Energy use efficiency and economic feasibility of Jerusalem artichoke production on arid and coastal saline lands

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\textbf{A B S T R A C T}

Jerusalem artichoke (Helianthus tuberosus L.) is a potential biofuel feedstock crop in China. To conduct a comprehensive evaluation of energy use efficiency and economic perspectives for this crop, face-to-face surveys were collected from farmers in Gansu and Shandong provinces. The results demonstrated highest energy use efficiency (2.47 in Gansu and 2.37 in Shandong), net energy (59,926 MJ/ha in Gansu and 55,298 MJ/ha in Shandong) and energy productivity (0.77 kg/MJ in Gansu and 0.74 kg/MJ in Shandong) for Jerusalem artichoke plantation size ranging from 4.0–20.0 ha in Gansu and for plantation sizes > 35.0 ha in Shandong. Moreover, the lowest total production costs, namely, 9913 CNY/ha and 12,264 CNY/ha, were incurred by plantation size of 20.1–35.0 ha in Gansu and > 35.0 ha in Shandong, respectively. Consequently, plantation size of < 35.0 ha in Gansu and > 35.0 ha in Shandong are recommended for Jerusalem artichoke production with the use of mechanization in conjunction with the use of Jerusalem artichoke straw for bioenergy production. Therefore, Jerusalem artichoke may make a large contribution in meeting the growing future challenges for bioenergy production for an expanding population.

\section{1. Introduction}

During the past century, China has become the world’s largest energy consumer. Unfortunately, fossil fuels have served as China’s main energy sources (Lin and Ouyang, 2014) despite devastating environmental consequences from their use. Subsequently, the need for alternative and sustainable energy sources, including bioenergy, has become an important priority in China. Both aboveground and belowground plant biomass have great potential uses as raw materials for generation of bioenergy as part of a greater strategy to meet rapidly growing and sustainable energy/fuel supply demands (Koçar and Civas, 2013). According to Liu et al. (2012), bioenergy production could be the most important potential future energy source due to its low or no environmental pollution impact.

Jerusalem artichoke (Helianthus tuberosus L.), a plant originating from North America, holds great promise as a source of biomass material (Sierchhoofs and Renquist, 2013) to meet China’s non-food bioenergy crop needs (Li et al., 2010). The many advantages of Jerusalem artichoke over traditional agricultural crops (e.g., maize and wheat) include a maximum tuber dry matter yield that can reach 14–16 t/ha (Ercoli et al., 1992) and shoot dry biomass yield ranging between 4 and 35 t/ha (Gunnarsson et al., 2014). Moreover, Jerusalem artichoke is tolerant to salt and alkaline stress (Liu et al., 2015b; Long et al., 2010; Wu et al., 2006a, 2006b, 2008) and its cultivation prevents land erosion (Denoroy, 1996).

Jerusalem artichoke could be planted in marginal land and thus not to compete with food crops for fertile land. Thus, this crop should minimally contribute to conflicting land use priorities between food crops and bioenergy crops, which is a topic of current debate (Rosegrant and Msangi, 2014). For this reason, great attention has been focused on use of marginal lands with relatively high saline-alkali content for growth of bioenergy crops. Such marginal lands are present in great abundance in certain areas of China (Zhuang et al., 2011) and have been abandoned due to their unsuitability for food crop production. However, Jerusalem artichoke, can often grow under harsh marginal land conditions. Ultimately, the total suitable area of such land that is available for Jerusalem artichoke production in China would be approximately 2.36 million ha (Zhuang et al., 2011).

Jerusalem artichoke fresh tubers contain approximately 80% water, 15% carbohydrate and 1–2% protein (Kays and Nottingham,
Currently, the main use of crop carbohydrates is as food additives, such as inulin (Yang et al., 2015). Inulin is important in food manufacturing (Flamm et al., 2001) because its specific carbohydrate composition confers benefits as an energy source for human health (Kaur and Gupta, 2002). Chicory (Cichorium intybus L.) roots are considered the most abundant source of inulin and are currently used commercially for extraction of inulin and oligofructose for food use (Shoaib et al., 2016). Because Jerusalem artichoke can be grown on marginal lands without interfering with the food chain, it is a promising energy crop for sustainable biofuel production (Matías et al., 2015). With respect to biofuel production, a long history of tuber ethanol fermentation from various feedstocks has led to an abundance of accumulated knowledge regarding this method of biofuel generation (Seonghun and Chulho, 2014). After considering current technologies, available marginal land resources and Jerusalem artichoke’s potentially high biomass yield and polysaccharide content (Li et al., 2013), this crop should serve as an effective commercial-scale biomass feedstock for bioenergy production (Kerkhoffs and Renquist, 2013).

