

ECONOMIC VIABILITY OF HYDROPONIC FARMING: A REVIEW OF COSTS, RETURNS AND PROFITABILITY

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ABSTRACT

Hydroponic farming has emerged as an alternative production system for intensive cultivation under conditions of limited land and water availability. Although hydroponic systems offer potential advantages in productivity, resource-use efficiency and year-round production, their economic viability depends on the relationship between capital investment, operating costs, production performance and market returns. This review synthesises evidence on the economic viability of hydroponic farming, with emphasis on investment requirements, cost structure, productivity, returns, profitability and financial feasibility across different crops, production systems and scales of operation. The reviewed literature indicates that hydroponic enterprises can generate positive economic returns, but profitability varies considerably with initial investment, energy and nutrient costs, labour requirements, crop selection, scale of production, technology adoption and market prices. Financial indicators such as benefit-cost ratio, net present value, internal rate of return and payback period demonstrate economic feasibility under favourable production and market conditions, while sensitivity analyses highlight the vulnerability of profitability to changes in input costs, energy prices, yields and output prices. Major economic constraints include high capital requirements, technical complexity, recurring operating costs and market uncertainty, whereas intensive production, specialised markets, direct marketing, automation and renewable-energy integration provide potential opportunities. Important research gaps remain in standardised cost accounting, long-term financial assessment, crop- and scale-specific benchmarks, risk analysis and integrated evaluation of profitability with resource-use efficiency. Overall, hydroponic farming should be considered a context-specific economic enterprise whose viability depends on appropriate technology, crop, production scale, resource management and market strategy.

KEYWORDS: Hydroponic farming; Economic viability; Cost of production; Profitability; Financial feasibility; Resource-use efficiency.

INTRODUCTION

1.1 Background and Emerging Importance of Hydroponic Farming

Hydroponic farming is a soilless production approach in which crops are cultivated with their roots supplied with water and essential mineral nutrients through a managed growing system. It forms an important component of controlled-environment agriculture (CEA), where environmental and production conditions can be regulated to improve crop growth, resource management and production consistency. Increasing pressure on agricultural land, water resources and climate-sensitive production has stimulated interest in hydroponics as an alternative production system, particularly for vegetables and other high-value crops (1,2). The development of protected structures, nutrient-management systems, artificial lighting, sensors and automated environmental controls has further expanded the technological scope of hydroponic production (3,4).

Hydroponic systems differ considerably in their technical configuration, including nutrient film technique (NFT), deep-water culture, substrate-based systems, drip irrigation and vertical production arrangements. These configurations influence production capacity, input requirements, labour requirements and investment needs. Vertical arrangements can increase production per unit of ground area, while controlled nutrient delivery can improve the precision with which water and mineral nutrients are supplied to crops (5,6). However, the economic implications of these technologies depend on whether the additional productivity and product value generated by the system are sufficient to compensate for its infrastructure, energy, nutrient, labour and management costs.

The expansion of hydroponics has therefore shifted discussion beyond its technical advantages towards questions of commercial viability and long-term financial sustainability. Although hydroponic systems can reduce land requirements and improve water management, their operation may involve substantial expenditure on protected structures, pumps, fertigation equipment, nutrient solutions, environmental control and monitoring

systems. Resource-use advantages consequently do not automatically translate into economic advantages. Economic performance must be assessed in relation to the production system, crop, scale of operation, input prices and market conditions (7,8).

Recent empirical evidence demonstrates the growing commercial interest in hydroponics across different production contexts. Studies from Brazil have examined the financial feasibility of hydroponic systems under both commercial and small-farm conditions, while research from Nigeria has evaluated profitability at different production scales (10,11). More recent evidence from India has also reported positive financial indicators across hydroponic vegetable farms of different sizes, although investment and operating costs varied substantially between production units (12).

Thus, hydroponic farming should not be viewed solely as a resource-efficient production technology. It represents an interaction between technology, resource use, production scale and market returns.

1.2 Economic Significance of Hydroponic Farming

The economic significance of hydroponic farming arises primarily from its ability to generate high-value output from relatively limited production space while providing greater control over production conditions. Unlike conventional field cultivation, hydroponic production lets producers regulate nutrient availability, irrigation, and, in more advanced systems, temperature, humidity, light, and carbon dioxide. Such control can support more continuous production and improve the predictability of crop supply, which may be particularly valuable in urban and peri-urban markets where proximity to consumers can reduce marketing distances and facilitate direct sales.

However, economic performance cannot be inferred from productivity or resource-saving characteristics alone. Hydroponic production requires expenditure on infrastructure and specialized equipment, and the relative importance of these costs varies according to the level of environmental control and technological sophistication. The capital requirements may include protected structures, growing channels or containers, reservoirs, pumps, fertigation systems, sensors, lighting, water-treatment facilities and post-harvest infrastructure. Consequently, the economic advantage of hydroponics depends on the relationship between investment expenditure, recurring production costs and the value obtained from the harvested crop.

Evidence from different production systems illustrates this variation. A commercial-scale assessment in Nigeria found positive economic returns for both small- and medium-scale hydroponic systems, but the medium-scale system generated substantially higher net returns per unit area because of differences in production performance and cost structure (11). In India, recent evidence from eight hydroponic farms showed wide variation in initial investment, fixed costs and variable costs across farm sizes and crops, demonstrating that hydroponic economics cannot be represented by a single generalized cost estimate (12).

The economic importance of hydroponics is therefore better understood through investment efficiency, production efficiency and market efficiency. Investment efficiency concerns the capacity of the system to recover initial capital and generate an acceptable return. Production efficiency concerns the relationship between inputs and output, while market efficiency concerns the ability of producers to obtain remunerative prices and maintain stable market access. These dimensions jointly determine whether a technically successful hydroponic farm is also economically sustainable.

1.3 Evidence on Costs, Returns and Profitability

The existing literature provides evidence that hydroponic farming can be financially viable, but profitability varies considerably across crops, production systems, scales and market environments. Economic evaluation studies have commonly used indicators such as gross returns, net returns, benefit-cost ratio (B:C), net present value (NPV), internal rate of return (IRR) and payback period to assess investment performance.

An economic viability assessment of a hydroponic system in Brazil reported an initial investment of approximately US\$89,654 and positive financial indicators, including an NPV of US\$177,846, an IRR of 30.45 per cent and a B:C ratio of 2.13 (9). The study also found that changes in the price received by producers had a strong influence on NPV, emphasising the importance of market conditions in hydroponic investment decisions. Similarly, a study of hydroponic systems on small rural properties reported an NPV of US\$15,575.63, an IRR of 32.87 per cent, a cost-benefit ratio of 1.57 and a discounted payback period of 3.69 years (10). These findings suggest that relatively small-scale hydroponic investments can be economically feasible when the production system and market conditions are appropriately matched.

Evidence from Nigeria further demonstrated the importance of production scale. Both small- and medium-scale hydroponic farms generated positive NPVs, with B:C ratios of 5.07 and 4.91, respectively. However, the medium-scale farms recorded considerably greater annual net returns per square metre, while small-scale farms were more sensitive to changes in recurrent costs and reductions in revenue (11).

