Comparative Cost Analysis of Vegetable Crops under Different Irrigation Systems in Small Scale Farms of Assam

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Abstract
This study evaluates the cost-effectiveness and water efficiency of four irrigation systems-Surface Drip Irrigation (SD), Sub-Surface Perforated Pipe Irrigation (SSPP), Flood Irrigation (FL) and Sub-Surface Drip Irrigation (SSD) for vegetable cultivation in small-scale farms in Assam, India. Focusing on cauliflower and turnip cabbage (kohlrabi), the analysis employs key metrics such as Irrigation Water Productivity (IWP), Benefit-Cost Ration (BCR), Net Present Value (NPV), Internal Rate of Return (IRR) and Payback Period (PBP). Results indicate that SSPP achieves the highest water efficiency (IWP: 159.26 kg/m³ for cauliflower), while SD and SSD offer superior economic returns with shorter payback periods (3.10–4.18 years) and higher NPVs. Despite its lower short-term profitability, SSPP emerges as a sustainable solution for Assam's water-scarce conditions during dry season from November to March. The study highlights the trade-offs between economic viability and water conservation, advocating for tailored irrigation strategies to enhance agricultural sustainability in fragmented landholdings. These findings underscore the need for strategic irrigation choices to balance productivity, cost-efficiency and water sustainability in fragmented agricultural landscapes like Assam.

Keywords: Cost-Benefit Analysis, Drip Irrigation, Subsurface Irrigation, Water Productivity, Small-Scale Farming, Irrigation Efficiency, Payback Period, Internal Rate of Return (IRR), Net Present Value (NPV), Sustainable Irrigation Systems.

1. Introduction

Assam has a diverse and extensive network of water bodies, it has lot of wetlands, lakes (locally known as beels) and major rivers. One of the most significant rivers, the Brahmaputra has an average annual discharge of about 20,000 cumec with an average dry season discharge of 4,420 cumec. The river basin covers approximately 70,634 sq.km of Assam [11]. These water bodies play an important role in the state's economy, ecology and cultural heritage. Sustainable irrigation is crucial for preserving soil health, conserving water resources and to reduce greenhouse gas emissions. However, to meet increasing food demand, farmers often use excessive fertilizers to increase crop yields. This practice adversely affects surrounding ponds, lakes and wetlands. Although, Assam receives abundant rainfall during monsoon (Kharif season), but experiences acute water shortages during Rabi season (October to March). Another major challenges for farmers is fragmented land holdings, which make efficient water use more difficult.

Frequent flooding further complicates irrigation, often damaging canal systems under Flow Irrigation System (FIS) and Lift Irrigation System (LIS), both of which require more financial investment. Therefore, efficient water management and sustainable agricultural practices are essential for Assam, considering the region's small, fragmented landholdings and frequent flooding events.

Cost-effective, water-efficient and scalable irrigation solutions, such as drip Irrigation can be adapted to diverse terrains and microclimates without requiring large infrastructure investment. Modern drip and subsurface irrigation technologies offer greater efficiency compared to traditional flood irrigation (FL), which remains widely used despite it's inefficiencies. This study evaluates the cost-benefit dynamics of four irrigation systems-Surface Drip Irrigation (SD), Sub-surface Perforated Pipe Irrigation (SSPP), Flood Irrigation (FL) and Sub-surface Drip Irrigation (SSD) in the cultivation of cauliflower and turnip cabbage. The analysis focuses on both agronomic performance (yield and water productivity) and economic indicators such as Benefit Cost Ratio (BCR), Net Present Value (NPV), Internal Rate of Return (IRR) and Payback Period (PBP). The study intends to assist farmers in selecting the most effective irrigation techniques to maximize crop yields while conserving water and minimizing input costs.

2. Literature Review

The following literatures relevant to the present study have been reviewed and the same are presented sequentially.

Romero, P et al. (2005) had conducted a cost-benefit analysis of regulated deficit irrigation (RDI) strategies under subsurface drip irrigation (SDI) for almond orchards in Southeastern Spain. It compared three treatments: T1 (full irrigation), SDI T2 (80% reduction during kernel-filling), and SDI T3 (80% reduction during kernel-filling and 50% post-harvest). SDI T3 saved 45% water with only a 17% yield reduction, achieving higher water use efficiency (0.28 kg/m^3) and profitability (10.46%) compared to T1. Despite higher initial costs, SDI T3 reduced operational expenses by 21%, making it economically viable, especially in water-scarce regions. The findings highlight SDI T3 as a sustainable and profitable alternative for almond cultivation in semiarid environments.

