Hydroponic Cultivation

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Contributor: Dimitra I. Pomoni, Maria K. Koukou, Michail Gr. Vrachopoulos, Labros Vasiliadis

The increasing demand for food, the lack of natural resources and arable land, and the recent restrictions on energy consumption require an immediate solution in terms of agricultural activities. The soil loss, the crop/soil contamination, and the greenhouse gas emissions were the criteria for the environmental comparison of conventional agriculture and hydroponics. As for resource consumption, the water consumption rates (L/kg), energy consumption rates (kWh), and energy required (kW) were the criteria for comparing conventional agriculture with hydroponics.

Keywords: hydroponics ; conventional agriculture ; environment ; water ; land

1. Introduction

The United Nations forecasts that the world population will reach approximately 9 billion by 2030 [1]. Other research indicates that the world population has doubled since 1960, while statistics indicate that the world's population will reach 9.8 billion people by 2050 [2]; the same predictions have been made by the World Food and Agriculture Organization of the United Nations (FAO) [3]. In the past 150 years, the world's population has grown by 8.7 billion [4]. In 2016, global hunger grew to affect 815 million people worldwide, confirming the fragile state of global food security [5], and by 2030 it is expected that global food demand will have increased by up to 50% [6]. From 2005 to 2015, the rate of undernourishment declined; more specifically, the rate of undernourishment in 2005 was 14.5%, while in 2015, it reached 10.6% [2]. According to the same research, 947.2 million and 785.4 million people were undernourished in 2005 and 2015, respectively [2]. The same research indicated that the rate of undernourishment remained almost constant from 2015 to 2018, at 10.6% (2015) and 10.8% (2018), while the number of undernourished people grew from 785.4 million people (2015) to 821.6 million people (2018), representing an increase of 4.6% [2]. In 1996, the World Food Summit (WFS) decided that all people should experience food security [7]. Access (via natural presence, financial resources, and as social human beings) to adequate, safe, and nutritious food for people to satisfy their needs for nutrition, ensuring a healthy and active life, is an inalienable right [7].

Since 2000, academic publications mentioning the term "conventional agriculture" have become more frequent; more than 70% of such articles were published in the last ten years, establishing the term "conventional agriculture" as a topic in the literature [8]. Conventional agriculture involves high inputs of pesticides, herbicides, fertilizers, and chemical drugs, which pollute the soil and cause severe risks to human health and the environment [9]. In contrast to conventional agriculture, hydroponics can increase production without the extensive disposal of chemicals into the environment [10]. The nutrient solutions used in hydroponics mainly contain soluble inorganic salts [11].

Conventional cultivation requires soil, in contrast to hydroponics, which is a soilless form of cultivation [12] whereby the crop is submerged in a nutrient solution [13] or different types of substrates [10]. The rising demand for accommodation and the urbanization of agricultural land due to population growth has increased the need for disposable arable land for food production [14]. This situation has arisen because the abrupt growth in the world's population has created a rapid increase in the demand for food production to meet people's nutritional needs [15]. Currently, the agricultural sector accounts for 11% of the world's land area, representing 1.5 billion hectares of land [16]. In contrast to conventional agriculture, hydroponics works in controlled environments and can provide higher annual yields [17], ensuring less land use than conventional agriculture.

Nowadays, the agricultural sector consumes 70% of the world's water withdrawn from aquifers, streams, and lakes and is ultimately responsible for 13.5% of global greenhouse gas emissions [16]. On the other hand, hydroponics saves up to 95% of irrigation water compared to conventional agriculture [18]. In the case of hydroponics implemented as part of a closed system, the water consumption and nutrient supply are reduced [19]. A study on lettuce yield that compared hydroponics with conventional agriculture showed that the water demands were 20 ± 3.8 L/kg/y and 250 ± 25 L/kg/y, respectively, for this crop [17].

For conventional agriculture in greenhouses, most energy is spent on meeting the heating needs [20], as well as cooling and lighting [21]. However, studies have proven that hydroponics has a higher energy consumption than conventional greenhouse cultivation. A helpful example is a study of a hydroponic greenhouse (in the Mediterranean climate zone) that was shown to consumes 2559 kWh/year to cover its electricity needs for cooling and heating [22]. The main characteristics of this greenhouse were: a surface area of 24 m^2, height of 3 m, south-east orientation, and polyurethane panel covering [22].