Recent Indian evidence provides another perspective. (12) reported initial investments ranging from ₹0.42 million to ₹20.4 million across eight hydroponic farms in Hyderabad. Fixed and variable costs also differed substantially among farms, while B:C ratios ranged from 1.75 to 2.71 and IRRs from 59 to 85 per cent. The wide variation demonstrates the importance of farm size, crop choice and production configuration when evaluating hydroponic profitability.

At the crop level, (13) reported a total production cost of ₹2,21,280, gross returns of ₹2,38,000 and net returns of ₹16,720 for basil grown in a hydroponic system under polyhouse conditions. The resulting B:C ratio was 1.08, with a payback period of approximately 3.19 years. Their results also indicated that improving production capacity through additional growing structures could substantially improve economic performance. These studies collectively indicate that profitability is possible but not automatic. Differences in capital intensity, recurring expenditure, production efficiency, scale and output prices can lead to substantially different economic outcomes even within hydroponic farming.

1.4 Need for an Economics-Focused Review

Although hydroponic farming has received increasing scientific attention, economic evidence remains fragmented across different crops, production technologies, geographic regions and analytical approaches. Many studies focus primarily on agronomic performance, water productivity, nutrient management or environmental impacts, while comparatively fewer provide detailed analysis of investment requirements, cost structures, profitability, financial feasibility and production risk.

This fragmentation creates difficulties in comparing the economic performance of different hydroponic systems. For example, a study reporting high yield per unit area does not necessarily establish economic viability because higher productivity may be accompanied by higher energy, infrastructure or labour costs. Similarly, a system with low water consumption may not be economically attractive if electricity expenditure or capital depreciation is excessive. Economic assessment therefore requires simultaneous consideration of costs, physical productivity, resource use and market returns.

The existing financial literature demonstrates this need clearly. Studies have reported favourable economic outcomes under particular production conditions, but sensitivity analyses have also shown that hydroponic profitability can change considerably with variations in running costs, output prices and production performance.

A review focused specifically on economics can therefore provide a useful synthesis of how investment requirements, cost structures, productivity, returns, profitability, risk and market conditions interact to determine the economic viability of hydroponic farming and the conceptual framework of hydroponic farming system is shown in the figure 1.

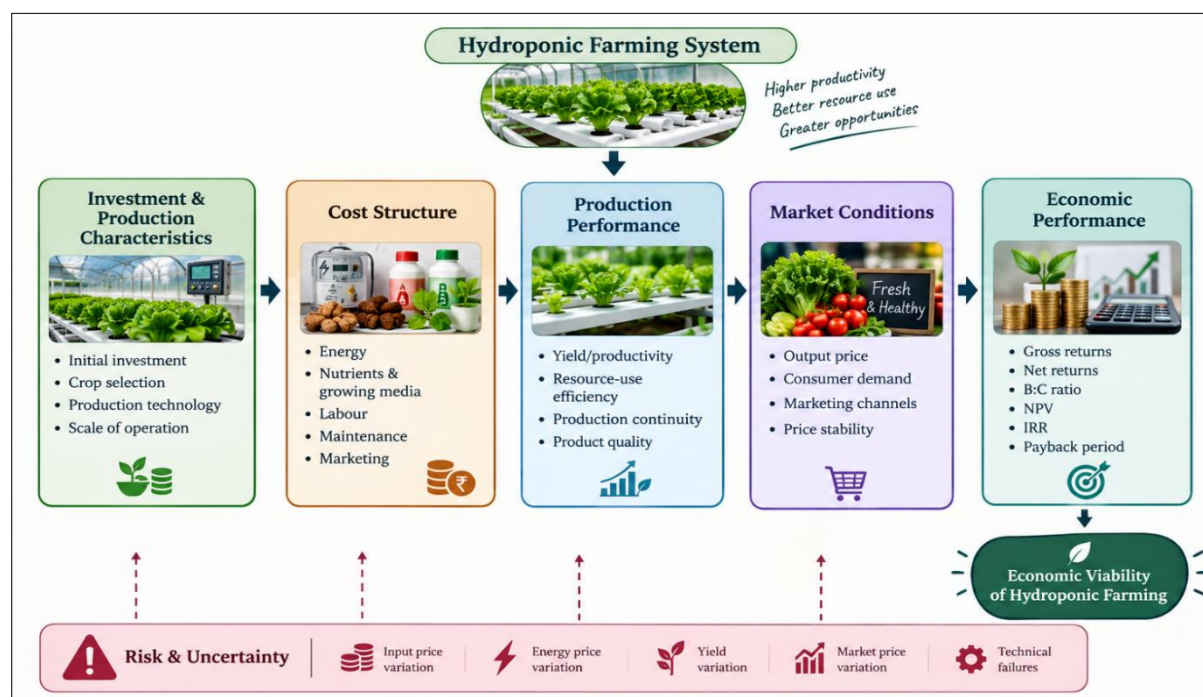


Figure 1: Conceptual framework of hydroponic farming system

1.5 Objectives:

The review aims to:

1. Synthesise the available evidence on investment requirements and cost structures associated with hydroponic farming.
2. Examine evidence on productivity, returns, profitability and financial feasibility of hydroponic production across different crops, technologies and production scales.
3. Identify the major economic factors, constraints, opportunities and research priorities influencing the long-term viability and expansion of hydroponic farming.

2. Investment Requirements and Cost Structure of Hydroponic Farming

Hydroponic farming requires a distinct cost structure compared with conventional soil-based cultivation because production depends on infrastructure, water and nutrient delivery systems, growing structures and, in technologically advanced systems, environmental monitoring and automation. The economic burden of these investments varies substantially with the type of hydroponic system, crop, production scale and degree of environmental control. Consequently, when assessing the economic viability of hydroponic farming, investment requirements and recurring costs must be examined together.

2.1 Initial Investment Requirements

The establishment of a hydroponic farm generally involves expenditure on protected structures, growing channels or containers, nutrient reservoirs, pumps, irrigation and fertigation equipment, growing media, electrical installations and other farm infrastructure. More sophisticated systems may additionally require sensors, automated nutrient dosing, environmental controllers, artificial lighting, cooling and ventilation systems. The initial investment therefore increases with the technological intensity and degree of environmental control incorporated into the production system.

The scale of investment can differ considerably even among farms using broadly similar hydroponic technologies. Recent evidence from Hyderabad showed that initial investment across eight commercial hydroponic farms ranged from ₹0.42 million to ₹20.4 million, with substantial differences associated with farm size and crop combinations (12). The same study identified protected structures and hydroponic growing infrastructure as major components of establishment expenditure, highlighting the importance of capital intensity in determining the financial requirements of commercial production.

Earlier economic assessments similarly demonstrated that infrastructure constitutes a substantial share of the capital requirement. A hydroponic investment assessment in Brazil reported an initial investment of about US\$89,654 for the production system, while a later evaluation of hydroponics on small rural properties reported an investment requirement of approximately US\$11,467 for a 390 m² hydroponic greenhouse (9,10). These differences illustrate that investment requirements are strongly influenced by system configuration, production scale and the level of infrastructure adopted.

