ECONOMIC ANALYSIS OF SOIL-BASED AND SOILLESS FARMING SYSTEMS: A CASE STUDY FROM DA LAT CITY

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Abstract

Nowadays, to secure production in the case of restricted natural resources requires innovative farming approaches to achieve a balance between agriculture and environmental protection. This study investigates, via investment metrics and sensitivity analysis, the most popular current farming practices to clarify whether or not these systems can fulfill current and future demands with limited natural resources and at lowest cost. The research analyzes soil-based and soilless (hydroponics and aeroponics) lettuce farming systems to highlight the economic efficiency and limitations of each practice. Outcomes confirm that soilless systems are more efficient in terms of production outputs than soil-based systems. The sensitivity analysis of soil-based systems reveals that the impact of stochastic inputs is in the decreasing magnitude of interest, gross revenue, and total operating cost. The importance of NPV varies under the impact of gross revenue in the systems of hydroponics and aeroponics. This also indicates that alterations in prices or output quantities are much more critical than total operating cost and interest.

Keywords: Aeroponics; Hydroponics; Sensitivity analysis; Soil-based agriculture.

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SO SÁNH HIỆU QUẢ KINH TẾ CỦA CÁC HỆ THỐNG CANH TÁC TRÊN ĐẤT VÀ KHÔNG CẦN ĐẤT: TRƯỜNG HỢP ĐIỂN HÌNH TẠI THÀNH PHỐ ĐÀ LẠT

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Tóm tắt

Ngày nay, nhằm đảm bảo sản xuất trong điều kiện các nguồn tài nguyên thiên nhiên hạn chế đòi hỏi các phương pháp sản xuất sáng tạo để đạt được sự cân bằng giữa trồng trọt và bảo vệ môi trường. Nghiên cứu này điều tra các thực hành canh tác phổ biến nhất hiện nay để làm sáng tỏ các hệ thống có thể đáp ứng nhu cầu hiện tại và tương lai với mức tiêu thụ tài nguyên thiên nhiên và chi phí thấp nhất, thông qua việc sử dụng các chỉ số đánh giá đầu tư, và phân tích độ nhạy. Nghiên cứu này tiếp cận hệ thống canh tác rau xà lách trên đất và không cần đất (thủy canh, khí canh), để làm nổi bật khả năng kinh tế và giới hạn của mỗi công nghệ. Các phát hiện cho thấy các hệ thống không đất hiệu quả hơn về sản lượng sản xuất chung và hiệu quả kinh tế so với các hệ thống dựa trên đất. Kết quả phân tích độ nhạy trên canh tác không dùng đất, tác động của các biến đầu vào lên Hiện giá ròng NPV giảm dần theo thứ tự: Lãi suất, tổng doanh thu, và tổng chi phí vận hành. Tầm quan trọng của NPV thay đổi nhiều nhất dưới tác động của tổng doanh thu trong hệ thống thủy canh và khí canh, trong khi ở hệ thống dựa trên đất chỉ đứng thứ hai. Tác động lớn nhất của tổng doanh thu cũng cho thấy sự thay đổi đến từ giá bán hoặc sản lượng đầu ra, quan trọng hơn nhiều so với chi phí hoạt động và lãi suất.

Từ khóa: Canh tác trên đất; Khí canh; Phân tích độ nhạy; Thuỷ canh.

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1. INTRODUCTION

Nowadays, assuring adequate supplies of clean, safe food has become pivotal in the context of the global population boom (Alexandratos & Bruinsma, 2012) and the rising awareness of consumers regarding the quality, quantity, and safety of food (Dang & Tran, 2020a, 2020b; Putra & Yuliando, 2015). According to the forecast of the Food and Agriculture Organization, the world will need 70% more food to feed 9.1 billion people in 2050 (FAO, 2009). Hence, sustainable farming in parallel with the population growth rate has become essential (Dang, 2020).