A.A. Siyal, M.Y. Hasini et al. (2011) conducted field experimental works using baked clay pipes carried out on an area 500 m^2 of a sandy loam at the Faculty of Agricultural Engineering, Sindh Agriculture University, Tandojam, Pakistan to assess viability of the porous clay pipe irrigation as a water conservation technique under arid climate. The experimental results showed that water saving up to 80% were achieved compared to that of surface irrigation methods. Also yield of vegetables irrigated with subsurface clay pipe irrigation was 5 to 16% more than that of obtained with conventional surface irrigation methods.

G. Peng, W. Bing et al. (2013) had discussed their field experimental works conducted using both Sub-surface irrigation (SUI) and flood irrigation (FLI) in a cherry orchard located in a hilly semi-arid area of Shandong Province in northern China to explore the influence of SUI on soil conditions and its water saving efficiency. Results showed that compared with FLI, the average water-saving efficiency of SUI was 55.6%, and SUI increased the irrigation productivity by 7.9-12.3 kg m^{-3} ha^{-1}.

B.S. Bhople, K. Adhikary et al. (2014) had described works carried out in the Department of Agricultural Engineering, Ahmadu Bello University, Zaria and Sindh Agricultural University on crop production and water use efficiency under sub-surface clay pipe irrigation system. Clay pipe segments were joined together and then buried in trenches and water was supplied from an overhead tank to distribute water within root zone. The experimental results revealed that water savings up to 80% were achieved and 5 to 16% more production was obtained compared to surface irrigation methods. They concluded that country like India which has a culture of pottery would initiate the employment in this field and generate the income.

Gunurathna M. H. J. P. et al. (2017) had investigated an Optimized Subsurface Irrigation System (OPSIS) to irrigate upland crops as an effort to identify super water-saving subsurface irrigation system that aim to use water more efficiently and effectively while minimizing costs so as to improve profitability and sustainability in the face of climate change. They concluded that OPSIS shows improved water-saving capabilities compared with other systems as it is able to function with minimum percolation, evaporation, and surface runoff. Moreover, the method is cost effective, durable, requires less land levelling and confirms high yields.

Subrata Gorain et al. (2018) evaluated the societal impacts of drip irrigation, focusing on water-intensive crops like sugarcane and banana. Key findings reveal substantial water savings (5,940 m^3/ha for sugarcane and 3,659 m^3/ha for banana) and energy efficiency (4,060 kWh/ha for sugarcane and 2,202 kWh/ha for banana), translating to significant monetary benefits (₹1.18 lakh/ha and ₹69.9k/ha, respectively). Social benefits also include off-farm employment (₹250/ha), while costs involve government subsidies (₹60k/ha) and forced well investments (₹37k/ha). With a social benefit-cost ratio of 2.08 (at a 10% discount rate), the study concludes that drip irrigation is economically and socially viable, justifying continued subsidies and suggesting solar energy integration for further efficiency gains. Published in *Economic Affairs*, the research underscores drip irrigation's role in sustainable water management in water-scarce regions.

Maneesha et al. (2019) evaluated the cost-benefit analysis of drip fertigation and flower induction in pineapple ('Giant Kew') cultivation in Goa, India. Fertigation with 100% or 75% of recommended NPK (RDN) combined with flower induction using Ethephon (25 ppm + Urea 2% + Sodium Carbonate 0.04%) yielded the highest net returns (₹1,396,412.28 and ₹1,383,500.47, respectively) and benefit-cost ratios (3.34 and 3.32). Drip fertigation reduced water and labor costs while improving yield uniformity. Despite higher initial setup costs, drip systems proved economically viable, especially with optimized nutrient and flowering treatments. The findings support drip fertigation and chemical flower induction as profitable practices for pineapple farmers in water-scarce regions.

Mamatha Prabhakar and H.D. Rank (2021) had conducted field study at RTTC, Junagadh Agricultural University, Gujarat during the Rabi 2018, to study the effectiveness of subsurface porous pipe irrigation system on crop production. The study revealed that the subsurface porous pipe irrigation system is an efficient and economically feasible irrigation method for sweet corn cultivation in semi-arid regions. They opined that the use of subsurface porous pipe irrigation system is a good option not only for water and fertilizer saving but also for improved crop production and yield.