2. Advantages and Disadvantages of Hydroponic Cultivation

2.1. Advantages of Hydroponic Cultivation

Many countries have adopted hydroponic cultivation systems to serve their needs, with Latin America, Brazil, and Mexico considered the most prominent users [23]. Hydroponics as a production method is advanced and promotes large-scale cultivation in the absence of soil [24], ensuring the increased production of many crops at significantly higher yields through vertically accumulated trays to provide more space [25]. Hydroponic systems are efficient, industrial-type vegetable production systems. A plant's growth rate in hydroponic cultivation is 30–50% faster than in soil cultivation [26]. For example, the growth rate of lettuce via hydroponics is 11 times higher than via conventional cultivation (**Table 1**) [17]. Food production by hydroponic methods is a well-known technique and its application is increasing worldwide [27], ensuring higher quantities in a shorter crop cycle and high-quality, high-nutritional-value products. This phenomenon has resulted from ever-increasing production, which has allowed the development of crop diversification and higher profits for producers [28]. This fact is important because it represents economic efficiency, which is the central goal of farmers [29][30]. The numerous products generated by hydroponic cultivation, the industrialization of its systems, the automation offered by its equipment, its applicability in smaller areas, and the increase in productivity make it an economically viable alternative food production investment [31].

The hydroponic growing method is flexible, and there are opportunities for its improvement using simplified models; such an attempt was made by Bradley and Marulanda [32]. They presented a simplified hydroponic model that required 25% of the land area used by soil cultivation for immediate hunger reduction [32]. Large cultivation areas are considered a disadvantage of conventional crops [17][33]. The combination of automatic fertilization and automatic soil control represents a benefit of hydroponics, because it ensures a clean planting environment and saves space due to the vertical production of multiple layers [34]. This allows better performance with the least possible land use [20]. Hydroponic cultivation methods using 10% less land, according to Barbosa et al.'s (2015) comparative lettuce production study, resulted in eleven-times higher yields than conventional cultivation methods [17]. Hydroponics is important for agriculture globally as an opportunity for cultivation in areas with no access to soil [23]; hence, it is applied in areas with adverse climatic conditions and a lack of arable land, producing food without soil [35]. These characteristics and benefits make hydroponics viable for urban areas [36]. Additionally, the phenomenon of growing crops in areas that could be expropriated is common, but hydroponics offers investment stability and reduces the high risks of this practice [37]. Finally, the benefits of soilless cultivation to soil protection are remarkable [38].

Hydroponic cultivation is prevalent in the modern agricultural world [39] as a clean and easy method compared to the traditional types of cultivation [40]. The absence of soil makes the crops quite clean, removing the need for washing [41]; at the same time, this agricultural system faces a low risk of contamination [42]. Additionally, hydroponics can effectively control the use of not only water but also fertilizers and chemicals [43], which are applied to combat diseases and pests [20]. On the other hand, conventional agriculture uses pesticides and nutrients extensively, which is another disadvantage of conventional crops [17][33]. Therefore, hydroponics is safer than open-field cultivation because it can apply natural barriers against specific bacterial agents and reduce contamination factors [44]. Hydroponic products are grown without pesticides, prompting consumers to trust them more and be willing to spend more on their acquisition, thus creating food security [45]. According to Russo and Scarascia Mugnozza [46], hydroponic cultivation in a greenhouse dramatically reduces the environmental impact compared to greenhouse soil cultivation due to the use of pesticides and fertilizers.

The advantages of this system are summarized as follows: the better control of plant nutrition, the more efficient use of space, and the possibility of reducing the application of fertilizers [36]. Hydroponics supports innovative, sustainable, and environmentally friendly crops [47], presenting a lower environmental impact and lower greenhouse gas emissions [20]. In addition, the benefits of hydroponic technology mean that their environmental impact and pollution rates are lower than their sewage disposal rates [48]. According to Martinez-Mate et al. [49], the gas emissions of soil crops and hydroponics crops are 0.23 kg CO_2 equivalent and 0.11 kg CO_2 equivalent, respectively. An existing study found that in terms of raw materials, using wood instead of zinc-coated steel structures definitely has environmental benefits, but using recycled plastics for pipes, grow benches, and containers also works very well [46].

Wastewater reuse is also considered to be extremely important in environmental protection and balance, as wastewater reuse reduces the pollution load in rivers, groundwater, and soil and provides a reliable water supply throughout the year [50]. Water recycling in the agricultural sector requires adequate and economically efficient approaches [51]. In hydroponics, treated wastewater and domestic wastewater, as a nutrient medium, are a viable solution [52]. Water saving and the possibility of reusing water [53] are considered vital features and benefits of hydroponic cultivation. A study by Grewal et al. [48] demonstrated that crops such as cucumber and tomato can be grown using 33% drainage water.