Soil-based farming is still the predominant means of producing food. However, novel farming practices, such as irrigation technologies, polyhouses, rotation, and intercropping, are gaining great traction. To reach their potential, environmental trade-offs deems in place (Gomiero, Pimentel, & Paoletti, 2011). To maximize efficiency, traditional agriculture overuses inputs of agricultural chemicals, leading to negative environmental consequences (AlShrouf, 2017), such as soil degradation accompanied by erosion (Barbosa et al., 2015). Besides, the land is increasingly impoverished owing to the loss of beneficial microorganisms (Barman, Mehedi, Rezuanul, & Banu, 2016) and continuous farming plus adverse weather, poor management of water resources, and groundwater depletion threaten soil-based faming.

Under the above mentioned conditions, cutting-edge farming practices are expected to foster a more sustainable agriculture (Lakhiar, Gao, Syed, Chandio & Buttar, 2018). Soilless farming (hydroponics and aeroponics) is expected to be the holy grail in modern agriculture (AlShrouf, 2017). These farming systems can reduce 98% of water demand, 60% of fertilizer, and 100% of pesticide/insecticide use while optimizing yield from 45% to 75% (NASA, 2006). These solutions offer a more sustainable pathway to overcome environmental and economic problems while still balancing nutrient quality (Barbosa et al. 2015).

In the context of Vietnam, soilless farming has been widely adopted mainly for growing leafy green vegetables. Hydroponics is currently being adopted more often than aeroponics. However, the analysis of the case study of aeroponics in Da Lat city fits well to complement the missing piece of the full picture of soilless farming practice.

Research studies of soilless farming systems are very limited from the economic perspective and mainly focus on physical, chemical, and biological properties, such as environmental impacts (Barrett, Alexander, Robinson, & Bragg, 2016), water retaining capacity (de Boodt & Verdonck, 1972; Fonteno, 1992) fertilizer (Bragg, 1995; Handreck, 1993) and nutrients (Handreck, 1992). Giafiadellis, Mattas, Maloupa, Tzouramani, and Galanopoulos (2000) found that, besides the technical perspectives, there is a need for in-depth economic efficiency analysis. Several past studies contributed to the literature on soilless farming of potatoes in Latin America (Mateus, de Haan, Andrade, & Res, 2013), and the farming of tilapia, cinnamon, lettuce, and tomatoes in Central America (Quagrainie, Flores, Kim, & McClain, 2018). Their study revealed positive economic outcomes of modern farming systems, but also that capital intensive methods are required for optimal results (Quagrainieet al., 2018). On the other hand, the financial analysis of Mattas, Bentes, Paroussi, and Tzouramani (1997) found that hydroponics does not achieve economic efficiency for Greek farmers because of the high capital investment and fuel costs. Souza, Gimenes, and Binotto (2019) also noted that farmers need to be aware of the heavy capital investment required by hydroponics. Previous work did not delve into the necessary risk-oriented elements, such as price, quantity, cost of production, and interest. The lack of necessary scientific information could hinder the adoption of new technologies in Vietnam.

By virtue of this, the assessment of the pros and cons of soilless farming systems (hydroponics and aeroponics) against soil-based systems is critical in the context of the transition of agriculture toward a more modern, sustainable system in Vietnam. For that reason, this paper aims at clarifying the advantages and disadvantages of farming systems from an economic feasibility standpoint. The analytical assessment is expected to benefit other developing countries in the same phase of converting to high-tech agriculture as Vietnam.

2. RESEARCH BACKGROUND

With 4,400 ha of polyhouses and 1,200 ha of nethouses, Lam Dong is the leading province in high-tech agriculture nationwide, and Da Lat city holds 2,760 ha of greenhouses including 1,250 ha for vegetable production (Lâm, 2018). Utilizing greenhouses in vegetable cultivation yields advantages. In fact, while farmers from other provinces have incomes of approximately 100 million VND/ha/year, high-tech vegetable farmers in Da Lat can make around 500 to 600 million VND/ha/year. According to the Department of Agriculture and Rural Development of Lam Dong province, the area devoted to greenhouses has increased by 300 to 350 ha annually since 2010. Specialized vegetable growing areas have formed beside flower village, and many advanced technologies were absorbed and applied by Da Lat farmers to production. In addition to greenhouses, sprinkler systems, drip irrigation with fertilizer, lighting technology to modify growth time, tissue culture technology in plant propagation, and modern farming technologies, such as hydroponics and automatic farming have also been applied effectively (Nguyễn, 2016).