Mohamed Abdel-Hamid et al. (2022) *had compared traditional drip/sprinkler systems with flexible* irrigation in Egypt, focusing on water and cost efficiency. Results show the flexible system reduces costs by **9% (drip) and 27% (sprinkler)** while saving **14% and 56% of water**, respectively, through features like return pumps and automated valves. Case studies on tomato (drip) and wheat (sprinkler) farms highlight lower labor expenses and higher irrigation efficiency (90% vs. 60–80%). The authors advocate for flexible systems to address Egypt's water scarcity, exacerbated by the Alnahda Dam, and suggest future research on quantifying water savings' economic value. Published in *Innovative Infrastructure Solutions*, the study underscores the system's potential for sustainable agriculture.

Wan, L., et al. (2024) evaluated subsurface drip irrigation (SSDI) combined with deficit irrigation for tomato cultivation in water-scarce Yunnan. Results show SSDI improved water productivity by 8.5–21.8%**,** enhanced fruit quality (e.g., soluble sugar increased by 7.3–21.6%), and boosted root growth (root/shoot ratio rose by 8–18%) compared to surface drip irrigation. Despite slightly lower yields, SSDI reduced water use by 14.6–22.6% and prolonged fruiting periods. The study highlights SSDI's potential to address seasonal droughts in monsoon regions, recommending its adoption for sustainable agriculture. Published in *Agronomy*, it provides actionable insights for water-stressed areas.

3. Methodology

In order to assess the effectiveness and feasibility of irrigation systems in small scale vegetable farming, the study employs a comprehensive methodology involving soil and water analysis, field experiment, crop management practices and performance evaluation. This systematic approach ensures the generation of reliable data aimed at enhancing agricultural productivity, water use efficiency and cost analysis.

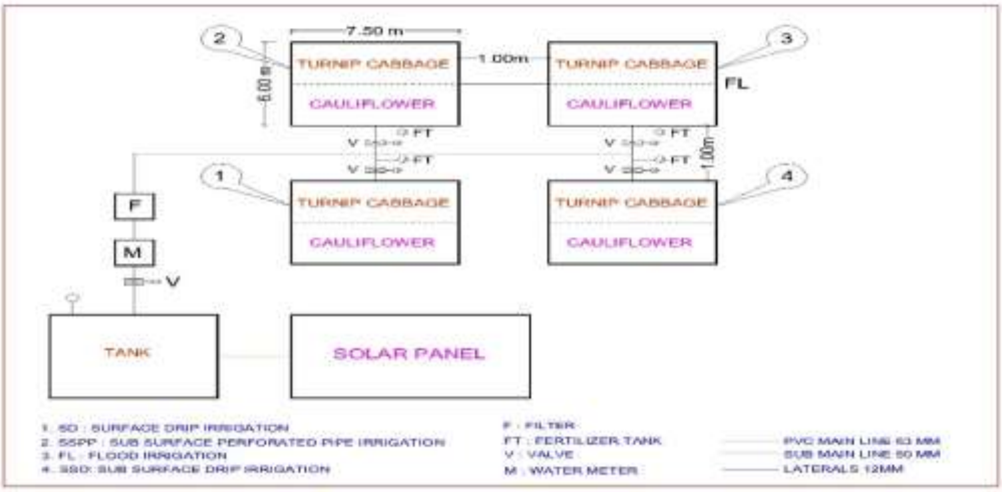
3.1 Study Area Description

Located on the western side of Guwahati city, adjacent to National Highway 37, the Horticultural Research Station, Kahikuchi is a commodity research station managed by Assam Agricultural University. The Krishi Vigyan Kendra (KVK) is also situated within the premises of this research station. Covering an area of 32 hectares, the station lies approximately 20 kilometers from the Guwahati Railway station and just 2 kilometers from the Lokapriya Gopinath Bordoloi International Airport. The station is positioned at an elevation of 64 meters above mean sea level, at latitude $26^0 06' 40''$ N and longitude $91^0 36' 34''$ E. The station falls within the Lower Brahmaputra Valley Agro-climatic Zone of Assam, which receives an average annual rainfall ranging from 1800 to 2000mm. The mean maximum temperature varies from 19^0 to 35^0C and the mean minimum temperature ranges between 8^0 and 27^0C.

