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Economic Analysis of Soilless Media and Deficit Fertigation Strategies in Greenhouse Tomato Production in Wet and Dry Seasons

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ABSTRACT

Greenhouse tomato production in Ghana is expanding, yet high input costs, particularly imported soilless substrates and irrigation, limit profitability. This study evaluated the economic viability of locally formulated soilless media under different deficit fertigation regimes for greenhouse tomato production across wet and dry seasons from May to October 2023 and October 2023 to March 2024, respectively. The experiment utilized a split-plot design with three deficit fertigation (DF) (40%, 20%, and 0% DF) as the main plot and four soilless media: 100% Cocopeat (CP100), 60% Cocopeat + 40% Rice husk biochar (CP60 + RHB40), 40% Cocopeat + 40% Sawdust + 20% Sorghum haulm biochar (CP60 + SD40 + 20% SHB20), and 60% Cocopeat + 40% Rice husk (CP60 + 40% RH40) as the sub-plot treatments utilizing four replications. Profitability was assessed using the Benefit-Cost Ratio (BCR) and Marginal Rate of Return (MRR). The results showed that yield and financial returns were significantly influenced by the media type and deficit fertigation. Tomato yield increased with decreasing deficit fertigation in both seasons. Wet-season yields ranged from 32.7 to 72.0 kg m^{-2}, while dry-season yields declined to 20.7-71.8 kg m^{-2}. Across all fertigation regimes, the CP60 + RHB40 consistently produced the highest yields and revenues. At 0% deficit fertigation, CP60 + RHB40 recorded the highest BCR in both the wet (1.93) and dry (2.20) seasons, outperforming 100% Cocopeat (1.47 and 1.78, respectively). Partial budget analysis showed that replacing 40% of cocopeat with rice husk biochar under 40% DF reduced substrate costs by approximately 20-30% and generated exceptionally high marginal returns, with a 17501% marginal rate of return in the wet season and 461.5% under 0% DF in the dry season. Media containing raw rice husk consistently recorded the lowest economic returns. The results demonstrate that locally available rice husk biochar can partially replace imported cocopeat while enhancing profitability. Adoption of CP60 + RHB40 with 40% to 20% DF offers a cost-effective strategy for farmers and supports sustainable greenhouse intensification aligned with SDGs 2, 6 and 12.

Keywords: Soil-less media, greenhouse, Tomato, Cocopeat, Biochar, Benefit-Cost Analysis, Marginal rate of return

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INTRODUCTION

Soilless media are developed to address challenges such as non-availability of fertile soils, soil-borne diseases, and soil salinity among others (Ghehsareh et al., 2011). Cocopeat, rice husk, rice husk biochar, sawdust, and sorghum haulm biochar are among the soilless media that have been investigated because of their potential use as substrates for growing media (Khan et al., 2024; Banitalebi et al., 2024; Sharma and Chhabra, 2024).These substances do not only promote plant development but also solve the environmental and financial issues related to the use of conventional substrates (Adekiya et al., 2022; Li et al., 2023; Sarma et al., 2024). Cocopeat, a common substrate in soilless culture, is recognized for its high-water holding capacity (WHC) and low bulk density, which promotes plant growth and development (Adekiya et al., 2022). Rice Husk enhances substrate aeration and it is light in weight. It improves plant performance and nutrient retention when mixed with cocopeat (Adekiya et al., 2022). By increasing microbial activity and cation exchange capacity (CEC), biochar made from rice husks improves soil health (Adekiya et al*.,* 2022). Sawdust, frequently added to blends can help retain moisture, but because it is high in carbon, it may need additional nutrients (Gruda et al., 2021). Like rice husk biochar, sorghum haulm biochar improves soil structure and retains nutrients, which supports sustainable farming systems (Sabatino, 2020).

Tomato (*Solanum lycopersicum*) cultivation is crucial for global agriculture, significantly impacting economies and enhancing food security (Govindasamy et al*.,* 2025). As a major source of vitamins and minerals, tomatoes are among the most widely grown vegetables, with global production reaching approximately 182 million metric tons in 2020 (Canton, 2021). It plays a vital role in various culinary products and is essential for the livelihoods of millions of farmers, contributing to agricultural GDP and job creation in both developed and developing nations (Kumar et al*.*, 2020). Additionally, the tomato industry supports related sectors such as machinery and agrochemicals, further amplifying its economic significance (Kaundal et al*.*, 2024).