In addition to the positive results, the application of high-tech agricultural production still has several shortcomings. The application of postharvest technology, preservation and processing is limited. The price of agricultural products is not stable. The consumer market is still difficult, and the rate of agricultural exports is still low. Farmers lack capital (Dang, Dam, Pham, & Nguyen, 2019) and are not bold enough to invest in new technology. The link between farmers and businesses and cooperatives is not yet tight in the production and consumption stages.

In Vietnam, as with studies of soil-based and soil-free farming systems globally, studies of the economic efficiency of these models are very limited. Previous authors have mainly focused on analyzing technical factors. In the case of Lam Dong province, it has changed its orientation from the high-tech agriculture of 2004-2010 to clean and sustainable agriculture in recent years (Hảo, 2019). Besides organic farming, the role of farming systems such as hydroponics and aeroponics that are able to control and use fertilizers in permissible and economical doses has become essential to ensure quality while still creating a significant source of income for farmers. In particular, the research of Lê, Nguyễn, Nguyễn, and Nguyễn (2016) indicated that the level of copper accumulation in the soil affects the growth of some vegetables. Although the lack of the required amount of copper limits the growth of crops, an excess is toxic to plants. The use of coal to absorb wastewater affects NH_3 emissions and the growth of lettuce. Specifically, the coal can be reused after the adsorption of biogas wastewater as a fertilizer source for plants while minimizing environmental contamination (Huỳnh, Nguyễn, Phan, & Ngô, 2011).

These studies reveal that soil-based farming provides certain disadvantages and difficulties. A study pointed out that selecting diversified led lighting and various light durations could influence the growth and yield of lettuce grown hydroponically in Can Tho city (Vietnam), and, of course, growers can also opt for optimal led types and lighting times (Phan, Ngô, Nguyễn, Tống, Võ, & Trần, 2016). Research in Thua Thien-Hue province (Vietnam) showed that the concentrations of NQ_2 nutrient solution have a good influence on the growth, yield, and economic efficiency of spring lettuce, but specifically, the formula for mixing a solution of 1,000 ppm concentration of nutrient solution is the best (Lê & Nguyễn, 2015). The work of Đỗ, Hà, Lê, and Phạm (2016) resulted in a strong correlation between the amount of manure and the organic content in intensive vegetable soil in Lam Dong province. Besides, it is clear that cultivation by hydroponic and aeroponic methods has the outstanding advantage of being able to take the initiative in nutrients and stimulate the development of economically efficient cultivation methods backed by scientific evidence. Based on that fact, this study is performed to contribute a more theoretical basis for the scientific view of the economics of this matter.

3. METHODOLOGY

3.1. Description of farming systems

In terms of characteristics, there are many farming systems depending on the definition of the output, the technology of application, and the practice. Therefore, this study was conducted based on some brief definitions of comparable systems, as shown below:

- *Soil-based farming (traditional):* Crops are grown in soil and in greenhouses. Modern irrigation systems are used (drip irrigation or spray irrigation). Fertilizers and pesticides are used in traditional farming.

- *Hydroponics:* A method of growing plants in a mixed nutrient solution. The plant grows on an inert substrate (coir) and its roots are in contact with the nutrient solution.

- *Aeroponics:* Different from hydroponics in that the plant roots are suspended in air and are frequently moistened with mist.

3.2. Data collection

Data were collected in December 2018 using a structured questionnaire given to lettuce growing households in Dalat, Lam Dong Province. The questionnaire covered investment costs, variable costs, revenue, and the socio-economic characteristics of the farm. The questionnaire was checked and pilot tested first to determine the intelligibility and meaning of the questionnaire. Farmers were selected at random using the snowball method; they included 68 households growing lettuce (60 soil-based, seven hydroponic, and one aeroponic). The sample of soilless farming households was limited due to their scattered nature, limited number, and the inaccessibility of some households during the research process. Two outliers were rejected because they were greater than two standard deviationss. Therefore, the remaining 66 observations were used for analysis.