3.2 Layout of Experimental Field

Four experimental blocks each measuring 7.50 m × 6.00 m (Figure 1) were prepared in the field. The blocks were separated by a 1.00 m wide trench and raised 15 cm above ground level. Each block was further divided into two smaller plots of 7.50 m × 3.00 m. Laterals were installed within these smaller plot at a spacing of 0.45 m for each of the irrigation system: Surface Drip Irrigation (SD), Sub-Surface Perforated Pipe Irrigation System (SSPP) and Sub-Surface Drip Irrigation (SSD). The remaining two smaller plots were used for surface irrigation. The experimental set up included a tube well, an overhead water tank to store water temporarily, a Solar Photo Voltaic Power Plant for energizing a submersible pump. The system also incorporated a filtration unit for water purification, a fertigation unit for nutrient delivery and a network of pipe lines for the drip irrigation, sub-surface drip, sub-surface perforated pipe irrigation system and flood irrigation equipped with control devices such as valves, a water meter and other necessary components to manage and monitor the irrigation systems effectively.

Figure 1: Experimental Field



3.3 A Description of Irrigation Systems

Surface Drip Irrigation (SD): Delivered water directly to the root zone of plants through a network of tubing and emitters placed on or near the soil surface. The system comprises a main pipe line (63mm PVC pipe, 4kg/cm^2), a sub-main line (50mm PVC pipe, 6 kg/cm^2) and laterals (12mm 2.5 kg/cm^2) along with control valves, water meters and emitters.

Sub-Surface Perforated Pipe Irrigation (SSPP): The system consists of a well distributed network of main line (63mm PVC pipe, 4kg/cm^2), sub-mains and perforated PVC laterals pipes (50 mm PVC pipe, 6 kg/cm^2) buried just below the root zone of crops along with valves to regulate both the quantity and the pressure of all water coming into the irrigation system. Subsurface perforated pipes release water to the soil while flowing by gravity, which is subsequently taken up by the crop due to capillarity.

Flood Irrigation (FL): Traditional method with water applied to the entire field or planting area. The system consists of main pipe line (63mm PVC pipe, 4kg/cm^2), sub-main line and laterals made up of 50mm dia PVC pipe, 6 kg/cm^2 and laid on the surface of the ground. The laterals have 6mm dia perforations at spacing 150 mm for the entire length. At the end of each lateral, there was an end cap to block the lateral line, thereby preserving water supply.

Subsurface Drip Irrigation (SSD): Delivered water directly to the root zone of plants through a network of tubing and emitters placed near the soil surface. These pipes release water directly into the soil, wetting the root zone of plants. The system consists of main pipe line (63mm PVC pipe, 4kg/cm^2), sub-main line (50mm PVC pipe, 6 kg/cm^2) and laterals (Excel +12mm 1.6 lph) along with control valves and water meters.

Ground water lifted to overhead tank from a tube well using submersible pump energized by solar power and stored in the overhead tank to create an elevation head. Water from the overhead tank flows through the distribution network consisting of mainline, sub-line and laterals under gravity. Subsurface perforated pipes released water to the soil, which is taken up by the crop due to capillarity. Performance of the system has been compared with surface drip, flood irrigation and sub-surface drip irrigation system.

3.4 Crop Selection and Planning

Crops Studied: Cauliflower and Turnip Cabbage (Kohlrabi)

Planting Details: The row-to-row and plant-to-plant spacing for cauliflower and turnip cabbage was standardized at 45 cm based on established agronomic recommendations. Both the crops have a moderately shallow, branched root system. The effective root zone depth typically ranges from 30 to 45 cm with the majority of roots concentrated in the top 40 cm of the soil. Perforated pipes were installed at a depth of 18 cm which is the effective root zone depth. Fertilization and pest control measures were uniformly applied across all irrigation systems to ensure consistency in crop management practices.

3.5 Data Collection

Soil samples were collected from auger pits at 30cm and 60cm soil depths. The soil contains high clay (44.55%), silt (38.35%) and low sand (17.10%). The mechanical analysis results shows that the soil falls in clay region when plotted in soil texture triangle. Analysis of nutrient contents indicates the soil is acidic in nature.

Well water was analysed and the results indicated no salinity issues, moderate total soluble solids, a normal pH range, absence bicarbonates, chlorides and a high sodium absorption ratio. Overall, the irrigation water quality was found to be within the acceptable range.

Water Application: The total amount of water applied in all the irrigation systems were measured using a water meter.

Yield Measurement: Mature crops were harvested and both their number and weight were recorded.