The choice of production structure also affects the distribution of investment costs. In commercial hydroponic operations, expenditure may be concentrated in protected structures and NFT or other growing systems, whereas simpler substrate-based or small-scale systems may require considerably less capital. Thus, comparing hydroponic systems only on the basis of total investment can be misleading unless investment is expressed relative to cultivated area, production capacity or expected output.

Small-scale systems can reduce the financial barrier to entry, but lower investment does not necessarily ensure greater economic efficiency. A household-scale lettuce study in Indonesia reported positive financial indicators, including an NPV of approximately Rp. 24.13 million, a B:C ratio of 3.51 and a payback period of less than three months, illustrating that relatively simple hydroponic systems can be financially attractive under suitable local conditions (50). However, such results are highly context dependent because land availability, input prices, household labour and market prices influence the underlying economics.

Investment requirements are also affected by the degree of environmental control. Open or naturally ventilated structures generally require less capital than fully controlled indoor systems, whereas artificial lighting, climate-control equipment and automation can substantially increase establishment expenditure. This distinction is particularly important for vertical and indoor hydroponic systems, where the additional infrastructure required for lighting and environmental regulation may create a higher capital burden even when land requirements are substantially reduced.

Therefore, initial investment should be evaluated not simply as an absolute expenditure but in relation to productive capacity, expected useful life of infrastructure, annual output and expected cash flows.

2.2 Fixed and Variable Costs

Once the hydroponic system is established, the producer incurs both fixed and variable costs. Fixed costs generally include depreciation of structures and equipment, land or facility charges, permanent infrastructure and, in some cases, interest on fixed capital. Variable costs vary with production intensity and commonly include seeds or planting material, nutrient solutions, growing media, electricity, water, labour, packaging, transportation, pest and disease management and maintenance-related expenditures.

The distinction between fixed and variable costs is particularly important because hydroponic systems often have a relatively high fixed-cost component. Structures, growing channels, pumps, reservoirs, irrigation networks and environmental-control equipment continue to generate costs even when production levels fluctuate. Consequently, capacity utilisation becomes an important determinant of unit cost. A farm operating substantially below its productive capacity may have a higher cost per kilogram because fixed expenditure is distributed over a smaller quantity of output.

Commercial evidence from Nigeria illustrates this relationship. The annual operating cost of small- and medium-scale hydroponic farms was approximately €9,938 and €54,780, respectively. Electricity, labour, nutrient/fertilizer, pest and disease management, transportation and other operating expenses constituted important components of recurring costs (11). Although the medium-scale farms incurred greater total

expenditure, their production was also considerably higher, demonstrating the importance of evaluating costs relative to output and cultivated area rather than relying only on absolute expenditure.

A business-level assessment of hydroponic vegetable production in Indonesia also demonstrated considerable variation in the relative contribution of fixed and variable expenditure. Fixed costs accounted for approximately 60–71 per cent of total costs for the commodities examined, with depreciation, permanent labour and distribution among the important components. Variable expenditure included daily labour, seeds, growing materials, nutrients and packaging. This suggests that hydroponic enterprises may face substantial fixed commitments in addition to production-dependent expenditure.

The treatment of depreciation is particularly important when comparing economic studies. Different useful lives, salvage values and depreciation methods can lead to substantially different estimates of annual fixed cost. For this reason, standardised reporting of depreciation, infrastructure life and capital valuation would improve comparability between hydroponic economic studies.

Similarly, the inclusion or exclusion of family labour, land opportunity cost and interest on invested capital can substantially affect reported profitability. An apparently profitable hydroponic enterprise may therefore show a different economic outcome when all opportunity costs are included. Future economic evaluations should distinguish clearly between accounting profitability and economic profitability.

2.3 Energy, Nutrient and Labour Costs

Energy represents one of the most important recurring cost components in technologically intensive hydroponic production. Electricity may be required for pumps, water circulation, fertigation, ventilation, cooling, environmental control and artificial lighting. The importance of energy expenditure increases considerably in indoor vertical farms because lighting and climate-control systems operate continuously or for extended periods. Research comparing controlled-environment production systems has demonstrated that energy requirements can become a major economic constraint even when hydroponic systems provide substantial land and water savings. For example, hydroponically produced lettuce has been shown to achieve substantially greater yield per unit area and lower water use per kilogram than conventional production, but its energy requirement can be considerably higher (7). Similarly, comparisons between plant factories and greenhouses indicate that the resource-efficiency benefits of controlled environments may be accompanied by substantially higher purchased-energy requirements (8).

More recent research has explicitly incorporated energy into economic modelling. An integrated energy-yield-cost assessment of vertical farming estimated unit production costs of approximately US\$3.87 kg⁻¹ and identified lighting and dehumidification as major energy consumers. The study further showed that alternative energy strategies and CO₂ utilization could reduce unit production costs (28).

The economic importance of energy is therefore not restricted to the electricity bill itself. High energy demand can increase production costs, reduce profit margins and expose producers to electricity-price fluctuations. Recent work on dynamic vertical farming has emphasized that changing electricity prices can alter the economically optimal environmental conditions for crop production, reinforcing the need for flexible management of lighting, temperature, humidity and other production parameters (29).

Nutrient expenditure is another important recurring cost. Hydroponic crops depend on carefully formulated nutrient solutions containing essential macro- and micronutrients. The cost of nutrient inputs is influenced by crop requirements, nutrient concentration, solution replacement practices, water quality and whether the system is open or recirculating. Effective nutrient management can therefore have both agronomic and economic implications. Improved monitoring and recycling of nutrient solutions may reduce unnecessary input expenditure while maintaining crop productivity (34).

Labour costs also remain important despite the potential for automation. Labour is required for nursery management, transplanting, system cleaning, nutrient monitoring, harvesting, grading, packaging and maintenance. In the Nigerian case, labour was one of the important recurring expenditures, particularly in medium-scale production where the larger production volume required more workers (11).

Automation can reduce repetitive labour requirements, but it also involves additional capital expenditure and technical skills. Thus, the economic benefit of automation depends on whether savings in labour and production losses are sufficient to justify the additional investment.

An alternative approach to reducing energy dependence was examined by (33), who evaluated a human-powered hydroponic system using life-cycle costing alongside environmental assessment. Their work highlights the possibility of redesigning hydroponic infrastructure to reduce dependence on conventional energy inputs, although such approaches remain technologically specific and require further economic validation under commercial conditions.

2.4 Cost Variation with Crop, System and Scale

Hydroponic production costs cannot be represented by a single standard cost estimate because the economic structure varies according to crop characteristics, production technology and farm scale. Crops differ in production duration, plant density, yield, nutrient requirements, labour requirements and market price. Similarly, NFT, deep-water culture, substrate systems and vertical systems have different infrastructure and operating requirements.

The importance of crop selection is evident from economic assessments of different hydroponic crops. Commercial farms in Hyderabad cultivated lettuce, kale, basil, spinach, amaranthus, mint and coriander, and the reported investment and cost structures differed considerably among production units (12). Likewise, economic modelling of small-scale plant factories has shown that profitability can vary considerably between crops, with lettuce and basil performing more favourably than tomato under the scenarios examined (25).