Although this crop is planted in at least 24 provinces in the country (Liu et al., 2011), its large-scale production farms are distributed in the drought land of Northwest China and the coastal saline and alkaline land along Bohai to produce inulin and animal feed (Xu et al., 2013; Biqingyuan, 2018). Recently, various studies have been performed to optimize cultivation of Jerusalem artichoke as a non-food energy crop in China. Most previous studies have been performed on an experimental basis and not on a commercial scale (Liu et al., 2012, 2011, 2015b; Long et al., 2010; Wu et al., 2006a, 2006b, 2008). Nevertheless, energy balance (the relationship between energy input and output) is one of the most important indicators to consider while developing sustainable agriculture practices. Through photosynthesis, agriculture converts solar energy into plant biomass that serves as food and fiber for humans and animals (Khan et al., 2010). Although numerous studies have investigated energy balances of crop systems with a focus on cereals (Kardon et al., 2013; Khan et al., 2010; Shahn et al., 2008; Bekele et al., 2009), few such studies have been devoted to the study of energy balance for Jerusalem artichoke. Another important parameter, economic benefit, should also be considered before exploring the potential of a crop for specific production on a commercial scale. However, no financial analysis has yet been reported for Jerusalem artichoke production. As a potential biorefinery crop, Jerusalem artichoke possesses multi-purpose utility for generation of several types of products from both tubers and aerial biomass to achieve high economic value (Johansson et al., 2015). However, the advantages of Jerusalem artichoke have only come to light recently. According to a study by Kays and Nottingham (2007b), the economic value of Jerusalem artichoke production in different countries between 1980 and 2000 was found to be relatively low. Subsequently, no large-scale production has since been reported although this crop is resistant to frost, drought and most pests and diseases (Gunnarsson et al., 2014; Slimestad et al., 2010). The development of newer technologies, the emphasis on cleaner energy sources and land use conflicts have changed China’s overall priorities. Thus, this crop should be re-evaluated for bioenergy production. However, Jerusalem artichoke should first undergo serious evaluation of its energy balance and economic benefits before its further development into bioenergy feedstock on a commercial scale.

The aims of this study were to examine the energy input and output of Jerusalem artichoke production based on Jerusalem artichoke plantation size in Northwest dry land in Gansu Province and coastal saline and alkaline land in Shandong Province. The analysis of the financial budget for this crop was based on face to face questionnaire interviews with Jerusalem artichoke farmers and producers. Finally, we compared three farm operation scenarios with the baseline for Jerusalem artichoke production to assess impact of labor and machinery on the financial balance. The results of this study may serve as a foundation to determine the suitability of Jerusalem artichoke as a bioenergy crop after analysis of both the energy and financial balances of this crop. Ultimately, the goal of this research was to evaluate the value of Jerusalem artichoke for large-scale bioenergy production in China.

2. Methods

2.1. Data collection

Face-to-face interviews were conducted with Jerusalem artichoke growers in 2013 to gain knowledge about current farming practices in China. In the first stage, a survey was conducted by trained personnel who collected and computerized data on plantation size, and available knowledge on Jerusalem artichoke yield and publication data. The data presented and used in the present study are based on results obtained from plantations with minimum size of 4 ha. In the second stage, face-to-face interviews using a questionnaire were conducted after the purpose and significance of the research project were explained to farmers and their consent was received. Interviews focusing on crop production (input and output energy usage) and cultivation costs were conducted from August 17th–31st in 2013, while information about crop yield was obtained after harvest in November 2013.

We focused on drought land in Gansu Province and coastal saline and alkaline land in Shandong Province for our field surveys. This survey included 10 farms, namely, Gansu (5 farms, including 3 farms in Baiying city and 2 farms in Dingxi city) and Shandong (5 farms, including 4 farms in Kenli district and 1 farm in Tai’an). The plantation land area devoted to Jerusalem artichoke in the surveyed farms was assigned to three size levels of small size from 4.0 to 20.0 ha (4.0–20.0 ha), medium size from 20.1 to 35.0 ha (20.1–35.0 ha); and big size higher than 35.0 ha (> 35.0 ha). The location, soil and climate characteristics of the sampled Jerusalem artichoke plantation size in Gansu and Shandong provinces are presented in Table 1. The sites exhibited marginal land types with alkali, salinity, drought, and barren characteristics.

2.2. Energy balance

The evaluation of Jerusalem artichoke energy inputs recorded from each interview at each site were based on use of the following parameters: farm labor, machinery, diesel fuel, fertilizers, pesticides, irrigation water, plastic film and tuber seed. Plastic film was used to cover the land with a strip of some 50 cm width. Tuber seeds were planted in the middle of the plastic film strip. Energy outputs consisted of tuber yield and aboveground biomass. Inputs and outputs were expressed as various diverse units that necessitated conversion of field data into a common energy unit, i.e., energy equivalents (Table 2). For comparison, energy equivalents were collected from published literature and textbooks. Ultimately, basic information on energy inputs and Jerusalem artichoke tuber and straw yields were entered into Excel 2016 spreadsheets for further analysis. The energy ratio (energy use efficiency), energy productivity and net energy were calculated using the following equations:

Energy use efficiency = Energy output (MJ/ha)/Energy input (MJ/ha)

(1)

Energy productivity = Tuber yield (kg/ha)/Energy input (MJ/ha)

(2)

Net energy = Energy output (MJ/ha) – Energy input (MJ/ha)

(3)

For crop production, energy inputs were classified as direct energy and indirect energy, and they were also classified as renewable energy and non-renewable energy. Direct energy included energy embodied by labor, irrigation water usage and diesel (petrol), while indirect energy included machinery operation, irrigation system, fertilizers, pesticides, plastic film and tuber seed costs. Renewable energy consisted of labor, tuber seed and irrigation water, while non-renewable energy included...
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