Soil Moisture Monitoring: Tensiometers were installed at root zone depths to monitor soil moisture conditions.

Some photographs illustrating the growth of cauliflower and turnip cabbage are provided in Figure 2.

Figure 2: Photographs showing growth of cauliflower and turnip cabbage

4. Results

The results were derived based on performance metrics for all selected crops. Data on costs were recorded including installation, operation and maintenance as well as benefits such as yield and water productivity for cauliflower and turnip cabbage. The total volume of water applied also documented. Based on these data, the key water use efficiency and cost indicators were calculated including Irrigation Water Productivity (IWP), Benefit Cost Ration (BCR), Net Present Value (NVP), Internal Rate of Return (IRR) and Pay Back Period (PBP). For the purpose of cost analysis, the market price for both cauliflower and turnip cabbage was considered to be Rs. 40.00 per kilogram. **Table 1** presents the performance and financial metrics for the four irrigation systems evaluated across cauliflower and turnip cabbage cultivation.

4.1 Irrigation Water Productivity (IWP)

Irrigation Water Productivity also known as water use efficiency in irrigation is defined as the crop yield per unit of water applied. It commonly expressed in units such as kg/m^3 or kg/litres. It gives a quantitative measure of how effectively water is used in crop production. Climate, soil type, crop selection, irrigation techniques and management practices are all variables that affect water productivity. Irrigation Water Productivity (IWP) is calculated as the ratio of the crop yield to the total seasonal irrigation water applied according to Al-Jamal *et al*. (2001) using the following formula.

$$\mathrm{IWP(kg/m^3)} = \frac{\mathrm{Yield(kg/ha)}}{\mathrm{Total\ water\ applied\ (kg/ha)}}$$

4.2 Benefit-Cost Ratio (BCR)

A cost-benefit analysis (CBA) of an irrigation project involves evaluating its feasibility and profitability by identifying, quantifying and comparing all associated costs and benefits. It helps determine whether the project's benefits outweigh its costs, ensuring a sound investment. CBA supports informed decision-making by assessing economic viability, comparing alternatives and promoting efficient resource use. The Benefit Cost Ratio is calculated using the formula:

$$BCR = \frac{\text{Present Worth of Benefits}}{\text{Present Worth of Cost}}$$

A BCR greater than 1 suggests a profitable investment, with higher values reflecting greater returns. The BCR decreases as the discount rate increases, reducing the present value of future benefits.

4.3 Net Present Value (NPV)

The Net Present Value (NPV) is a discounted cash flow measure that accounts for the time value of money. NPV represents the present value of the incremental net benefits or cash flows generated by a project. NPV is calculated by subtracting the present worth of the cost stream from the present worth of the benefit stream. The value of NPV can be computed by using the following formula:

$$NPW = \sum_{t=0}^{n} \frac{(B_t - C_t)}{(1+r)^t}$$

Where, B_t= Benefit in year t

C_t= Cost in year t

t=1,2,3…………….n

r= discount rate

n= number of years

The formal decision rule for NPW is:

- Accept a project if NPW ≥ 0 (i.e., benefits equal or exceed costs at the given discount rate).
- Among competing options, the project with the highest NPW is considered the most economically viable.

This method provides a comprehensive evaluation of project worth by integrating both cost and benefit streams over time.

4.4 Internal Rate of Return (IRR)

The Internal Rate of Return (IRR) is the discount rate at which the Net Present Value (NPV) of a project's incremental net benefit or cash flow stream becomes zero. In simple terms, IRR represents the maximum interest rate a project can afford to pay on the capital invested while still breaking even. There is no specific formula for computing the internal rate of return. However, the following formula can be used for determining the IRR, based on NPW

$$\text{IRR is the rate at which} : \sum \frac{(B_t - C_t)}{(1+IRR)^t} = 0$$

Where:

B_t = Benefit in year t, C_t = Cost in year t, t = Year, IRR = Internal Rate of Return

4.6 Pay Back Period

The payback period is the length of time from the beginning of a project until the net value of incremental income equals the total capital investment. In other words, it is the time required to recover the initial investment from the project's returns. Among various technological options, the one with the shortest payback period is generally considered the most economically viable for adoption. This method provides a quick, approximate way to compare investment options, especially when there is a high level of financial risk involved. Cumulative cash flows sheet is prepared and the year in which the cumulative cash flow turns positive for the first time is identified as the payback year. The payback period is calculated using the following formula

$$\text{Payback period} = \text{the last year with negative cash flow} + \frac{\text{Amount of cash flow at the end of that year}}{\text{Cash flow during the year after that year}}$$