Production scale can influence costs through economies of scale, capacity utilization, labour organization and purchasing arrangements. The Nigerian evidence showed that medium-scale farms achieved higher output per unit area and lower electricity, nutrient and transportation costs per square metre for several cost components, although labour and other expenses remained substantial (11).

However, larger scale does not automatically guarantee higher profitability. Expansion may increase expenditure on labour, land or facility management and may expose producers to greater market risk if additional output cannot be sold at remunerative prices. Therefore, scale economies should be evaluated together with market capacity and productive utilization of installed infrastructure.

The production system itself also influences the cost structure. Simple hydroponic systems may have lower initial capital requirements but require greater manual intervention, whereas automated systems can reduce labour requirements while increasing depreciation, maintenance and technical-service costs. Vertical systems may improve land productivity but can involve additional lighting and environmental-control costs. Hence, the economically optimal system is not necessarily the most technologically advanced system, but the system that provides an appropriate balance between investment, operating cost, productivity and market value.

3. Productivity, Returns and Profitability

Productivity and profitability are closely related but distinct dimensions of hydroponic economic performance. High physical productivity does not necessarily result in high profitability if the additional output is obtained at disproportionately high costs. Conversely, a system with moderate yields may remain economically attractive when production costs are low and the crop obtains a favourable market price. Economic assessment therefore requires simultaneous consideration of physical output, gross returns, net returns, benefit-cost relationships and the long-term financial performance of investment.

3.1 Productivity and Yield Performance

Hydroponic systems can achieve high productivity per unit of cultivated area because plant density, nutrient availability, irrigation and environmental conditions can be controlled more precisely than in many conventional production systems. This advantage is particularly relevant for leafy vegetables and short-duration crops, where several production cycles may be completed within a year. Vertical arrangements can further increase production per unit of floor area by using multiple growing levels (65).

Comparative experiments have demonstrated substantial differences in productivity among hydroponic configurations. In lettuce, deep-water culture and NFT systems have both demonstrated productive advantages, although performance differed according to system design and crop characteristics (14). Similarly, comparative research on lettuce grown under different soilless systems has shown that water-saving and yield outcomes vary according to the production method (21). These findings indicate that the term “hydroponic productivity” should not be treated as a uniform characteristic of all systems.

Crop quality can also influence the economic value of production. Hydroponically produced tomatoes have been shown to achieve higher water-use efficiency and, under controlled comparisons, higher concentrations of certain quality-related compounds than soil-grown tomatoes (20). Similarly, differences in cultivar and production environment can influence yield, biomass production and marketable quality in hydroponic lettuce (19). Such characteristics may generate additional economic value when consumers or buyers are willing to pay premium prices for consistent quality.

Productivity should therefore be evaluated using indicators such as yield per unit area, yield per plant, marketable yield, production cycles per year and output per unit of resource used. Simply reporting total annual production can be misleading when hydroponic farms differ substantially in size or cropping intensity.

The economic importance of productivity is particularly evident in capital-intensive systems. Since structures, growing systems and equipment represent substantial initial investments, increasing the utilization of installed production capacity can reduce fixed cost per unit of output. Recent research on commercial hydroponic systems has therefore emphasized the importance of improving crop performance and production density to achieve competitive production costs.

Thus, productivity contributes to economic viability only when the additional output generates sufficient revenue relative to the additional costs required to obtain it.

3.2 Gross and Net Returns

Gross returns from hydroponic farming depend primarily on marketable output and the price received by producers. Net returns, in contrast, reflect the amount remaining after deducting production and operating costs. The difference between these indicators is important because high gross revenue can coexist with relatively low profitability when production costs are high.

Commercial-scale evidence from Nigeria demonstrates this distinction clearly. Small-scale hydroponic farms generated annual revenue of approximately €11,227, while medium-scale farms generated approximately €86,797. After accounting for operating costs, annual net returns were approximately €1,289 and €32,007, respectively (11). The results indicate that larger production capacity can generate substantially greater absolute returns, although the relationship between scale and profitability depends on the corresponding cost structure. Recent Indian evidence also demonstrates substantial variation in financial performance among hydroponic farms. Across eight farms examined in Hyderabad, annual gross returns and total costs differed considerably according to farm size and crop combination. The study reported positive net returns across the evaluated production units, although the magnitude varied substantially between farms (12). At the crop-specific level, basil production under NFT hydroponics in a naturally ventilated polyhouse generated a gross return of ₹2,38,000 against a total cost of ₹2,21,280 for a 250 m² production area, resulting in a net return of ₹16,720 (13). The relatively modest margin illustrates that technically successful production does not necessarily translate into a large economic surplus. Economic returns can also be enhanced through improved production density. The basil study projected substantially higher returns when the number of A-frames and net cups was increased, indicating that utilization of available infrastructure can be an important determinant of profitability (13). The relationship between productivity and returns is therefore influenced by both physical performance and market valuation. A crop with high yield but a low market price may generate lower returns than a lower-yielding crop that commands a premium price. Consequently, crop selection in hydroponic enterprises should be based not only on biological suitability but also on expected revenue, production cost and market demand.

3.3 Benefit-Cost Ratio

The benefit-cost ratio (B:C) is widely used to assess whether the monetary benefits generated by an agricultural investment are sufficient relative to its costs. B:C ratio greater than one generally indicates that the benefits exceed the corresponding costs under the assumptions of the analysis. However, the interpretation of B:C ratios requires attention to the time period, discount rate and cost components included in the calculation. Commercial hydroponic production in Nigeria demonstrated high B:C ratios for both small- and medium-scale systems, with values of 5.07 and 4.91, respectively, over a ten-year evaluation period (11). The results indicated favourable economic performance under the conditions considered, although the sensitivity analysis showed that the profitability of smaller farms was more vulnerable to changes in recurring costs and revenue. Other studies have reported more moderate economic returns. The basil hydroponic system evaluated in India recorded a B:C ratio of 1.08, despite generating positive net returns. The difference between this result and the much higher B:C ratio reported for commercial-scale Nigerian systems illustrates why B:C values should not be compared without considering differences in crop, technology, scale, cost accounting and evaluation period. Economic comparisons of lettuce production have also indicated favourable returns from hydroponic systems relative to protected soil-based production under particular conditions. (14) reported B:C ratios above two for the hydroponic systems examined, suggesting that improved production performance and resource utilization can translate into economic benefits under appropriate production conditions. Therefore, B:C ratio is useful for screening economic feasibility, but it should ideally be interpreted alongside net returns, NPV, IRR, payback period and sensitivity analysis rather than being used as the sole indicator of profitability.

3.4 Financial Feasibility

Financial feasibility examines whether an investment generates sufficient future cash flows to recover its initial investment and provide an acceptable return over its economic life. Common indicators include NPV, IRR, profitability index and payback period. These measures are particularly important for hydroponic farming because establishment requires substantial upfront expenditure while returns are generated over multiple production cycles.

A hydroponic investment assessment in Brazil reported an NPV of approximately US\$177,846, an IRR of 30.45 per cent and a B:C ratio of 2.13, indicating financial feasibility under the conditions evaluated (10). A subsequent study of hydroponics on small rural properties also reported positive financial indicators, including an NPV of US\$15,575.63, IRR of 32.87 per cent and discounted payback period of 3.69 years.

