crop yield is responsible for several environmental impacts, including depletion of non-renewable energy resources, loss of biodiversity and increase of GHG emissions [1–3]. Energy efficiency is an important indicator of sustainability since it directly links energy performance with environmental impacts and several economic features, such as cost of energy and loss of productivity. Therefore, monitoring of the energy performance of irrigated cultivation systems is fundamental for providing guidelines and adopting eco-efficient management strategies towards achieving the optimum use of energy resources and sustainable socio-economic growth at farm level [4–6]. Currently, energy flow (input–output) analysis is a well-recognized assessment method that is used to investigate the energy use efficiency in cultivation systems and determine the environmental aspects of inefficient energy consumption as well as the degree of their dependence on non-renewable energy resources i.e. fossil fuels [7,8].

Pistachios are, among the tree nuts, the richest source of heart-healthy and anti-cancer compounds such as unsaturated fatty-acids, metals, phytosterols, phenolic and other compounds and therefore their consumption has become increasingly popular over the past decade [9]. *Pistacia vera* L. belongs to Anacardiaceae family (cashew family) and it is the only important cultivated species in the genus with great economic importance. Although in the past it was mainly cultivated in the Mediterranean region of Southern Europe and the Middle East, today its cultivation has been expanded in several countries. Globally, pistachio production shows an increasing trend during the period 1994–2014 with an average increment of about 25,000 Gg per year, ranking pistachio fifth in world production behind cashew, walnut, almond and chestnut [10]. Iran leads world production of pistachios (415 Gg), followed by USA (233 Gg), Turkey (80 Gg) and China (77 Gg). Among European countries, Greece has the largest production (5.7 Gg) followed by Italy (3.6 Gg) and Spain (2.5 Gg). In Greece, pistachios are mainly cultivated in the regions of Attica (Aegina island, Megara), Central Greece (Viotia, Phthiotis and Euboea) and North Greece (Chalkidiki), wherein around 60–70% of the total pistachio production is harvested. Aegina island is world known for its pedoclimatic conditions that yield the production of high quality Protected Designation of Origin (PDO) pistachios. Today, 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. Pistachio production is of

* Corresponding author.
E-mail address: gbartzas@metal.ntua.gr (G. Bartzas).

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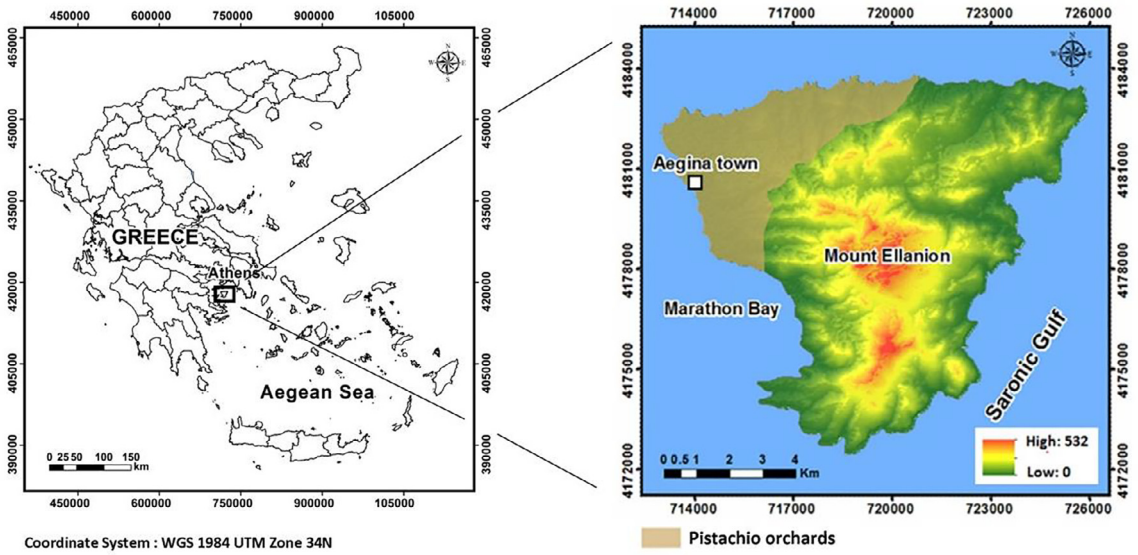

Fig. 1. Location and altitude map of the study area.

considerable importance for Aegina's economy as it is estimated that approximately 1500 families are traditionally associated with it [9].