3.3. Comparison between soil-based and soilless farming

Capital budgeting is an appropriate approach to assess the economic efficiency of farming systems. Net present value (*NPV*) was used to evaluate economic efficiency over the lifetime of the project using Equation (1).

$$NPV = -CF_0 + \sum_{t=1}^{n} \frac{NCF_t}{(1+i)^t} \quad (1)$$

where CF_0 is the initial investment, NCF_t is the net cash flow in period t, equal to the annual cash flow minus the total annual operation cost, i is the discount rate, and n is the lifespan of the investment. The economic analysis was conducted for farming systems with an assumed lifespan of 10 years. After the 10^{th} year, most of the important equipment requires reinvestment. Thus, 10 years is long enough to provide a full picture of profit for the project life cycle, assuming no unexpected uncertainties.

Other financial indices were also used, such as: internal rate of return (*IRR*), modified internal rate of return (*MIRR*), discounted payback period (*DPP*), and benefit cost ratio (*BCR*). Internal rate of return (*IRR*) is a classical economic instrument used to balance discounted cash flow created within the lifespan of the project with the initial investment (Equation 2).

$$\sum_{t=0}^{n} \frac{R_t}{(1+IRR)^t} - \sum_{t=0}^{n} \frac{C_t}{(1+IRR)^t} = 0 \quad (2)$$

where R_t is the revenue generated during time t, C_j is the cost at time t, t is the time of occurrence of R_t and C_t, and n is the project life cycle. Moreover, *MIRR* is used to overcome the weakness of *IRR* and solve the re-investment rate issue.

The benefit-cost ratio (*BCR*) is the ratio between the current value of revenue and the current value of cost with certain discount rates. This ratio indicates a viable project when greater than 1 and vice versa when less than 1 (Equation 3).

$$BCR = \frac{\sum_{t=0}^{n}\frac{R_t}{(1+i)^t}}{\sum_{t=0}^{n}\frac{C_t}{(1+i)^t}} \quad (3)$$

where *BCR* is the benefit-cost ratio, R_t is the revenue at time *t*, C_t is the cost at time *t*, *i* is the discounted interest rate, *t* is the time of occurrence of R_t and C_t, and n is the project life cycle.

The discounted payback period (*DPP*) assesses the economic efficiency of an investment per unit of time. This criterion evaluates the number of years of payback from the net cash flow, discounting the value of the currency over time (Equation 4).

$$DPP = A + \frac{B}{C} \quad (4)$$

where *A* is the final stage with the cumulative cash flow at a negative discount, *B* is the absolute value of the discounted cumulative cash flow at the end of phase *A*, and *C* is the discounted cash flow post *A*.

The modified internal rate of return (*MIRR*) is a measure of the financial attractiveness and ranking of investment projects. The *MIRR* removes the possible mathematical uncertainty in nonconventional cash flows and the *IRR* reinvested from the market (assuming the IRR). *MIRR* is more advantageous than *IRR* because it is an indicator of the real rate of return/long-term rate of return of a project (Equation 5).

$$MIRR = \sqrt{\frac{FV(Positive\ cash\ flows\ x\ Cost\ of\ capital)}{PV\ (Initial\ outlays\ x\ Financing\ cost)}} - 1 \quad (5)$$

where *n* is the equal amount of time at the end of the cash flow occurring, PV is the present value (at the beginning of the first period), $PV = CF_0 - \sum \frac{CF_i}{(1+r)^i}$, and *FV* is the future value (at the end of the final period), $FV = \sum_{i=1}^{n} CF_i(1 + r_e)^{i-1}$.