Financial feasibility has also been demonstrated in small-scale vertical hydroponic production. A Ugandan study of non-greenhouse vertical lettuce production reported an NPV of US\$16.37, IRR of 12.57 per cent, profitability index of 1.1 and a non-discounted payback period of 4.5 years (17). The study also found that NPV was sensitive to the discount rate and selling price, showing that financial feasibility depends on the assumptions underlying future cash flows.

A hydroponic tomato greenhouse assessment in Western Greece further demonstrated the importance of scenario-based financial analysis. For a 0.2 ha farm, annual revenue was estimated at €63,000 and annual operating costs at €35,491, producing annual net cash flow of approximately €27,509. Under the baseline scenario, the investment produced an IRR of 13 per cent, an NPV of €25,270.67 and a payback period of approximately five years (18).

The Greek study is particularly important because it demonstrated that positive financial performance under the baseline conditions did not imply complete immunity from adverse market conditions. When variable costs

increased substantially without a corresponding increase in producer prices, the financial performance deteriorated markedly. Under the most adverse scenario, the NPV became negative and the IRR fell to zero. Recent evidence from India has also reported positive financial indicators. (12) found B:C ratios ranging from 1.75 to 2.71 and IRRs ranging from 59 to 85 per cent across the hydroponic farms examined in Hyderabad. However, the wide variation between farms reinforces the importance of considering scale, crop choice and infrastructure configuration when interpreting financial performance.

These findings suggest that financial feasibility should be evaluated over the entire investment life rather than from a single production cycle. Short-term positive cash margins may not be sufficient if infrastructure replacement, depreciation, maintenance and future capital expenditure are ignored.

3.5 Risk and Sensitivity of Profitability

Hydroponic profitability is exposed to several sources of uncertainty, including fluctuations in electricity prices, nutrient and input costs, crop yields, selling prices, labour expenditure and equipment performance. The relatively high fixed investment associated with many hydroponic systems can increase the financial consequences of adverse changes in these variables.

Sensitivity analysis therefore provides an important complement to conventional cost-return analysis. In the Nigerian study, small-scale hydroponic farms were considerably more sensitive to increases in recurring costs and reductions in gross annual revenue than medium-scale farms. A 15 per cent reduction in gross annual revenue was sufficient to produce a negative net return for the small-scale system under the specified assumptions.

Similarly, the Brazilian analysis found that the price received for hydroponic produce was a major determinant of investment performance, demonstrating the importance of market-price risk in financial planning (9). The Greek tomato study reached a similar conclusion: increases in variable costs without adequate compensation through output prices substantially reduced NPV and IRR (18).

Energy-related uncertainty is particularly important for technologically intensive systems. Vertical and indoor farms may have relatively high electricity requirements, meaning that changes in electricity tariffs can directly influence production costs. Recent research on dynamic vertical farming has consequently emphasized adaptive control strategies that balance crop performance, resource use and energy expenditure under changing operating conditions (29).

Risk can also arise from technical failures. Pump failure, nutrient imbalance, environmental-control malfunction or interruptions in electricity supply can rapidly affect crop performance because hydroponic crops depend heavily on managed water and nutrient delivery. The economic consequences may include yield losses, additional maintenance costs and reduced marketable output.

Recent research on commercial viability has therefore increasingly emphasized the need to evaluate hydroponic systems under multiple scenarios rather than relying only on a single expected-price and expected-yield assumption. Scenario analysis can examine combinations of changes in input prices, energy costs, crop yields and output prices and can identify the conditions under which an investment changes from economically viable to financially unattractive.

4. Factors Influencing Economic Viability of Hydroponic Farming

The economic viability of hydroponic farming is determined by the interaction of production technology, input costs, productivity, scale, crop selection and market conditions. Unlike conventional crop production, hydroponic enterprises generally involve higher dependence on infrastructure, electricity, nutrient management and technical supervision. Consequently, economic performance can vary substantially even among farms using similar production systems. Evidence from different countries indicates that profitability is influenced not by a single factor but by the combined effect of investment intensity, operating efficiency, production scale and the ability to obtain remunerative prices.

4.1 Initial Capital Investment

Initial capital investment is one of the most important determinants of hydroponic economic viability because the production system requires infrastructure before revenue can be generated. Major capital components may include protected structures, growing channels, nutrient reservoirs, pumps, irrigation and fertigation systems, electrical installations, environmental-control equipment, sensors and monitoring devices. The capital requirement increases further when production moves towards indoor or highly automated systems.

Recent evidence from Hyderabad demonstrated considerable variation in initial investment among commercial hydroponic farms, ranging from ₹0.42 million to ₹20.4 million. The variation was associated with farm size and crop combinations, highlighting the importance of matching investment intensity with productive capacity and market opportunities (12).

Financial studies from Brazil have similarly demonstrated that substantial initial investment can nevertheless be justified when future cash flows are sufficient to generate positive NPV and IRR. However, the recovery period means that producers must maintain production and market access over several years to realize the expected returns (9,10).

High capital requirements can particularly constrain entry by small producers who have limited access to institutional credit. Thus, the economic viability of hydroponics at farm level depends partly on the availability and cost of finance. A technologically efficient system may remain economically inaccessible when the producer cannot mobilize the required initial capital at an affordable interest rate.

The issue is therefore not simply whether hydroponics requires high investment, but whether the expected additional income generated by the investment is sufficient to recover the capital within an acceptable period.

4.2 Energy Costs

Energy expenditure is a major factor affecting the economics of hydroponic systems, particularly where pumps, ventilation, cooling, heating, dehumidification and artificial lighting are used. The importance of electricity increases with technological intensity and is particularly pronounced in indoor vertical farming.

Comparative resource assessments have demonstrated that hydroponic systems can substantially improve land and water productivity while simultaneously requiring greater energy inputs than conventional production (7). Similarly, comparisons of plant factories and greenhouses have shown that controlled-environment systems may require substantially more purchased energy, depending on the production environment and technology adopted (8).

Energy costs can therefore reduce the economic advantage associated with high productivity. This is particularly relevant when electricity prices increase or when production systems depend heavily on artificial lighting. Recent research has emphasized the need for dynamic management of lighting, temperature and root-zone conditions to balance resource use, crop performance and energy expenditure (29).

The economic importance of energy also creates opportunities for technological innovation. Renewable-energy integration, energy-efficient lighting, improved insulation and optimization of environmental controls may reduce operating expenditure. However, these technologies themselves involve additional capital expenditure, meaning that their economic benefit should be assessed using investment appraisal rather than assuming that energy savings automatically improve profitability.

4.3 Nutrients and Growing Media

Nutrient management directly influences both crop productivity and production expenditure in hydroponic farming. Unlike soil cultivation, where nutrient availability is partly buffered by the soil environment, hydroponic production depends on the deliberate preparation and management of nutrient solutions. The quantity and frequency of nutrient application therefore influence both crop performance and operating cost.

Hydroponic nutrient management involves expenditure on macro- and micronutrients, water treatment and, depending on the system, growing media such as cocopeat, rockwool or other substrates. Recirculating systems can potentially reduce nutrient losses, but they require monitoring of electrical conductivity, pH and nutrient balance. Inadequate management can result in nutrient wastage, physiological disorders or yield reduction.