Table 1: Financial and Performance metrics

Crop	Indicators	SD	SSPP	FL	SSD
Cauliflower	**Irrigation Water Productivity (kg/m3)**	142.48	159.26	63.75	151.11
	Benefit-Cost Ratio (BCR)	1.21:1	1.13:1	1.25:1	1.22:1
	Net Present Value (NPV)(Lakh)	23.85	15.96	27.66	24.87
	Internal Rate of Return (IRR)	41.00%	18.10%	47.44%	43.65%
	Payback Period (PBP) (Years)	4.18	9.81	3.10	3.96
Turnip Cabbage	**Irrigation Water Productivity (kg/m3)**	67.80	80.90	32.80	71.10
	Benefit-Cost Ratio (BCR)	1.19:1	1.00:1	1.28:1	1.19:1
	Net Present Value (NPV)(Lakh)	11.55	0.24	15.84	11.85
	Internal Rate of Return (IRR)	26.16%	10.13%	32.62%	27.20%
	Payback Period (PBP) (Years)	3.33	9.28	3.06	3.27

5. Graphical Insights

Based on the financial and performance metrics table for all four irrigation systems and the two vegetables- cauliflower and turnip cabbage, corresponding graphs have been created. These graphs display various metrics along the Y-axis, with the four irrigation systems represented on the X-axis.

Figure 3: Irrigation Water Productivity for cauliflower and turnip cabbage

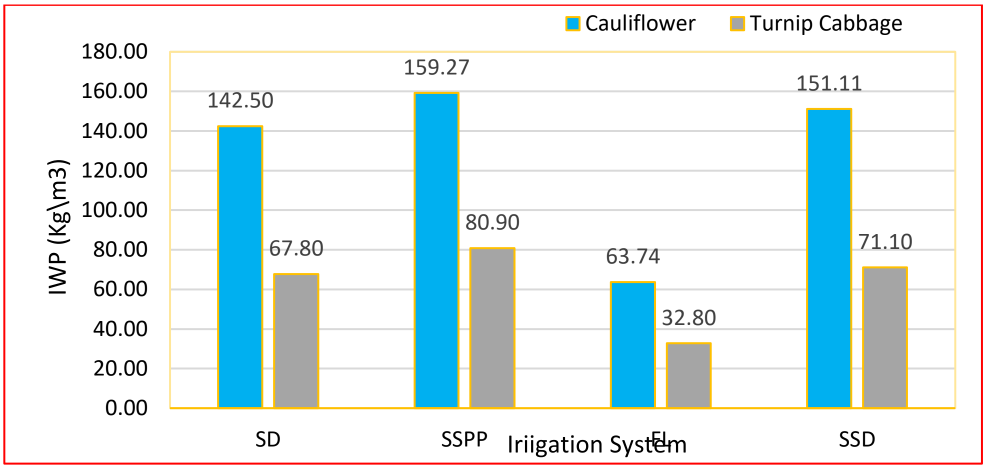


Figure 4 : Benefit Cost Ratio for cauliflower and turnip cabbage

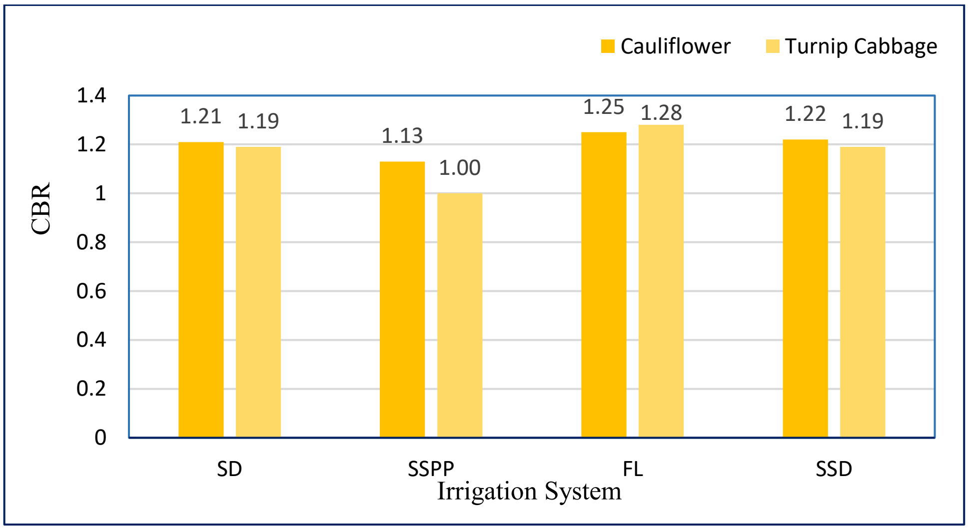


Figure 5 : Net Present Value of cauliflower and turnip cabbage.