3.4. Sensitivity analysis

The role of sensitivity analysis is to assess the change in the investment evaluation values. This paper mainly focuses on sensitivity analysis to identify changes in the NPV caused by changes in operating costs, gross revenue, and discount rates. Operating expenses are subtracted from depreciation, and interest payable is used in a similar way to calculate NPV. In terms of gross sales, the article shows fluctuations in NPV, given by changes in total sales, reflecting the same results as those given by changes in price or output. Therefore, the use of total revenue is considered adequate. NPV's sensitivity to variation in interest rates is also examined in the study to study the attractiveness of farming systems under different investment perspectives. The simulation scenarios are based on changes of -20% to +20% to certain factors. For each farming system, the sensitivity analyses for the different scenarios were processed individually for all observations and averages were then computed. The main purpose of sensitivity analysis is to evaluate the input variables that influence the economic efficiency of farming systems under variable circumstances.

4. RESULTS AND DISCUSSION

4.1. Initial investment costs for soil-based and soilless systems

The initial investment costs of the lettuce farming systems are shown in Table 1. The results show that hydroponics and aeroponics require high investment costs, namely, greenhouses, machinery, and equipment, while the cost of farming on land is very low. Irrigation costs for hydroponics ($17,810/1,000 m^2) include a nutrient recirculation system needed to maintain high yields (Hassall & Associates, 2001). However, once the initial investment has been completed, the ratio of operating cost to revenue favors the soilless rather than the soil-based system (AlShrouf, 2017). Average investment costs of $38,830 (hydroponics) and $39,730 (aeroponics) were estimated for a greenhouse of about 1,000 m^2. The initial investment cost of hydroponics in this study is equivalent to that reported by Souza et al. (2019), which is $89,653.66 for a greenhouse of 2,475 m^2 in Brazil. The initial investment cost for aeroponics is lower than that found in the study of Mateus et al. (2013) who reported $9,210 for a 80 m^2 greenhouse in Peru and $8,782 for a 150 m^2 greenhouse in Ecuador.

Table 1. Average investment costs for soil-based and soilless systems

Items	Traditional	Hydroponics	Aeroponics
Water tank	0.56	0.61	-
Irrigation system	0.51	17.81	8.56
Greenhouse	6.47	9.84	11.56
Electrical system	0.48	1.06	0.51
Pump	0.26	0.50	0.30
Well	0.81	1.22	-
Tarpaulin cover	0.08	0.51	2.14
Ploughing machine	1.17	-	-
Street paving	0.57	2.05	4.28
Nursery	0.36	0.74	-
Concrete	0.30	-	-
Seeding machine	-	0.11	-
Nutrition tank/tub	-	2.10	0.17
Lighting system	-	1.09	2.57
Control system	-	3.06	4.28
Semi-auto control system	-	1.22	0.86
Test equipment	-	0.65	0.21
Generator	-	0.58	0.86

Notes: Exchange rate 23,355 VND/USD from Agribank in May 2019;
Unit: $1,000/1,000m^2.
Source: Authors' calculation (2019).

Table 1. Average investment costs for soil-based and soilless systems (cont.)

Items	Traditional	Hydroponics	Aeroponics
Worker shelter	-	1.40	-
Water test	-	0.07	-
Safe-practice certificate	-	0.29	3.43
Total	**7.99**	**38.83**	**39.73**

Notes: exchange rate 23,355 VND/USD from Agribank in May 2019;
Unit: $1,000/1,000m^2.
Source: Authors' calculation (2019).

4.2. Economic efficiency of soil-based versus soilless systems

Table 2 shows the production costs of lettuce for the three systems. The average variable cost of soil-based lettuce farming is $5,400/1,000 m^2 and that of soil-free farming is $17,010/1,000 m^2 for hydroponic and $23,640/1,000 m^2 for aeroponics. The cost of water and energy accounts for about 13.88% (hydroponic) and 5.07% (aeroponic) of the input material cost. The high cost is due to continuous pump operation to maintain flow in the gutters. In contrast, traditional farming mainly uses fossil fuels, including the electricity used to operate the irrigation pump (Barbosa et al., 2015).

