Applied Energy 203 (2017) 201–218

Contents lists available at ScienceDirect

Applied Energy

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

Technical and economic assessment of geothermal soil heating systems in row covered protected crops: A case study from Greece

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HIGHLIGHTS

- Two geothermal soil heating projects are presented and analyzed.
- The projects operated successfully for early production of asparagus.
- Low temperature geothermal fluids and ground water source heat pumps were used.
- The projects succeeded very encouraging economic results.

ARTICLE INFO

Article history:
Received 2 February 2017
Received in revised form 31 May 2017
Accepted 12 June 2017

Keywords:
Geothermal energy
Heat pumps
Soil heating
Asparagus earliness
Economic analysis
Northern Greece

ABSTRACT

The application of soil heating can securely transfer the harvest procedure of cultivated plantations to the early or very early season, maximizing in this way the marketable yield and added value. Extended experimentations with geothermal soil heating were elaborated under real operating field conditions based on the running harvest practices and asparagus rows protection techniques. Production and energy data have been collected and processed systematically during the harvest seasons 2002–2007 for direct use of geothermal waters in Neo Erasmio-Xanthi and for the seasons 2006–2016 for low grade shallow energy (heat pumps) applications in Chrysoupoli-Kavala, both in Northern Greece. The application of maximum heating loads in the order of 100–110 kW/ha along with maximum entering water temperatures at 35 °C has been demonstrated as the most cost effective energy option for off season harvest onset. The main objectives of the present comparative approach are (i) the conclusion on a suitable geothermal soil heating scheme for asparagus cultivation and (ii) the quantification and financial evaluation of soil heating impact on asparagus precocity and total yield at commercial scale. The performed analysis gives prominence to low enthalpy and shallow low grade geothermal energy as efficient, valuable and cost effective energy tools in soil heating.

1. Introduction

Geothermal energy relies on the Earth's heat, in contrast to all other renewables, with a natural energy current estimated at 30 TW [1]. High grade geothermal resources are rather rare being limited to the tectonic plate boundaries. On the other hand, semi-thermal areas (temperature gradient 40–80 °C/km) are associated with anomalies away of plate boundaries and consequently more dispersed, while normal geothermal areas (temperature gradient <40 °C/km, average conductive heat flow 60 mW/m^2) are almost everywhere exploitable e.g. by the use of ground coupled heat pumps [2]; the energy from these more spread low grade geothermal resources can be exploited in a variety of non-electric uses, but practically on site offering in this way entrepreneurial opportunities chances for employment and contributing to the local social and economic development.

The several uses of geothermal energy were concisely listed in the well-known Lindal-diagram [3]. Soil warming, referred also as soil heating (usually inventoried together with greenhouse applications [4,5]) had been regarded at that diagram as a use with the lower temperature requirements (e.g. from 20 to 40 °C). In spite of the fact that Lindal-diagram was proposed some decades ago, it is still principally valid [6,7]

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http://dx.doi.org/10.1016/j.apenergy.2017.06.029
0306-2619/

In soil heating, heat exchange between a buried heating network and the surrounding ground takes place. Similar heat transfer phenomena prevail in a few other applications like the ground coupled heat pumps [8,9], greenhouse and covered ground heating uses [10], heat or cold storage in the ground [11], and in soil remediation [12]. The use of heat pumps or waste heat (e.g. from power plants) have also been investigated for soil heating [13]. Notwithstanding the significant analysis and research work already done in the frame of these analogous applications [14–16], the boundary and operating conditions in soil heated row covered protected crops are obviously different.

The first geothermal soil heating system was reported back in 1880s in Iceland [17]. Although soil heating seems quite simple, several problems may arise from its improper use. Barbier and Fanelli [18] reported on such problems and on the potential advantages of soil heating, without however proceeding to details. Geothermal soil heating has been historically used to cultivate carrots, cabbages, leeks and cauliflower [17,19], but relevant technical data rarely appear in the literature [17,20]. In this work we consider for the first time the application of geothermal soil heating in outdoor white asparagus cultivation (one of the most popular and high added value agricultural product), and give all technical details regarding the installation of the heating network, and the enhancement of productivity under real open field conditions. Soil heating may have negligible effect on the air temperature above the soil; hence the more positive consequences for earliness and productivity are to be expected for cultures such as asparagus, potatoes and similar crops [21]. For many open field protected crops like white asparagus, which grow in the soil under hoop supported low tunnels in spring, earliness is the key factor for a substantial shift of the harvest period and significant added value.

