
Economic performance and water footprint of solar-powered automated drip irrigation for durian and mangosteen production

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Abstract The economic performance and water footprint of a solar-powered automated drip irrigation system (SPADIS) with those of a conventional sprinkler emitter irrigation system (CSEIS) for durian and mangosteen production in farmer-managed orchards in Chanthaburi Province, Thailand, over the 2023-2024 production period were investigated. SPADIS had a higher initial installation cost, at approximately 52,500 THB/rai, compared with 17,000 THB/rai for CSEIS. However, its annual operating cost was considerably lower, ranging from approximately 3,000 to 3,600 THB/rai/year, compared with 10,800-11,700 THB/rai/year for CSEIS, largely because no electricity cost was required for irrigation. When the savings in operating costs were considered together with the higher crop returns, the additional investment in SPADIS was recovered in approximately 2 years and 9 months. The water footprint was also lower with SPADIS for both crops. In 2024, the water footprint was 0.38 m³/kg for durian and 0.33 m³/kg for mangosteen, both substantially lower than the corresponding values under CSEIS. Overall, SPADIS provided lower operating costs and more efficient water use than the conventional system, indicating its potential for reducing production costs and improving water management in perennial fruit orchards.

Keywords: Economic performance, Water footprint, Automated drip irrigation, Solar power, Sustainable agriculture

Introduction

Irrigation management is an important consideration in perennial fruit production, particularly as electricity costs increase and water resources become more limited (Guno and Agaton, 2022). These concerns are particularly relevant

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to durian and mangosteen orchards in eastern Thailand, where adequate water supply is important for fruit development and yield. Solar-powered automated drip irrigation systems (SPADIS) offer an alternative to conventional irrigation by reducing reliance on grid electricity and allowing water to be applied more directly. However, evidence of their economic performance and water use under commercial orchard conditions is still limited. Assessing both economic performance and water footprint is therefore important for determining the practical value of SPADIS for fruit growers.

Previous research has examined the economic feasibility of using solar energy for agricultural irrigation. Wangsupphapol *et al.* (2024), for example, reported lower energy costs and a payback period of less than five years after combining photovoltaic panels with repurposed lithium-ion batteries in a commercial durian orchard. Their results indicate that renewable energy can reduce the operating costs associated with orchard irrigation.

Water footprint research has also examined water use in durian and mangosteen production. Jampala *et al.* (2021) reported a water footprint of 2.79 m³/kg for ‘Monthong’ durian. In mangosteen production in Chanthaburi Province, Aurama *et al.* (2021) found that green water accounted for more than 80% of the total water footprint. These studies show that water use is an important consideration in the production of both fruit crops. Together, these studies demonstrate the importance of optimizing irrigation practices to reduce water consumption and environmental impacts.

Although previous studies have examined either the economic feasibility of solar-powered irrigation systems or the water footprint of fruit production, few have evaluated both aspects simultaneously under farmer-managed orchard conditions. Consequently, the combined economic and environmental performance of solar-powered automated drip irrigation systems remains insufficiently documented for durian and mangosteen production in Thailand. The study evaluated the economic performance and water footprint of SPADIS compared with a conventional sprinkler emitter irrigation system to determine its potential for improving resource-use efficiency and farm profitability.

Materials and methods

Experimental equipment and materials

Field experiments were conducted during 2023–2024 in two farmer-managed orchards located in Pluang Sub-district, Khao Khitchakut District, Chanthaburi Province, Thailand. One orchard was equipped with a solar-powered automated drip irrigation system (SPADIS), whereas the other used a conventional sprinkler emitter irrigation system (CSEIS) as the control. A total

of 40 trees in the early production stage were included in the study, comprising 20 mangosteen and 20 durian trees.

The SPADIS consisted of six photovoltaic panels (500 W each), a DC water pump, an automated control unit, a 1,000-L water storage tank, filtration equipment, and a drip irrigation network. The system supplied irrigation to approximately 20 rai and was designed to serve about 500 trees planted at a spacing of 8×8 m.

Data were collected to compare the technical and economic performance of the two irrigation systems. Installation costs included equipment purchase and labor associated with system installation. Annual operating costs included electricity maintenance, repairs, and routine management. Crop income was calculated using the total marketable yield and the distribution of fruit grades. Water use was estimated from irrigation records and rainfall recorded during the study period.

Economic analysis

The economic performance of SPADIS and CSEIS was compared using installation cost, annual operating cost, net profit, and payback period. Net profit was calculated by subtracting annual operating costs from gross revenue. The payback period was calculated based on the additional installation cost of SPADIS and the annual economic benefit obtained from its use.