Table 2. Average economic efficiency of systems

Items	Traditional	%	Hydroponics	%	Aeroponics	%
i) Initial investment cost	7.99	-	38.83	-	39.73	-
ii) Revenue						
Price (USD/kg)	0.43	-	1.38	-	1.37	-
Quantity (Ton/1,000m^2/year)	16.89	-	30.38	-	44.00	-
Total ($1,000/1,000m^2/year)	7.15	-	42.28	-	60.28	-
iii) Variable cost						
Seedling	0.76	18.91	2.90	14.92	1.93	16.30
Fertilizer	0.48	11.93	1.65	8.49	0.64	5.43
Pesticide	0.20	4.99	0.52	2.67	0.51	4.35
Electricity	0.08	2.05	1.18	6.04	0.43	3.62
Water	0.10	2.57	0.50	2.56	0.17	1.45
Gasoline	0.11	2.69	1.03	5.28	-	-
Packaging	0.19	4.65	1.46	7.49	1.28	10.87
Transportation	0.23	5.58	2.29	11.77	1.28	10.87
Home labor	1.40	34.76	3.76	19.32	3.00	25.36
Hired labor	0.48	11.89	4.17	21.45	2.57	21.74
Total	5.40	100.00	17.01	100.00	23.64	100.00

Notes: Exchange rate 23,355 VND/USD from Agribank in May 2019;
In addition to items with separate units, items without the unit of calculation use the common unit;
Unit: $1,000/1,000 m^2/year.
Source: Authors' calculation (2019).

Table 2. Average economic efficiency of systems (cont.)

Items	Traditional	%	Hydroponics	%	Aeroponics	%
iv) Fixed cost	4.04	-	19.46	-	11.82	-
Land rent	1.47	-	4.02	-	0.00	-
Depreciation	1.84	-	6.94	-	3.43	-
Interest rate (%)	0.94	-	0.97	-	0.00	-
Total	2.08	-	8.64	-	6.85	-
Average profit	1.75	-	16.63	-	45.04	-

Notes: Exchange rate 23,355 VND/USD from Agribank in May 2019;
In addition to items with separate units, items without the unit of calculation use the common unit;
Unit: $1,000/1,000 m^2/year.
Source: Authors' calculation (2019).

The average yield of traditional lettuce farming (16.89 tons/1,000 m^2/year) is 1.5-2 times smaller than that of hydroponics (30.38 tons/1,000 m^2/year) and aeroponics (44 tons/1,000 m^2/year). These results indicate that the yield of hydroponics/aeroponics is higher, but also more operating energy is consumed (Barbosa et al., 2015). One of the reasons for the difference in productivity is the number of crops cultivated. While traditional farming households grow only about 7-8 crops/year, the average hydroponic or aeroponic household grows 10-12 crops/year. In addition, the farming standards of large farmers are conventional farming, and the safe farming practice standard was noted as having no effect on the growing time of the crop or on the yield.

Along with higher productivity, hydroponics and aeroponics show higher costs; the fixed cost of aeroponics is $6,850/1,000 m^2, which includes greenhouse repair, machinery, and equipment, and for hydroponics the cost is $8,640/1,000 m^2, nine times higher than traditional farming. However, the average return is $45.04/1,000 m^2/year for aeroponics and $16,630/1,000 m^2/year for hydroponics, much higher than the average return for soil-based methods. The positive effect on revenue comes from higher volume and better selling price. The price difference comes from the difference in distribution channels, while traditional farmers often sell through traders or sell directly to traditional markets, high-tech farmers establish their own distribution channels and distribute to supermarkets and higher value-added supply chains, resulting in higher selling prices. In addition, since hydroponic and aeroponic households have a stable number of crops and yields all year round, they have an advantage in price negotiation when they can ensure the output supply to the purchasing unit. This finding is similar to that of AlShrouf (2017), showing that hydroponics and aeroponics work more efficiently.

Table 3 illustrates the following indicators: NPV, IRR, MIRR, DPP, and BCR. Aeroponics has the highest NPV of $185,470/1,000 m^2, followed by hydroponics with $109,380/1,000 m^2, and traditional farming with only $22,440/1,000 m^2. Positive NPVs show that farmers have returns higher than their costs. IRR shows similar results: aeroponics (92.11%), traditional (63.01%), and hydroponics (62.13%). The NPV and IRR values are higher than those of Mateus et al. (2013), who reported a NPV of $185,978 and an IRR above 40% in a comparison of aeroponics to traditional methods. On the other hand, the result of hydroponics is analogous to (Souza et al., 2019) who reported a NPV of $177,845.74 and an IRR of 30.45%. It is worth noting that the discrepancy between NPV and IRR of hydroponics and aeroponics in the study area compared to Latin America is owing to the number of crops cultivated, the local weather conditions, and the seedlings (Mateus et al., 2013).