There are a number of obstacles that traditional soil-based farming methods are faced with. These include pest infestations, water scarcity, and soil deterioration, which can negatively impact both yield and quality of produce (Kumar et al., 2020). Soilless cultivation methods like hydroponics and aeroponics have become practical substitutes in response to these challenges. As evidenced by numerous pre-harvest techniques that improve crop quality and efficiency prior to harvest, it is possible to precisely manipulate environmental parameters and nutrient supply in controlled environment agriculture to achieve greater yields and faster growth rates (Zhao et al., 2024). Furthermore, the potential for tomato production can be increased by implementing soilless systems in urban areas and areas with limited arable land (Al-Khazaali et al*.*, 2021). Gumisiriza et al. (2022) reported that a review of hydroponic system for urban vegetable farming showed encouraging financial results, such as a net present value and a payback period of roughly eight months, suggesting that it could improve food security and incomes of farmers in developing areas.

In addition to substrate selection, deficit fertigation is a critical determinant of productivity and economic returns in greenhouse tomato production. Increased fertigation improves nutrient availability, stabilizes root-zone moisture, and enhances nutrient uptake efficiency, often leading to higher yields (Bortolini and Tolomio, 2019; Yang et al., 2017; Bian et al., 2024). However, higher fertigation also increases irrigation, energy, and labor costs, making economic optimization essential (Koech and Langat, 2018). In light of growing water scarcity and expanding agricultural needs, optimizing irrigation is essential for preserving water resources and cutting agricultural expenses. Effective irrigation techniques contribute significantly to sustainable water management in addition to increasing crop yields. In areas where water resources are scarce, optimizing irrigation can result in large water savings (Allen et al., 2011).

One important factor driving the acceptance of soilless cultivation by farmers is its economic viability. Benefit-cost analysis (BCA) is a useful technique that helps stakeholders make well-informed decisions by evaluating the financial effects of various agricultural methods (Boardman et al., 2020). In analyzing the Benefit Cost Ratio (BCR) of different soilless media and deficit fertigation for greenhouse tomato production across dry and wet seasons, several studies provide valuable insights. Yang et al. (2024) demonstrated that continuous irrigation with a specific emitter discharge (0.26 L h^{-1}) significantly improved yield and root development compared to intermittent irrigation methods, suggesting that deficit fertigation plays a crucial role in optimizing productivity. Al-Khateeb et al. (2024) emphasized that although soilless cultivation approaches conserve water and improve water productivity, soil-based approaches produced larger profits as a result of increased fruit production, suggesting a trade-off between economic returns and water efficiency. Additionally, Vaddula and Singh (2023) discovered that fertigation in conjunction with a consistent irrigation approach maximized yield and net returns, highlighting the need for nutrient management in conjunction with irrigation techniques.

In agricultural operations, cost analysis is essential because it helps with decision-making, improves the efficiency of resource allocation, assesses the viability of projects, and ultimately produces better economic results (Ward and Deren, 1991). In order to ensure sustainable agricultural practices, maximize resource allocation, and increase financial viability and economic growth in the industry, cost analysis is essential (Gittinger, 1971). To ensure effective resource allocation and maximize the long-term benefits of soil conservation initiatives, cost analysis is essential to agricultural operations. It assesses the economic viability of conservation approaches (Zhou et al., 2009). In agricultural operations, cost analysis is essential because it allows for well-informed decision-making through benefit-cost comparisons, effective resource allocation, and the optimization of research investment returns (Marshall and Brennan, 2001). The Justification for this study lies in the potential of soilless cultivation techniques to enhance water productivity and economic viability, thereby improving food security and sustainability in agricultural practices.

The general objective of the study was to determine the profitability of cocopeat-based media in containerized system with specific focus on assessing the profitability of deficit fertigation and soilless media. The specific objectives were to determine profitability of the different deficit fertigation or soilless media used in the experiments.

MATERIALS AND METHODS

Experimental site

The study was a two-season experiments conducted from May to October 2023 (Wet season) and repeated from October 2023 to March 2024 (Dry season). It was conducted in a Gothic arc greenhouse, 480 m^2 (48 m x 10 m) with a north-south orientation. The trials were sited at Busunu in the West Gonja Municipal in the Savannah region of Ghana. The precise latitude and longitude are 9.1632442 and -1.5099705, respectively. The greenhouse's structure consists of galvanized poles with a 50-mesh net covering the sides. The roof is covered with a Solarig covering that blocks UV rays, diffuses 60% of the light, and has an anti-drip function to keep plants from dripping. The Don F1 indeterminate tomato variety used for this experiment was transplanted after being in the nursery for 21 days.

Experimental treatment

The experiment was a 3x4 factorial laid in a split-plot design with four replications involving deficit fertigation and soilless media (Table 1). The main plot factor was the deficit fertigation at 3 levels and the sub-plot factor was the soilless media having four levels. A sub-plot experimental unit consisted of one row of size 5 m × 0.3 m containing sixteen tomato plants. In all, there were 48 experimental units in the four replications.