Water footprint and water use efficiency

Water footprint (WF) was calculated by dividing the volume of water consumed by crop yield and was expressed as cubic meters per kilogram of harvested fruit (m^3/kg). Water use efficiency (WUE) was calculated dividing crop yield by total water use and was expressed as kilograms of fruit produced per unit volume of water supplied.

Statistical analysis

Differences between SPADIS and CSEIS were tested using an independent-samples t-test, with statistical significance set at $p < 0.05$. The analysis was performed using SPSS Statistics.

Results

Installation and operating costs

The two irrigation systems differed substantially in their initial installation costs (Tables 1 and 2). SPADIS costs 52,500 THB/rai to install, compared with 17,000 THB/rai for CSEIS. Thus, the installation of SPADIS required an additional 35,500 THB/rai, or approximately 208.82% more than the conventional system.

The higher installation cost of SPADIS was mainly related to the additional equipment needed for solar-powered operation. Photovoltaic panels accounted for the largest cost at 15,000 THB/rai, followed by the main and branch pipeline system at 10,000 THB/rai and the DC water storage tank also added to the total installation cost. CSEIS required fewer components and therefore had a lower initial installation cost (Table 1).

Although SPADIS required a substantially higher initial investment, most of the additional cost was associated with the solar-energy and automated irrigation components. This difference was considered in the subsequent comparison of the economic performance of the two systems.

Table 1. Installation and annual operating costs of solar-power automated drip irrigation system (SPADIS) and conventional sprinkler emitter irrigation system (CSEIS) per rai (THB)

Cost list	SPADIS (THB)	CSEIS (THB)
Installation Cost (One-Time)		
Solar Panels	15,000	0
DC Water Pump	8,000	0
Automatic Control Unit	5,000	0
1,000-liter water tank	3,000	3,000
Water Filter Unit	2,500	1,000
Main and branch piping systems	10,000	8,000
Drip Head/Sprinkler Head	4,000	2,000
Installation labor cost	5,000	3,000
Total installation cost	52,500	17,000
Annual Operating Costs (2023-2024 Average)		
Electricity/Pump Cost	0	8,350
Equipment maintenance costs	1,650	1,100
Administrative labor costs	1,000	1,500
repair and replacement of parts	650	400
Total annual operating costs	3,300	11,250

Annual operating costs

Annual operating costs also differed substantially between the two irrigation systems (Tables 1 and 3). SPADIS required an average operating cost of 3,300 THB/rai/year, whereas CSEIS required 11,250 THB/rai/year. The annual operating cost was therefore reduced by 7,950 THB/rai/year, equivalent to a 70.67% reduction compared with the conventional system.

The greatest difference was observed for electricity expenditure. Because SPADIS was powered entirely by solar energy, no electricity costs were incurred during system operation. In contrast, electricity represented the largest operating expense for CSEIS, averaging 8,350 THB/rai/year. Maintenance costs were slightly higher for SPADIS (1,650 THB/rai/year) than for CSEIS (1,100 THB/rai/year), while repair and routine management expenses differed only slightly between the two systems (Table 1).

When only annual operating costs were considered, the additional installation cost of SPADIS could be recovered within approximately 4 years and 6 months through reductions in yearly operating expenses (Table 3).

Table 2. Installation cost comparison between solar-powered automated drip irrigation system (SPADIS) and conventional sprinkler emitter irrigation system (CSEIS)

Variable	SPADIS (THB)	CSEIS (THB)	Difference (THB)
Total cost of installation	52,500	17,000	35,500
Percentage difference			SPADIS had an initial installation cost 208.82% higher than CSEIS.

Table 3. Annual operating cost comparison between solar-powered automated drip irrigation system (SPADIS) and conventional sprinkler emitter irrigation system (CSEIS)

Variable	SPADIS (THB)	CSEIS (THB)	Difference (THB)
Total operating cost	3,300	11,250	7,950
Percentage difference			SPADIS reduced operating costs by 70.67%

Economic performance

The reduction in annual operating costs, together with differences in crop revenue, resulted in clear differences in economic performance between the two irrigation systems (Table 4). In 2023, total income generated under SPADIS reached 8,661 THB/rai, compared with 7,456 THB/rai under CSEIS. A similar trend was observed in 2024, when total income increased to 10,560.8 THB/rai for SPADIS and 8,865.6 THB/rai for CSEIS.