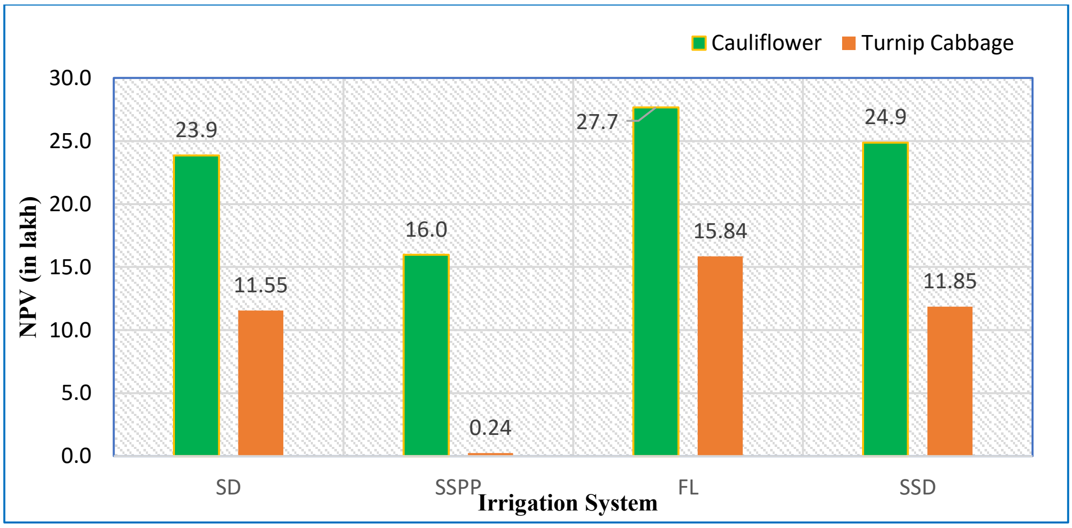


Figure 6 : Internal Rate of Return of cauliflower and turnip cabbage

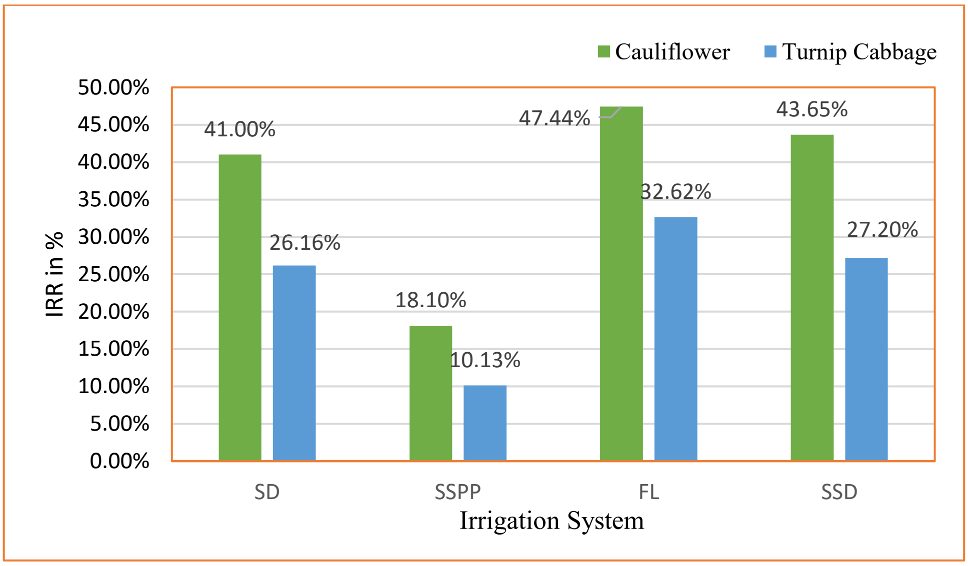
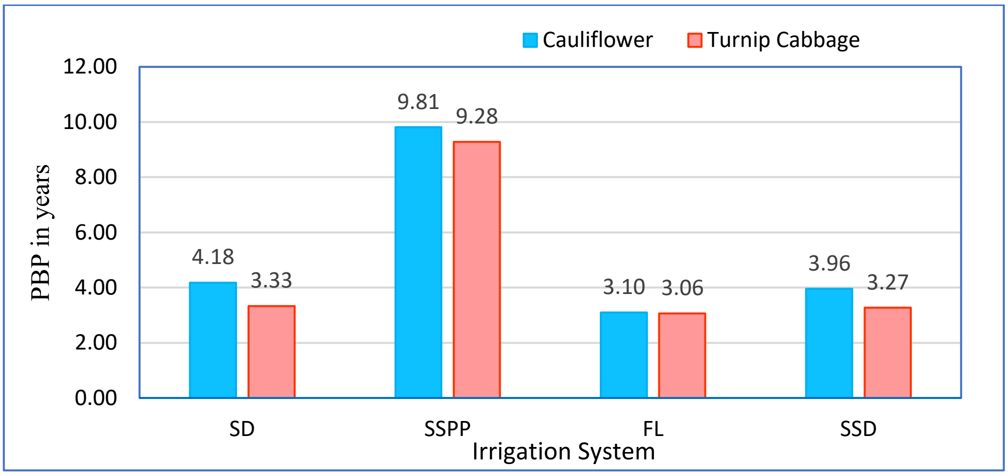