The technical literature emphasizes the importance of precise nutrient management for improving nutrient and water-use efficiency in hydroponic systems (6,26). From an economic perspective, improved nutrient-use efficiency can reduce expenditure per unit of marketable output while maintaining productivity.

Alternative nutrient sources may also influence production economics. Research examining treated domestic wastewater as a nutrient source for hydroponic tomato production has demonstrated the possibility of recovering nutrients from alternative water streams, although issues relating to crop safety, nutrient balance and treatment requirements must be considered before commercial adoption (27).

Therefore, nutrient management should be viewed not simply as an agronomic practice but as a cost-management strategy. Efficient nutrient utilization can contribute to profitability when input savings are achieved without compromising yield or quality.

4.4 Labour and Technical Skills

Hydroponic farming can reduce some field operations, but it does not eliminate labour requirements. Labour is needed for nursery management, transplanting, nutrient preparation, system monitoring, cleaning, harvesting, grading, packaging and marketing. In technologically advanced systems, workers additionally require knowledge of sensors, fertigation, nutrient management and environmental control.

Evidence from commercial-scale hydroponic production shows that labour remains an important component of operating costs. In the Nigerian case, labour expenditure increased substantially with production scale, reflecting the greater workforce required to operate larger systems (11).

Automation can reduce repetitive labour requirements, but the economic effect is not necessarily straightforward. Automated dosing, environmental control and monitoring equipment can reduce labour intensity while increasing capital investment, depreciation and maintenance requirements. The economic benefit of automation therefore depends on the scale of operation and the extent to which labour savings offset additional capital costs.

Technical skills are equally important. Hydroponic systems are highly dependent on correct management of water quality, nutrient concentration, pH, electrical conductivity, irrigation frequency and environmental conditions. Technical errors can rapidly translate into yield losses because crops have limited access to alternative nutrient sources outside the managed system.

Consequently, investment in training and technical support can have economic value by reducing production failures and improving resource-use efficiency.

4.5 Crop Selection

Crop selection is a central determinant of hydroponic profitability because different crops differ in production duration, yield potential, nutrient requirements, labour intensity, energy requirements and market price. Crops with short production cycles and high market value may generate faster revenue recovery, whereas fruiting crops may require longer production periods and more intensive environmental management.

Commercial hydroponic farms in Hyderabad cultivated lettuce, kale, basil, spinach, amaranthus, mint and coriander, demonstrating the diversity of crops used in commercial systems (12). The study also observed variation in financial performance between farms associated with crop choice and selling prices.

Recent comparative research provides an important qualification to the assumption that hydroponics is automatically more profitable. A comparison of hydroponic, substrate and soil cultivation of leafy vegetables in China found that soilless systems had substantially higher unit costs than soil cultivation. Hydroponic production generated favourable economic returns for some crops, but not uniformly across all vegetables. The findings highlighted the importance of yield and pricing in determining profitability.

This suggests that crop selection should be based on an integrated assessment of biological suitability, production cost, expected yield, market price and consumer demand rather than solely on yield potential.

4.6 Scale of Production

Scale influences hydroponic economics through capacity utilization, purchasing power, labour organization, infrastructure utilization and marketing efficiency. Larger farms can distribute fixed costs over greater output and may benefit from bulk purchasing and specialized labour. However, expansion also increases exposure to market risk and requires sufficient demand for the additional production.

Evidence from Nigeria found that medium-scale farms generated substantially greater net returns per unit area than small-scale farms and were less sensitive to changes in recurring costs (11). This suggests that economies of scale may improve financial resilience under certain operating conditions.

However, scale advantages are not universal. If expansion results in underutilized infrastructure or if additional output cannot be sold at profitable prices, the financial benefits of scale may diminish. The large variation in investment and financial indicators observed among Hyderabad hydroponic farms also demonstrates that farm size alone does not determine economic success (12).

Thus, economically optimal scale should be determined according to production capacity, market absorption capacity, available finance and management capability rather than physical expansion alone.

4.7 Market Price and Marketing Channels

Market price is one of the most influential determinants of hydroponic profitability because production costs are generally higher than those of some conventional systems. Producers therefore require sufficient output prices to compensate for higher capital and operating expenditure.

Financial modelling in Brazil demonstrated that variations in the selling price received by farmers had a particularly strong effect on NPV (9). Similarly, the Ugandan vertical hydroponic study found that NPV was sensitive to changes in unit selling price, while revenue varied according to both quantity sold and price received (17).

Marketing channels can therefore influence profitability as much as production efficiency. Direct marketing to consumers, restaurants, hotels, supermarkets and institutional buyers may provide opportunities for premium pricing, but these channels may also involve additional expenditure on packaging, transportation, branding and customer management.

Recent research on hydroponic vegetable businesses has also demonstrated the potential role of social-media-based marketing in connecting producers directly with consumers. Such channels may reduce dependence on intermediaries, although the economic benefits depend on customer retention, delivery costs and the volume that can be sold through direct channels.

The economic viability of hydroponics is therefore closely linked to market segmentation and the producer's ability to capture value from differentiated products.

4.8 Technology and Automation

Technology can influence hydroponic profitability by altering productivity, labour requirements, resource efficiency and production consistency. Sensors, automated nutrient dosing, climate-control systems, remote monitoring and automated irrigation can improve the precision of production management. However, technology also increases investment requirements and may create additional maintenance and technical-service costs.

Automation is particularly relevant in vertical farming, where environmental conditions must be carefully controlled across multiple production levels. Research on dynamic vertical farming has emphasized the need to optimize environmental conditions while accounting for energy expenditure and production objectives (29).

The economic value of automation therefore depends on the difference between the additional revenue or cost savings generated by the technology and its capital and operating costs. Automation that improves yield but requires disproportionately high energy expenditure may not increase net profitability.

Recent research on commercial hydroponic viability has consequently emphasized the importance of identifying production targets that allow technology-intensive systems to achieve competitive unit costs (52). The implication is that technological sophistication should be evaluated in terms of economic performance rather than adoption alone.

4.9 Resource-Use Efficiency

Resource-use efficiency represents another important link between technical performance and economic viability. Hydroponic systems can potentially increase output per unit of land and water by delivering resources directly to the crop. However, improvements in one resource-use indicator may involve higher requirements for another resource, particularly energy.

A widely cited comparison of hydroponic and conventional lettuce production demonstrated substantially higher land productivity and much lower water use per kilogram under hydroponics, but also substantially greater energy use (7). This illustrates an important economic trade-off: saving water may provide economic value in water-scarce regions, but increased energy requirements can raise production costs.

Similar trade-offs have been reported in comparisons of plant factories and greenhouses, where water and land efficiency improvements may occur alongside increased purchased-energy requirements (8). Consequently, resource-use efficiency should not be evaluated independently of input prices.

The economic relevance of resource efficiency ultimately depends on the relative scarcity and price of each resource. Water-saving technologies may provide greater economic benefits where water is expensive or scarce, while energy-saving technologies become more valuable where electricity constitutes a large share of production costs.