After annual operating costs were deducted, SPADIS generated positive net profits of 5,661 THB/rai in 2023 and 6,960.8 THB/rai in 2024. By comparison, CSEIS recorded negative net returns of –3,344 THB/rai and –2,834.4 THB/rai during the respective production years. Consequently, the economic advantage associated with SPADIS increased from 9,005 THB/rai in 2023 to 9,795.2 THB/rai in 2024.

When both the annual operating cost savings and additional crop income were considered, the payback period was reduced from approximately 4 years and 6 months to 2 years and 9 months (Table 4). Thus, including crop income resulted in a shortened recovery period than considering operating cost savings alone.

Table 4. Net profit comparison between solar-powered automated drip irrigation system (SPADIS) and conventional sprinkler emitter irrigation system (CSEIS) per rai

List	Year 2023 (THB)	Year 2024 (THB)
Total Revenue		
SPADIS	6,600 (durian) + 2,061 (mangosteen) = 8,661	8,096 (durian) + 2,464.8 (mangosteen) = 10,560.8
CSEIS	5,712 (durian) + 1,744 (mangosteen) = 7,456	6,720 (durian) + 2,145.6 (mangosteen) = 8,865.6
Net profit (gross revenue - annual operating costs)		
SPADIS	8,661 – 3,000 = 5,661	10,560.8 – 3,600 = 6,960.8
CSEIS	7,456 – 10,800 = -3,344 (loss)	8,865.6 – 11,700 = -2,834.4 (loss)
Net profit margin = difference in net profit (SPADIS – CSEIS)	9,005	9,795.2

Water footprint

Water footprint (WF) was consistently lower under SPADIS than under CSEIS for both durian and mangosteen during the study period (Table 5). In 2023, the WF of durian under SPADIS was 0.48 m³/kg, compared with 0.74 m³/kg under CSEIS. A similar pattern was observed in 2024, when WF decreased to 0.38 m³/kg under SPADIS, whereas CSEIS recorded a value of 0.55 m³/kg. These values represented reductions of approximately 35.14% and 30.91% in 2023 and 2024, respectively.

Mangosteen showed the same trend. Water footprint under SPADIS declined from 0.40 m³/kg in 2023 to 0.33 m³/kg in 2024, while corresponding values for CSEIS were 0.60 and 0.46 m³/kg, respectively. Compared with the conventional irrigation system, SPADIS reduced the water footprint of mangosteen by approximately 33.33% in 2023 and 28.26% in 2024 (Table 5).

Independent-samples t-tests confirmed significant differences in water footprint between the two irrigation systems for both crops during the two production years. Test statistics ranged from –3.88 to –7.76, with all probability values below 0.01 (Table 5). The coefficients of variation ranged from 12.86% to 25.77%, indicating acceptable consistency among the observations.

Table 5. Statistical comparison of water footprint (WF) and water use efficiency (WUE) between solar-powered automated drip irrigation system (SPADIS) and conventional sprinkler emitter irrigation system (CSEIS)

Parameter	Plant Species	Year	SPADIS	CSEIS	T-test	Sign. ¹	CV (%)
WF (m ³ /kg) (Lower is better.)	Durian	2023	0.48	0.74	-7.76	**	12.86
	Durian	2024	0.38	0.55	-5.07	**	19.71
	Mangosteen	2023	0.40	0.60	-5.97	**	16.67
	Mangosteen	2024	0.33	0.46	-3.88	*	25.77
WUE (kg/L) (Higher is better.)	Durian	2023	0.00208	0.00136	4.50	**	22.22
	Durian	2024	0.00291	0.00182	6.81	**	14.68
	Mangosteen	2023	0.00250	0.00167	5.19	**	19.23
	Mangosteen	2024	0.00306	0.02170	5.56	**	17.96

¹/*: Significant ($p < 0.05$); **: Highly Significant ($p < 0.01$)

Water use efficiency

Water use efficiency (WUE) exhibited the opposite trend to the water footprint, with higher values generally recorded under SPADIS than under CSEIS (Table 5). For durian, WUE increased from 0.00208 kg/L in 2023 to 0.00291 kg/L in 2024 under SPADIS, whereas CSEIS recorded values of 0.00136 and 0.00182 kg/L during the same period. These results indicate more efficient use of irrigation water under the solar-powered automated drip irrigation system.

A similar pattern was observed for mangosteen. WUE under SPADIS increased from 0.00250 kg/L in 2023 to 0.00306 kg/L in 2024. The corresponding CSEIS values are presented in Table 5. WUE differed significantly between the two irrigation systems for both crops and production years, with t-statistics ranging from 4.50 to 6.81 ($p < 0.01$). The coefficients of variation ranged from 14.68% to 22.22%, showing relatively low variation among the observations.