Table 3. Financial analysis of farming systems with fixed operating costs and price

Indicator (average)	Traditional	Hydroponics	Aeroponics
NPV	22.44	109.38	185.47
IRR (%)	63.01	62.13	92.11
MIRR (%)	24.81	24.46	30.84
DPP (year)	2.40	2.60	1.20
BCR	3.60	2.70	2.60

Notes: NPV and BCR use units of $1,000/1,000 m^2.
Source: Authors' calculation (2019).

BCRs were found to be higher than 1 in all cases. Although the BCR of aeroponics is lower than that of the others, the system still has the highest NPV and a short payback period. The high BCR of soil-based lettuce farming is explained by the lower operation costs. However, it is also important to note that the total benefits of soilless farming are very large compared to the traditional method. In addition, the calculated MIRRs for traditional, hydroponic, and aeroponics are 24.81%, 24.46%, and 30.84%, respectively. Therefore, the effectiveness of all three models is clarified, especially soilless farming.

DPP results show that the payback period of aeroponics is only 1.20 years, relatively low compared to its 10-year life cycle. The DPP of hydroponics is 2.60 years, much longer than the 0.20 years of the traditional method. This indicator manifests a positive sign of transformation in the study area. This result is more encouraging than that of Souza et al. (2019), who found a payback period of 5.24 years for hydroponic leaf vegetable farming in Brazil, and Quagrainie et al. (2018), who found a payback period of 3.13 years for vegetable cultivation in the American Midwest.

4.3. Sensitivity analysis

One-way sensitivity analysis of NPV was used based on the fluctuation of input variables, including gross revenue, total operating cost (excluding depreciation and interest rate), and interest. Similar to Souza et al. (2019), this study applies a discount rate that does not include inflation on a fixed cash flow to avoid changes in risk due to inflation in the future. The interest rate changes on a 10% base rate. NPV ranges as (8.0%, 8.5%, 9.0%, 9.5%, 10%, 10.5%, 11%, 11.5%, and 12%). The NPV is calculated based on the input variable (-20%, -15%, -10%, -5%, 0%, +5%, +10%, +15%, and +20%). The results of the sensitivity analysis are presented in Table 4.

Table 4. One-way sensitivity analysis for NPV upon input changes

Magnitude	Traditional			Hydroponics			Aeroponics		
	Revenue	Total cost	Interest	Revenue	Total cost	Interest	Revenue	Total cost	Interest
-20%	21,142	22,841	25,243	57,423	131,689	123,016	111,387	214,520	206,201
-15%	21,467	22,741	24,506	70,411	126,110	119,428	129,909	207,258	200,750
-10%	21,792	22,641	23,794	83,399	120,532	115,963	148,431	199,997	195,483
-5%	22,117	22,542	23,107	96,388	114,954	112,613	166,952	192,736	190,394
0%	22,442	22,442	22,442	109,376	109,376	109,376	185,474	185,474	185,474
5%	22,767	22,342	21,799	122,364	103,798	106,245	203,996	178,213	180,717
10%	23,092	22,242	21,177	135,353	98,220	103,217	222,518	170,951	176,116
15%	23,417	22,142	20,575	148,341	92,641	100,288	241,040	163,690	171,664
20%	23,742	22,043	19,993	161,329	87,063	97,453	259,562	156,429	167,356

Notes: Interest: Data were presented with absolute value for one aeroponic farm;
Exchange rate used was 23,355 VND/USD from Agribank in May 2019.
Unit: $1,000/1,000 m^2/year.
Source: Authors' calculation (2019).