5. Economic Constraints and Opportunities

The economic performance of hydroponic farming depends not only on the productivity of the production system but also on the conditions under which the technology is adopted, operated and marketed. Hydroponics can provide intensive production, controlled resource use and year-round cultivation, but these advantages are accompanied by relatively high capital requirements, recurring operating expenses, technical dependence and exposure to market and energy-price fluctuations. Recent reviews and empirical studies have therefore emphasized that the commercial expansion of hydroponics requires attention to both its economic constraints and the opportunities through which these constraints can be reduced (48).

5.1 Economic Constraints

One of the principal constraints to hydroponic adoption is the high initial capital requirement. Protected structures, hydroponic channels, pumps, reservoirs, fertigation equipment, sensors and environmental-control systems require considerable investment before production begins. This can create a substantial entry barrier for small and resource-constrained producers. Recent evidence from India and other developing countries has identified capital intensity as one of the major limitations to wider adoption of hydroponic and controlled-environment production (43,48).

Access to affordable finance is closely associated with this constraint. Even where a hydroponic system is potentially profitable over its useful life, producers may face difficulties in mobilizing the initial investment or servicing loans during the early years of operation. Financial feasibility studies demonstrate that positive long-term returns do not eliminate the importance of the initial cash requirement and payback period (10,36). A recent study of six hydroponic vegetable farmers in Indonesia reported positive NPV, IRR and Net B:C, but the average investment requirement exceeded IDR 104 million per respondent, illustrating the importance of access to investment capital.

High and unstable operating costs constitute another constraint. Electricity, nutrients, labour, maintenance, packaging and transportation can represent substantial recurring expenditures. The importance of these costs becomes particularly pronounced in technologically intensive systems that depend on artificial lighting, cooling or other environmental-control equipment. Commercial-scale evidence has shown that changes in recurring costs can significantly alter the profitability of hydroponic farms, with smaller systems potentially being more vulnerable to cost increases.

Technical and managerial requirements also constrain adoption. Hydroponic production requires continuous monitoring of water quality, pH, electrical conductivity, nutrient concentration, irrigation and environmental conditions. Failure in nutrient management, irrigation or equipment operation can rapidly affect crop performance. Recent system-dynamics modelling has shown that hydroponic commercial viability is influenced by interacting technical and operational variables, including light, humidity, nutrient delivery, location and service quality (41).

Another important constraint is market uncertainty. Hydroponically produced vegetables may require premium or differentiated markets to compensate for their relatively high production costs. If market prices decline or demand is insufficient, the expected economic advantage can be reduced substantially. Financial assessments

have repeatedly demonstrated the sensitivity of hydroponic investment performance to selling prices and revenue changes (9,17).

The perishability of fresh produce creates an additional economic challenge. Lettuce, leafy vegetables and other hydroponically produced crops have limited storage life, making production planning and market coordination important. Recent research on hydroponic crop planning has highlighted the possibility of mismatches between production and demand, which can result in unsold output, waste and financial losses.

Finally, the absence of standardised economic benchmarks makes it difficult for prospective producers to determine whether a proposed hydroponic enterprise is economically attractive. Studies differ in their treatment of depreciation, family labour, land costs, infrastructure life, interest on capital and maintenance expenditure. As a result, reported profitability indicators cannot always be compared directly across studies.

5.2 Economic Opportunities

Despite these constraints, hydroponic farming provides several economic opportunities, particularly where conventional agricultural production faces land, water or climate limitations. One important opportunity is intensive production in limited spaces. Hydroponic and vertical systems can increase output per unit of ground area, making them potentially suitable for urban and peri-urban locations where land is scarce or expensive. Vertical hydroponic production can also facilitate proximity to consumers and shorten supply chains (47).

Another opportunity arises from year-round and relatively predictable production. Controlled production conditions can reduce dependence on seasonal weather conditions and enable producers to supply markets more consistently. This continuity may be economically valuable for restaurants, hotels, supermarkets and institutional buyers that require regular supplies.

Product differentiation and premium markets provide another potential source of economic value. Hydroponic vegetables may be marketed on attributes such as consistent quality, cleanliness, traceability, local production and controlled production conditions. However, the economic benefit depends on actual consumer willingness to pay rather than assuming that hydroponically produced products will automatically command premium prices. Consumer research has shown that attitudes towards hydroponic and vertical-farming products are influenced by perceptions of sustainability, production methods and product characteristics (45,46).

Hydroponic enterprises can also benefit from direct and specialized marketing channels. Direct sales to consumers, restaurants, hotels, supermarkets and institutional purchasers can potentially reduce intermediary dependence and improve producer margins. The importance of market organisation is particularly evident in protected vegetable production, where direct-to-consumer channels have been associated with higher marketing efficiency and greater producer shares compared with channels involving multiple intermediaries.

Automation and digital technologies provide further opportunities to improve economic performance. Sensors, automated fertigation, remote monitoring and environmental-control systems can improve production consistency and reduce avoidable resource losses. However, the economic benefit depends on whether the reduction in labour, input wastage and production losses compensates for the additional capital and maintenance costs. Recent modelling work suggests that integrating technical and service components can improve commercial decision-making by identifying how operating conditions affect both yield and production costs (41).

Renewable energy integration is another emerging opportunity. Since electricity can constitute a significant operating cost, solar photovoltaic systems and other renewable-energy options may reduce exposure to conventional electricity prices. Their economic attractiveness, however, depends on installation costs, electricity tariffs, system lifetime, utilization and financing conditions. Therefore, renewable-energy adoption should be assessed as an investment decision rather than considered an automatic cost-saving measure.

There is also an opportunity to develop low-cost hydroponic systems specifically suited to small producers. Recent Indian reviews have emphasized the need for affordable system designs that reduce dependence on expensive infrastructure and intensive labour while maintaining adequate productivity (48). Such approaches may be particularly relevant in developing-country contexts where access to capital is a major barrier.

5.3 Implications for Adoption and Expansion

The distinction between economic viability, adoption feasibility and scalability is important when evaluating hydroponic farming. A hydroponic system may be profitable under a particular combination of crop, scale, technology and market conditions but still remain difficult for small producers to adopt because of capital or technical constraints. Similarly, a system that is viable at small scale may not remain profitable after expansion if market demand, labour requirements or operating costs increase disproportionately.

Evidence from commercial-scale hydroponics illustrates this distinction. Both small- and medium-scale systems in Nigeria were financially viable under the conditions evaluated, but their cost structures and sensitivity to changes in recurring costs differed considerably (11). Recent modelling also indicates that location, product quality and service arrangements can alter production costs substantially, demonstrating that commercial viability depends on more than physical production capacity (41).

For small producers, appropriate policy and institutional support may therefore include access to affordable credit, technical training, low-cost technologies, input information and reliable market linkages. For larger

commercial enterprises, the priorities may shift towards capacity utilization, energy efficiency, automation, supply-chain coordination and stable institutional markets.

The development of hydroponic farming should consequently not be based simply on promoting the technology. Instead, expansion should focus on identifying economically appropriate production models for particular crops, scales and market environments. Financial support without adequate technical knowledge or market access may not produce sustainable enterprises, while technology adoption without attention to cost structure can increase financial risk.