Another benefit of hydroponics is its ability to act as a subsystem in aquaponic systems. In recent years, aquaponics has become an exciting vegetable production approach for application near urban centres with minimal water consumption [54][55]. As a combination of aquaculture and hydroponics, it provides an environmentally and economically sustainable food production system by uniting two systems that normally operate independently [56][57][58][59]. This combined system (hydroponics and aquaculture) serves more directly the recycling of wastewater, as the output of one part of the system (wastewater) is used as the input (nutrients) of the other by creating the necessary conditions for the biological cycle [60]. The FAO [61] described aquaponics as a promising and fast-growing food production sector that already produces 50% of human-consumed fish and vegetables. The simultaneous recovery of nutrients makes aquaponics one of the most promising sustainable food production methods for the future [62].

Hydroponics, even as an independent method of food production, is considered more effective at optimizing resources than soil cultivation [63]. For example, the water resources are better managed, only 10% of water resources are used compared to conventional cultivation methods [64]. In hydroponics, the water consumption is seven times lower than in conventional greenhouse production and four times lower than in open-field cultivation [65]. As a result, hydroponics is self-sustainable and environmentally friendly [64]. According to Trang and Brix [66], the two main characteristics of hydroponics are the high efficiency of water use and its design plasticity.

Table 1. Advantages of hydroponic cultivation.

Source	Sector	Advantages of Hydroponics
Barbosa et al. [17]	Better land use	Reduction in land use by 10%.
Barbosa et al. [17]	Higher crop yield	Eleven-times higher lettuce yield with hydroponic cultivation.
Baddadi et al. [20]	Irrigation water saving/fertilizer saving	Hydroponics allows the controlled and efficient use of water, fertilizers, and chemicals.
Baddadi et al. [20]	Better land use	Better performance, less land use.
Baddadi et al. [20]	Lower environmental impact	Lower environmental impact and greenhouse gas emissions.
Bakhtar et al. [35]	Better land use	Hydroponics is applied in areas with adverse climatic conditions and a lack of arable land, producing food without soil.
Martinez-Mate et al. [49]	Lower environmental impact	Comparing soil crops and hydroponics crops, the gas emissions were 0.23 kg CO_2 equivalent and 0.11 kg CO_2 equivalent, respectively.
Sharma et al. [39]	Clean cultivation	Hydroponics is one of the most popular methods of modern cultivation, with its main characteristics being that it is clean and easy.
Croft et al. [23]	Better land use	Hydroponics is important for agriculture globally as an opportunity for cultivation in areas with no access to soil.
Müller et al. [24]	Better land use	Hydroponics as a production method is advanced and promotes large-scale cultivation without soil.
Link [25]	Higher crop yield/high-quality food	Hydroponics allows the multiplication of the number of crops to obtain higher yields.
Link [25]	Better land use	Hydroponics allows vertical crop cultivation and saves land use.
Joshi and Joshi [26]	Higher crop yield	The growth rate is 30–50% faster in hydroponic culture than in soil.