So far, very few studies have evaluated the energy performance of pistachio production and are limited mainly to rainfed cultivations in the Middle-East region and Turkey [11]. 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. Therefore, the objectives of this study were: (a) determine the energy performance of irrigated pistachio (*Pistacia vera* L.) production in Aegina, Greece, (b) quantify wasteful uses of energy and identify processes that may reduce energy requirements and (c) fill an important scientific gap and propose guidelines for developing energy efficient, eco-friendlier and goal-oriented sustainable strategies for the agricultural system under study.

Study area and methodology

Study area description

Aegina island is located approximately 27 km south of the port of Piraeus and has a total surface area of 87 km^2 [12] (Fig. 1). The study area is characterized by semi-arid Mediterranean climate, with mean annual precipitation of 234 mm and mean annual air temperature of 18.3 °C [13]. The north part of the study area is intensively cultivated and the major land uses include family orchards with pistachio trees which are scattered in the urban areas. Approximately 32% of the cultivated land is irrigated and includes pistachios 63%, olive trees 20%, almond trees 7%, citrus trees 4%, vineyards 2% and others 4% [9]. The average size of a typical farm holding in the study area is approximately 0.4 ha, while the dominant soils according to the soil taxonomy of FAO are shallow Cambisols, Fluvisols and Leptosols [14].

Methodology

Data sources, collection techniques and processing

In this study, the main inventory data (agronomic inputs-outputs) needed for energy flow analysis were provided via an integrated on-site survey campaign which was conducted during the period 2012–2016 in 36 pistachio orchards in the study area. For that purpose, a detailed questionnaire was designed to collect from farmers appropriate primary data in terms of cultivation practices and socio-economic characteristics. Questions concentrated on three major topics: general characteristics (e.g number of cultivated pistachio trees per hectare, net pistachio production for each of the past 5 years), agricultural practices (e.g. amount and type of chemical fertilizers, nutrient content of the organic fertilizers and type and quantity of the water used for irrigation in the orchard) and other data (e.g. type of field operations, total working hours per year, number of employees, time period e.g. from October to November, type of machinery used, total operation hours of machinery per year). Secondary data were also 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, mineral and organic fertilizers, pesticides, diesel fuel, electricity, water for irrigation and agricultural machinery, whereas yield of dry in-shell pistachios was considered as the only output variable. Embodied energy required to produce each input or the energy required to perform a process was calculated by multiplying each input/process by its respective energy equivalent (Table 1).

Regarding agricultural machinery used in cultivation operations, it is mentioned that most pistachio farmers in the study area use small tractors (30 HP/22.3 kW) to avoid soil compaction, rutting and destruction of soil structure. Diesel fuel consumption of these tractors was

Table 1
Energy equivalent of inputs and output in pistachio production.

Production process	Unit	Energy equivalents (MJ $unit^{-1}$)	References
I. Direct energy inputs			
Human labor	h	1.96	[15,16]
Diesel fuel	L	47.8	[17,18]
Electricity	kWh	14.85	[19]
Water for irrigation	m^3	1.02	[16,18]
II. Indirect energy inputs			
Mineral Fertilizers			
N (as N)	kg	48.5	[20–22]
P (as P_2O_5)	kg	17.6	[18,21,22]
K (as K_2O)	kg	9.3	[18,21,22]
Organic Fertilizers			
Farmyard manure	kg	0.3	[15,16,18]
Agrochemicals			
Herbicides	kg	238	[18,23]
Fungicides	kg	216	[18,23]
Insecticides	kg	101.2	[18,23]
Agricultural machinery	h	59.3	[24–26]
III. Output			
In shell pistachios	kg	11.80	[16,27]