Overall, the literature suggests that hydroponic farming offers meaningful economic opportunities, but these opportunities are highly context dependent. High capital requirements, energy expenditure, technical complexity and market uncertainty remain major barriers, whereas intensive production, specialized markets, direct marketing, automation and renewable-energy integration offer potential pathways for improving economic performance.

6. Research Gaps and Future Priorities

Although the economic literature on hydroponic farming has expanded, important gaps remain in the comparability, duration and scope of available evidence. Existing studies differ considerably in the way investment, depreciation, labour, energy and operating costs are measured, making direct comparison across production systems difficult. Moreover, economic assessments are concentrated in particular crops and production environments, while socio-economic research remains relatively limited compared with technical and biological studies. A scoping review of controlled-environment agriculture identified only 60 socio-economic studies among 610 studies reviewed, highlighting the need for greater economic attention to the sector (10). Recent techno-economic work has also shown that economic competitiveness depends on the interaction between crop performance, energy use, capital costs and production scale rather than on yield alone.

6.1 Standardized Cost Accounting

One of the major limitations in the existing literature is the absence of a consistent framework for estimating the cost of hydroponic production. Studies differ in their treatment of depreciation, interest on investment, labour, infrastructure maintenance, energy, nutrient solutions and other operating expenses. Such differences can substantially influence estimates of profitability and make results from different farms or countries difficult to compare. For example, economic studies have used different combinations of capital and operating costs when evaluating hydroponic systems at household, small-farm and commercial scales (10,11). Future research should therefore adopt standardized cost-accounting procedures that separately report capital expenditure, annual fixed costs, variable costs, replacement costs, depreciation, labour and energy expenditure. Such standardization would provide more reliable benchmarks for farmers, investors and policymakers.

6.2 Long-term Economic Evidence

A further gap concerns the limited availability of long-term economic evidence. Many assessments are based on a relatively short production period or a modelled representative year, while hydroponic infrastructure has a useful life extending over several years. Consequently, replacement of pumps, lighting equipment, sensors, growing systems and climate-control components, as well as maintenance expenditure, can influence the actual profitability of an enterprise over time. (9,10) incorporated discounted financial indicators and investment recovery into their assessments, illustrating the importance of evaluating hydroponics over the full investment horizon. Similarly, recent modelling demonstrates that capital costs per unit of output can decline as production increases, emphasizing the importance of considering investment utilization over time rather than relying only on annual returns.

Future studies should therefore use longer planning horizons and incorporate equipment replacement, maintenance, technological obsolescence, financing costs and changes in input and output prices. Such assessments would provide a more realistic understanding of the durability of hydroponic enterprises.

6.3 Crop- and Scale-Specific Evidence

Economic performance cannot be generalized across all hydroponic crops and production systems. Crop duration, yield potential, market price, plant density, nutrient requirements and labour requirements differ considerably among leafy vegetables, herbs, tomato, cucumber and other high-value crops. The available literature is also strongly concentrated on leafy vegetables, particularly lettuce, while comparatively fewer studies evaluate fruiting vegetables and other commercially important crops.

Scale is another important source of variation. (11) found that small- and medium-scale hydroponic farms differed in their economic sensitivity to changes in operating costs and revenue. Recent work similarly indicates that increasing output can reduce capital cost per kilogram through better utilization of infrastructure, although the resulting competitiveness remains crop- and technology-specific.

Future research should therefore develop crop-specific and scale-specific economic benchmarks for household, small, medium and commercial hydroponic systems under different climatic and market conditions.

6.4 Risk and Sensitivity Analysis

Conventional cost-and-return analysis may provide an incomplete picture of hydroponic profitability because the sector is exposed to considerable uncertainty. Electricity prices, input costs, crop yields, selling prices, equipment failures and market demand can change the financial outcome substantially. (demonstrated that small-scale hydroponic farms were particularly sensitive to changes in recurring costs and revenue. (10)also showed through sensitivity analysis and Monte Carlo simulation that output price was an important determinant of financial performance.

Future economic studies should therefore move beyond single-point estimates of NPV, IRR and benefit-cost ratio and incorporate sensitivity analysis, scenario analysis and probabilistic risk assessment. Particular attention should be given to energy-price shocks, fluctuations in market prices, yield variability and unexpected equipment or production failures. This would allow profitability estimates to reflect the uncertainty faced by actual hydroponic producers.

6.5 Integrated Economic and Resource Assessment

Another important research priority is the integration of economic performance with resource-use efficiency. Hydroponic systems are often promoted because of their potential for efficient use of land and water, but resource efficiency does not automatically translate into economic viability. Energy requirements, particularly in highly controlled systems, can offset some of the economic benefits associated with higher productivity. Recent research emphasizes that cost competitiveness depends on the interaction between energy efficiency, crop productivity, capital investment and crop-cycle performance (52).

Future research should consequently evaluate profitability together with water-use efficiency, energy-use efficiency, nutrient-use efficiency and productivity. Such integrated assessments would help identify production systems that are not only profitable but also efficient in their use of scarce resources. This approach is particularly important for comparing different hydroponic technologies and determining which systems are economically and environmentally appropriate under specific local conditions.

Overall, future research should move from isolated cost-and-return studies towards standardized, long-term, crop-specific, risk-adjusted and resource-integrated economic assessments. This would strengthen the evidence base required for investment decisions, technology selection and policy support for hydroponic farming.

7. CONCLUSION

Hydroponic farming has emerged as a promising production system for increasing productivity under conditions of limited land and water availability. However, its economic performance cannot be assessed solely on the basis of higher yields or resource savings. The reviewed evidence indicates that profitability is determined by the interaction of initial investment, production scale, energy and nutrient costs, labour requirements, crop selection, resource-use efficiency, market prices and production technology. Financial assessments from different production environments have demonstrated positive economic returns, but the magnitude and stability of these returns vary considerably among crops, production systems and scales of operation.

The major economic challenge is the relatively high capital requirement associated with protected structures, hydroponic equipment, climate-control systems and other infrastructure. Recurring expenditure on electricity, nutrients, labour and maintenance can further influence profitability. At the same time, efficient use of land and water, higher productivity per unit area, year-round production and access to premium or specialized markets can create important economic opportunities. Evidence from commercial-scale systems also suggests that larger operations may benefit from improved utilization of infrastructure and greater capacity to absorb changes in operating costs.

Overall, hydroponic farming should be regarded as a context-specific economic enterprise rather than an inherently profitable alternative to conventional agriculture. The appropriate production technology, crop, scale and marketing strategy need to be selected according to local resource availability, investment capacity, energy costs and market conditions. Future development should therefore emphasize standardized cost accounting, long-term financial assessment, crop- and scale-specific economic benchmarks, risk and sensitivity analysis, and the simultaneous evaluation of profitability and resource-use efficiency.

For farmers and investors, economic viability should be assessed before investment through realistic estimates of capital requirements, operating costs, expected yields, selling prices and investment recovery. For policymakers, targeted financial support, technical training, infrastructure development, access to appropriate technologies and stronger market linkages can help reduce barriers to adoption. Continued research integrating cost, profitability, risk, resource efficiency and market performance will be essential for identifying hydroponic production models that are economically sustainable and suitable for wider adoption.

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