Source	Sector	Advantages of Hydroponics
Borges and Dal'Sotto [28]	Higher crop yield/high-quality food/economic viability	Ever-increasing production allows the upward trend of crop diversification and higher profits for producers.
Souza, Toesca Gimenes, and Binotto [31]	Economic viability	Hydroponics ensures the financial viability of the investment and is an attractive alternative food production solution.
Bradley and Marulanda [32]	Better land use	Hydroponics responds to global hunger while using 25% less land than soil cultivation.
Wada [34]	Clean cultivation/better land use	Hydroponics ensures a clean planting environment and saves space due to vertical multi-layer production.
Rufí-Salís et al. [36]	Nutrition control/better land use/fertilizer saving	Hydroponics provides better plant nutrition control and more efficient land use and saves on fertilizers.
Rufí-Salís et al. [36]	Better land use	Hydroponics is a sustainable system of agriculture for urban areas.
Orellano et al. [37]	Better land use/economic viability	Hydroponics is a solution to the growing of crops on land that could be expropriated, providing investment stability and protecting growers from the high risks involved in this activity.
NOSB [38]	Clean cultivation	Hydroponics, as a soilless cultivation method, offers greater protection.
Coolong [41]	Clean cultivation	Hydroponics, as a soilless cultivation method, makes crops exceptionally clean without washing.
Lopez-Galvez et al. [42]	Clean cultivation	Low risk of soil and crop contamination.
Hussain et al. [43]	Clean cultivation/fertilizer saving	Hydroponics allows the efficient consumption of fertilizers and the reduced use of chemicals to control pests and diseases.
Orozco et al. [44]	Lower environmental impact/clean cultivation	Hydroponics is safer than open-field cultivation because it can apply natural barriers against specific bacterial agents and reduce contamination factors.
Phew et al. [45]	Lower environmental impact/clean cultivation	Hydroponic products are grown without pesticides, prompting consumers to trust them more and be willing to spend more on their acquisition, thus creating food security.
Russo and Scarascia Mugnozza [46]	Lower environmental impact	In terms of raw materials, using wood instead of zinc-coated steel structures has environmental benefits, but using recycled plastics for pipes, grow benches, and containers also works very well.
Russo and Scarascia Mugnozza [46]	Lower environmental impact/fertilizer saving	Hydroponic cultivation in a greenhouse greatly reduces the environmental impact compared to greenhouse soil cultivation due to the use of pesticides and fertilizers.
Li et al. [47]	Lower environmental impact	Hydroponics supports innovative, sustainable, and environmentally friendly crops.
Grewal et al. [48]	Lower environmental impact	Hydroponics is a beneficial technology with much lower environmental impacts and pollution rates, including effective sewage disposal.
Grewal et al. [48]	Irrigation water saving	Hydroponic cucumber and tomato crop cultivation could use 33% drainage water.
Sutar et al. [52]	Irrigation water saving	Hydroponics can apply treated sewage water, using household sewage as a nutrient medium.
Carmassi et al. [53]	Irrigation water saving	Hydroponics provides water savings and the possibility of reusing water.
Zou et al. [54]; Love et al. [55]	Better land use/irrigation water saving/nutrition control	Aquaponics is an interesting combined system of hydroponics and aquaculture for the production of vegetables near urban centres with minimal water consumption.

Source	Sector	Advantages of Hydroponics
König et al. [56]; Goddek et al. [57]; Xie and Rosentrater [58]; Tyson et al. [60]; Adler et al. [59]	Lower environmental impact/irrigation water saving/fertilizer saving/nutrition control	Aquaponics combines aquaculture and hydroponics, providing an environmentally and economically sustainable food production system compared to the independent operation of the systems.
FAO [61]	Higher crop yield	Aquaponics is a promising and rapidly growing food production sector, already producing 50% of the fish and vegetables consumed by humans.
Suhl et al. [62]	Nutrition control/fertilizer saving	The simultaneous recovery of nutrients makes aquaponics one of the most promising sustainable food production methods for the future.
Gwynn-Jones et al. [63]	Optimization of natural resource use	Hydroponics is more efficient at optimizing resources than soil cultivation.
Alshrouf [64]	Lower environmental impact/irrigation water saving	Hydroponics is a self-sustainable and environmentally friendly system, using 10% less water in comparison to conventional agriculture.
Romeo, Blikra Vea, and Thomsen [65]	Irrigation water saving	Water consumption in hydroponics is seven times lower than in conventional greenhouse production and four times lower than in open-field cultivation.
Trang and Brix [66]	Irrigation water saving/nutrition control	Hydroponics is characterized by a high efficiency of water use and design plasticity.

3.2. Disadvantages of Hydroponic Cultivation

Despite the numerous advantages of hydroponics, there are some disadvantages related to the high initial investment required, meaning that interested farmers should be cautious at first [31]. The annual requirements for energy consumption amount to 95.3% of the total energy, whereas 4.7% of the total energy is dedicated to electricity needs (**Table 2**) [67]. The initial high investment, the high energy expenditure, the requirements for special technical knowledge, and the need for continuous assistance and monitoring may prevent the adoption of this cultivation method [68].

Table 2. Disadvantages of hydroponic cultivation.

Source	Sector	Disadvantages of Hydroponics
Vourdoubas [67]	Higher energy consumption	The annual requirements for energy consumption correspond to 95.3% of the total energy, with 4.7% corresponding to electricity consumption.
Souza, Toesca Gimenes, and Binotto [31]	High initial investment	Hydroponics requires a high initial investment.
Muñoz [68]	High initial investment/higher energy consumption/required know-how	Hydroponics requires a high initial investment, high energy expenditure, special technical knowledge, and continuous assistance and monitoring.

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