Overall, the SPADIS showed lower water footprints and higher water use efficiency than the conventional irrigation system throughout the study period.

Discussion

Economic implications of the solar-powered automated drip irrigation system

Although SPADIS required a higher initial investment than the conventional sprinkler emitter irrigation system, the additional cost was partly offset by lower operating expenses and higher economic returns. The higher installation cost was mainly associated with the photovoltaic panels, DC water

pump, automatic controller, and other equipment needed for the system. This observation is consistent with Doan (2017), who reported that solar-powered irrigation systems generally require greater initial investment because of the photovoltaic components, while the cost can be recovered over time through savings in operating expenses.

The lower operating cost of SPADIS was mainly related to the absence of electricity expenses during irrigation. Electricity was the largest annual operating expense of the conventional system, while SPADIS operated using solar energy. Maintenance costs were slightly higher because of the additional equipment, but the total operating cost was still considerably lower than that of the conventional system. Siripool (2023) also reported that reducing electricity consumption can improve the economic feasibility of solar-powered irrigation systems.

The economic difference between the two systems became clearer when crop income was included in the analysis. The combination of greater net returns and lower operating expenses reduced the estimated payback period from approximately 4.5 years when only operating-cost savings were considered to less than three years when additional crop income was included. These results indicate that the economic assessment of irrigation systems should consider both the initial investment and the long-term financial returns rather than focusing solely on installation costs.

For growers, the payback period is an important consideration when deciding whether to invest in a new irrigation system. Although SPADIS required a greater initial investment, the savings in annual operating costs and the additional crop returns may make the system more attractive, especially in areas where electricity costs are high. Based on the conditions of this study, SPADIS could be a practical option for perennial fruit production in areas with similar environmental and production conditions.

Water footprint and water use efficiency

SPADIS produced a lower water footprint than the conventional sprinkler emitter irrigation system for both durian and mangosteen. In other words, less water was needed to produce one kilogram of fruit with the automated drip system. This difference may be related to the way drip irrigation supplies water directly to the root zone, which can reduce evaporation and unnecessary wetting of the soil surface. More of the applied water can therefore remain available for plant growth and fruit production. Similar benefits have been reported for drip irrigation in fruit production, where more precise water application improved irrigation efficiency and reduced water consumption.

The water footprint decreased from 2023 to 2024 in both irrigation systems. The decrease may have been related to improved crop establishment and orchard management during the second production year. However, SPADIS had a lower water footprint than the conventional system in both years. This consistent difference suggests that the irrigation system itself had an important role in improving water-use performance, rather than the change being caused only by differences between the two production years.

Water use efficiency showed the opposite pattern, with higher values under SPADIS. This means that more fruit was produced for each unit of irrigation water applied. The higher efficiency may be explained by the ability of the automated drip system to supply water more precisely according to crop requirements. Maintaining suitable soil moisture while avoiding unnecessary water loss can improve the amount of water available for fruit production. Abdelhamid *et al.* (2025) reported similar results, showing that the combination of solar energy and automated irrigation improved irrigation performance and resource-use efficiency in horticultural production systems.

The water footprint and water use efficiency results together indicate that SPADIS made more efficient use of irrigation water than the conventional system. This is particularly relevant to fruit production because improving water-use efficiency can help reduce water consumption as freshwater resources become more limited. For the orchards examined in this study, the combination of solar energy and automated drip irrigation appears to offer a practical way to improve water management in perennial fruit production.

Study limitations and future perspectives

There are several limitations that should be considered when interpreting the results. The economic analysis was based on the production conditions, input prices, and climate of a commercial orchard in eastern Thailand. Differences in electricity prices, equipment costs, labor availability, and local environmental conditions could affect the economic performance of a similar irrigation system in other areas. The study also covered only two production years. A longer period of observation would provide a better understanding of equipment durability, maintenance needs, and economic performance over the operational life of the irrigation system.

Future studies could examine solar-powered automated drip irrigation with other fruit crops under different orchard ages, soil conditions, and climatic regions. It would also be useful to include life-cycle assessment and carbon footprint analysis, as well as further optimization of irrigation scheduling. These approaches could provide a broader view of the environmental and economic

performance of the technology over the longer term and help assess its suitability for sustainable fruit production in different production areas.

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Conflicts of interest

The authors declare no conflict of interest.

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