Table 4 demonstrates the NPV variability of different soil-based and soilless models. NPV fluctuates according to the diminishing effects of interest rates, net sales, and total costs. In a traditional farming system, the magnitude of the impact is $5,250 (interest rate), $2,600 (net revenue), and $798 (total cost). In contrast, in hydroponics, the decreasing order of effect on NPV is $103,906 (revenue), $44,626 (total cost), and $25,563 (interest rate). Similar results for aeroponics are $148,175 (revenue), $58,091 (total cost), and $38,846 (interest rate). The NPV sensitivity is shown in Figure 1.

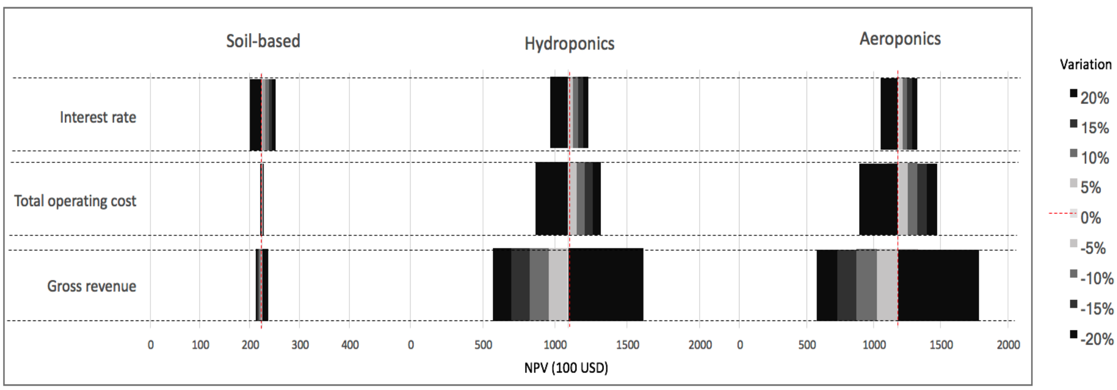

Figure 1. Combined tornado diagram of NPV sensitivities

Source: Authors' calculation (2019).

The authors found that the highest impact of revenue on NPV in a soilless system is reflected when a change occurs, because price or output has a larger impact than costs and interest rates. However, the soilless farming system shows a completely different story, a project with a good interest rate will help NPV outperform the revenue and cost. The authors found that this difference could be attributed to the large difference in selling price and yield for $1,000/1,000 m^2/year: $7.15 (traditional), $42.28 (hydroponics), and $49.33 (aeroponics). The effect of corresponding huge returns makes investing more compelling.

5. CONCLUSION

The paper analyzes the economic efficiency of the three lettuce farming systems in two approaches. Financial indices are used for comparison and sensitivity analysis is used to evaluate changes of NPV according to the impact factors. Research has found a direct relationship between the efficiency of modern farming systems and the complexity that requires sufficient operational knowledge. Indicators suggest that soil-based farming is less efficient than soilless farming with NPV of $185,470 for aeroponics and $109,380 for hydroponics, while that of traditional farming is only $22,440. The order of effects on NPV is also different between the two farming systems. In addition to efficiency, it is also necessary to recognize the bottleneck of soil-free farming due to high investment costs associated with agronomic knowledge and the irrigation systems needed to operate the system. These technologies are sensitive to water shortages, energy supplies, and system-borne diseases (Mateus et al., 2013). Therefore, soilless farming is more suitable for national programs, private companies, or entities with sufficient resources for implementation rather than smallholder farmers who often lack access to credit sources for many reasons (Dang et al., 2019).

The largest limitation of this article is the number of survey samples that are eligible for the study, as the small sample size seems not representative of the population, and, additionally, the data are not enough to analyze by farm size. Nevertheless, it should be recognized that the hydroponic, and especially aeroponic, farming models have only been applied in Vietnam recently. Hence, this study provides timely knowledge based on reliable data to help farmers make the right decisions. Future studies should analyze in depth the economic efficiency of different farm sizes and should consider the category of land-use opportunity cost for the aeroponic model to form a more comprehensive picture of farming systems in Vietnam. This paper did not consider this because only one household was observed using the aeroponic method on their own land.

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