Figure 7 : Payback Period for cauliflower and turnip cabbage



6. Key Observations

6.1 Irrigation Water Productivity (IWP)

- Cauliflower demonstrates higher Irrigation Water Productivity (IWP) than turnip cabbage across all methods, indicating superior water use efficiency. Under Sub-surface Perforated Pipe Irrigation, cauliflower achieves an IWP of 159.26 kg/m^3 compared to IWP of 80.9 kg/m^3 for turnip cabbage.
- Under the Flood Irrigation method, both crops exhibit the lowest Irrigation Water Productivity (IWP) compared to the other three systems- 63.75 kg/m^3 for cauliflower and 32.8 kg/m^3 for turnip cabbage. While SSPP maximizes water efficiency (IWP), it delivers relatively poor financial returns with lower NPV and IRR. In contrast, Flood Irrigation (FL) sacrifices water efficiency but offers significantly better profitability.
- For turnip cabbage, Sub-Surface Drip Irrigation (SSD) represents a balanced choice offering moderate Irrigation Water Productivity (IWP) and satisfactory Net Present Value (NPV).

6.2 Benefit Cost Ratio (BCR) :

- Flood Irrigation (FL) yields the highest Benefit-Cost Ratio (CBR) for both crops 1.25:1 for cauliflower and 1.28: 1 for turnip cabbage confirming its economic advantage.

- SSPP records the lowest Benefit-Cost Ratio 1.13:1 for cauliflower and 1:1 for turnip cabbage, making it the least economically viable option among the irrigation methods evaluated.
- SSPP's modular design is ideal for Assam's small, fragmented farms. Unlike FL, which requires uniform land leveling and canal infrastructure vulnerable to floods, SSPP's perforated pipes can be tailored to irregular plots, reducing installation and maintenance costs over time.

6.3 Crop Performance Overview:

- Cauliflower consistently outperforms turnip cabbage across all evaluated metrics including higher Net Present Value (NPV), Internal Rate of Return (IRR), Benefit-Cost Ratio (BCR) and shorter Payback Period (PBP) making it the more profitable and efficient crop.
- Turnip cabbage demonstrates weaker financial viability particularly under the SSPP system, where its NPV drops to nearly zero.

7. Conclusions

The study highlights the critical balance between economic viability and water efficiency in irrigation systems for small-scale vegetable farming in Assam. While Surface Drip Irrigation (SD) and Sub-Surface Drip Irrigation (SSD) systems deliver faster financial returns and higher profitability, Sub-Surface Perforated Pipe Irrigation (SSPP) excels in water conservation, making it ideal for long-term sustainability in water-scarce regions. Flood Irrigation (FL) though marginally cost-effective, proves inefficient in water use. For Assam's fragmented farms and variable climate adopting SSPP or SSD systems is recommended to optimize resource use and ensure agricultural resilience. Policymakers and farmers should prioritize these technologies to align economic goals with environmental sustainability, fostering resilient agricultural practices in the region.

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