Table 1: Split plot design showing the treatment combinations used in the study

Main plot treatment		**Sub plot treatment**
Deficit Fertigation (% DF)	**Daily Fertigation**	**Soilless Media Composition**
40	Three times	G1 (100 % Cocopeat (CP_{100}))
20	Four times	G2 (60 % Cocopeat (CP_{60}) + 40 % Rice husk biochar (RHB_{40})
0	Five times	G3 (40% Cocopeat (CP_{40}) + 40% Sawdust + 20% Sorghum haulm biochar (SHB_{20}))
		G4 (60% Cocopeat (CP_{60}) + 40% Rice husk (RH_{40}))

Data collection

Data were collected on yield and cost of production at the two seasons in a greenhouse experiment. The total yield of tomatoes was measured when they were ripened, and marketable fruits were sorted based on size and physical quality. The revenue obtained from the sale was based on the yield and prevailing market price at the time of harvest in September to October 2023 (wet season) and February to March 2024 (Dry season) The costs associated with the acquisition of soilless media, irrigation, fertilization and discounted cost of the greenhouse were used to perform a benefit-cost analysis. In order to conduct a comprehensive economic analysis of the various deficit fertigation and media composition used as treatments, a range of analytical techniques including partial budget analysis, dominance analysis, and marginal analysis were employed to narrow on deficit fertigation and soilless media that will bring greater economic returns. This analysis is distinct from full budget analysis as it only considers the incremental changes rather than the entire budget. Partial budget specifically computes the variable costs and net benefits associated with each treatment within an experimental framework. Subsequent to the partial budget analysis, a dominance analysis was carried out.

This procedure excluded treatments that result in greater additional costs with lesser net benefits in comparison to treatments that incur the same or lower additional costs from further consideration. Marginal analysis encompasses the evaluation of marginal (incremental) benefits against marginal (incremental) costs associated with transitioning from one treatment to an alternative one. It requires the computation of the following:

Net Benefit Analysis

The net benefits were determined through the following calculations:

$$Net\ Benefits\ (NB) = Gross\ Benefits\ (GB) - Total\ Variable\ Cost\ (TVC) \ldots\ldots \quad \ldots\ldots \text{Eqn 1}$$

Where GB =Output (Yield) × Output price, TVC =Sum of variable cost.

Marginal Rate of Return (MRR)

The most straightforward method to articulate the association between marginal net benefits and marginal costs is to compute the marginal rate of return (MRR) in the following manner:

$$MRR = \frac{\Delta NB}{\Delta TVC} \times 100 \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Eqn 2}$$

Where $\Delta NB = change\ in\ net\ benefits\ (marginal\ benefits)$ and $\Delta TVC = change\ in\ total\ costs\ that\ vary\ (marginal\ variable\ cost)$.

Benefit Cost Ratio (BCR)

$$Benefit\ Cost\ Ratio\ (BCR) = Benefit\ (B)/Total\ \ Cost\ (TC) \ldots\ldots\ldots\ldots \ \ldots\ldots\ldots\ldots \text{Eqn 3}$$

Data Analysis

Yield data were subjected to analysis of variance using statistical software GenStat version 12. The treatment means were separated and compared using the Duncan Multiple Range Test at a 5% probability level. The benefit-cost analysis and partial budget analysis were done using Microsoft Excel.

RESULTS

Cost of acquisition of soilless media

The materials used in the preparation of the soilless media were cocopeat made from coconut husk, rice husk obtained after milling paddy rice, sorghum haulm obtained as waste after processing the panicle and saw dust from timber factory. The rice husk was used as raw or charred to obtain rice husk biochar, the sorghum haulm too was charred. The materials that were used in the different media composition and the cost of each ingredient used is indicated (Table 2)

Table 2: Total cost of acquiring the different soilless media for each growing season

	Material	Quantity (bag)	Unit Price (GH₵)	Transport Cost (GH₵)	Total Cost (GH₵)
1	Sawdust	6	5.00	50.00	80.00
2	Cocopeat	60	30.00	700.00	2500.00
3	Rice husk	6	15.00	50.00	140.00
4	Rice husk biochar	12	15.00	50.00	230.00
5	Sorghum Haulm Biochar	6	5.00	200.00	230.00

Revenue from sales of marketable tomato in the wet and dry seasons

Table 3 summarizes the revenue generated from the wet and dry seasons cropping of tomatoes using different soilless media and deficit fertigation. The result revealed that yield increased with decreasing deficit fertigation and in each deficit fertigation 60% Cocopeat+40% Rice husk biochar gave the greatest yield which was not statistically different from when 100% Cocopeat was used.