Asparagus yield is the result of photosynthesis and also strongly depends on environmental conditions, cultivation practices, meteorological factors, plant age, asparagus cultivar, the length of harvest, carbohydrates accumulated in storage roots and temperature [22]. This notwithstanding, temperature is the main factor affecting not only the start, but also the end of harvest [23]. In addition to earliness and increase in yield, temperature control allows the avoidance of yield decrease due to low temperatures during the harvest period [24]. Knowledge of asparagus growth rate dependence on temperature is useful to estimate productivity (e.g. based on weather forecasts) and specify protection strategies. In this sense, most relevant previous research works deal mainly either:

a. with experiments under temperature controlled conditions, like in pots [25–27], in insulated wooden boxes [28], in conditioned rooms [23], in containers [29,30], in greenhouses [31], or
b. with experiments elaborated in open field, but with soil temperature uncontrolled but floating in response to ambient conditions [32–36].

Noticeably, most of these experiments deal with green asparagus, but only a few of them with white asparagus [28,29,31,37,38].

On the other hand, research works regarding soil heating in open field asparagus plantations are extremely limited, as the prerequisite for such an application is the availability of a low cost energy source. A series of relevant experiments were performed in Cadarache (France) by using nuclear reactor's cooling water and reported in [39], without revealing the technical details of the application neither the cultivar. The first short-scale experimentation for outdoor soil heating of asparagus cultivation with low enthalpy geothermal waters was carried out in Greece in the early '90s in the geothermal field of Neo Erasmio-Xanthi (Kolios N., personal communication, 2016). More recently realized experiments by using another renewable energy source, biomass (cores of peaches, a side product of peach canneries) [40]. These experiments were carried out in a single spanned arch-type greenhouse with vertical side-walls covered with polyethylene [41] and some of them outdoors [42]. Although the researchers demonstrated the impact of soil heating to early production and yield, they didn't publish any data concerning the energy used and the cost of the system neither concluded on the potential financial benefits and the economy of such a system when applied at commercial scale.

The innovative issues that are addressed in the present work are consequently the investigation of alternative geothermal energy soil heating schemes for white asparagus cultivating, the efficacy of such systems in perspective of earliness and yield (as these arise from long term open field experimentation and systematic measurements), and finally their financial evaluation. In this framework, two alternative schemes are considered and compared, the direct use of geothermal energy and the use of ground water source heat pumps. The work synthesizes and highlights the most relevant results (unpublished to date) regarding energy requirements, earliness of production and yield distribution from the diachronic observations, studies and monitoring conducted by the authors since 2000 on soil heating operations on 25 ha outdoor white asparagus cultivations in Northern Greece, under real operating conditions. The work is laid out as follows. In Section 2 information on asparagus cultivation and its precocity are reported. The technical characteristics of the two geothermal soil heating schemes are presented in details in Section 3, while the respective measurements and results are presented and analyzed in Section 4. The two alternative schemes are financially evaluated in Section 5. The work is integrated with the conclusions Section 6, while supporting material on the equipment used and on the financial evaluation is separately given in the Appendix.

2. Cultivation of asparagus and earliness considerations

Protected agriculture is referred to any technique used to modify a plant's growing environment in order to optimize plant growth. Such techniques are often used to protect plants from frost and wind in order to extend the growing season of a crop. Through earlier crop production, growers are able to capitalize on early markets and higher prices. One of the more popular, low cost and efficient technique used by commercial growers to extend the growing season of a crop is the use of row covers. Row covers are generally applied to enclose one or more rows of plants in order to enhance crop growth and production.

White asparagus crops are open field protected plantations grown integrally in the soil under hoop supported low tunnels. The asparagus spears are sufficiently protected by soil ridges, which are commonly covered by a single (floating) or more recently by a double transparent plastic film (floating and hoop supported). These covers can provide a modest soil temperature increase, resulting in a limited earliness exclusively in spring and fall, taking advantage of the solar radiation and seasonal air temperature rise. Furthermore, the application of soil heating can securely transfer the harvest procedure to the early season (up to two months precocity has been reported in the literature [39]), maximizing in this way the marketable yield and added value. However, growing in the early season is a costly procedure because of the high energy amounts required for soil heating. In this sense, the availability of an energy source at competitive price is a prerequisite.

White asparagus production is seasonally limited to the harvest period from March to May, which can be referred as the "conventional period" with emphasis on April. The activation of asparagus crowns and spears growth rate are tightly controlled by the prevailing air temperature, which is directly reflected in the soil tem-