The revenue was obtained by multiplying the yield by GH₵ 30.00 per kg, the prevailing market price. The revenue obtained followed the same pattern as the fruit yield (Table 3). The substitution of 40% of the Cocopeat with rice husk biochar gave higher revenue in any fertigation schedule. In contrast, when raw rice husk substituted for 40% Cocopeat the yield and revenue were decreased in all the fertigation schedules (Table 3).

The assessment of the dry season trial indicates that the revenue per planting was generally lower compared to the wet season due to lower yield (Table 3). At 40% and 20% deficit fertigation, 60% Cocopeat+40% Rice husk biochar always gave the highest fruit yield which resulted in the highest revenue per planting though the revenue was similar to that of 100% Cocopeat. Conversely, treatment 60% Cocopeat + 40% Rice husk recorded the least yield and revenue under 40% and 0% DF which resulted in a corresponding lowest revenue per planting (Table 3).

Table 3: Revenue derived from wet and dry season cropping while using different soilless media and deficit fertigation. A kilogram of fresh tomato was sold at GH₵ 30.00

		Wet season		Dry season	
Deficit Fertigation (% DF)	**Media Composition**	**Yield (Kg/m^2 /season)**	**Revenue per season (GH₵)**	**Yield (Kg/m^2 /season)**	**Revenue per season (GH₵)**
40	CP_{100}	47.79	1433.69	34.92	1047.72
40	$CP_{60} + RHB_{40}$	48.11	1443.34	37.09	1112.63
40	$CP_{40} + SD_{40} + SHB_{20}$	35.09	1052.60	23.86	715.68
40	$CP_{60} + RH_{40}$	32.67	980.24	20.72	621.73
20	CP_{100}	60.78	1823.47	56.45	1693.44
20	$CP_{60} + RHB_{40}$	57.79	1733.75	61.62	1848.67
20	$CP_{40} + SD_{40} + SHB_{20}$	36.76	1102.77	44.32	1329.55
20	$CP_{60} + RH_{40}$	43.45	1303.45	47.87	1436.20
0	CP_{100}	66.51	1995.21	71.84	2155.10
0	$CP_{60} + RHB_{40}$	71.97	2159.22	71.30	2138.98
0	$CP_{40} + SD_{40}$ + 20% SHB_{20}	60.78	1823.47	57.96	1738.8
0	$CP_{60} + RH_{40}$	50.72	1521.49	56.31	1689.41

NB: 100% Cocopeat (CP_{100}), 60% Cocopeat + 40% Rice husk biochar ($CP_{60} + RHB_{40}$), 40% Cocopeat + 40% Sawdust + 20% Sorghum haulm biochar ($CP_{60} + SD_{40}$ + 20% SHB_{20}), and 60% Cocopeat + 40% Rice husk (CP_{60}+ 40% RH_{40})

Cost of using different soilless media and fertigation during the wet season

Provision of irrigation, media formulation and fertilization constituted variable cost. The cost of 40% deficit fertigation was GH₵ 271.06 and further reduction to 20% incurred a cost of GH₵ 90.35 (Table 4). The cost of media was higher in 100% Cocopeat. The substitution of 40% of the Cocopeat with rice husk biochar reduced the cost which was similar to the substitution of 60% Cocopeat with sawdust and sorghum haulm biochar.

The substitution of 40% Cocopeat with uncharred rice husk reduced the cost by about 41%. Cost of fertilizer was the same for all media.

The total discounted cost of the greenhouse facility was GH₵3750 per year which was split into GH₵2500.00 for wet season and GH₵1250.00 for the dry season cropping and this cost was further shared among the treatments by dividing the discounted cost by the 12 treatments (Table 4). The total cost ranged between GH₵939.74 and GH₵ 1355.77.

Table 4: Cost of using different soilless media and deficit fertigation during the wet season

Deficit fertigation	Media Composition	Cost of Irrigation (GH₵)	Cost of Media (GH₵)	Cost of Fertilizer (GH₵)	Total Variable Cost (GH₵)	Discounted cost of the Greenhouse	Total Cost
40	CP_{100}	271.06	1083.33	186.06	1026.97	208.33	1235.30
40	CP_{60} + RHB_{40}	271.06	730.00	186.06	791.41	208.33	999.74
40	CP_{40} + SD_{40} + SHB_{20}	271.06	726.67	186.06	789.91	208.33	999.52
40	CP_{60} + RH_{40}	271.06	640.00	186.06	731.41	208.33	939.74
20	CP_{100}	361.41	1083.33	186.06	1087.20	208.33	1295.53
20	CP_{60} + RHB_{40}	361.41	730.00	186.06	851.65	208.33	1059.98
20	CP_{40} + SD_{40} + SHB_{20}	361.41	726.67	186.06	849.43	208.33	1057.76
20	CP_{60} + RH_{40}	361.41	640.00	186.06	791.65	208.33	999.98
0	CP_{100}	451.76	1083.33	186.06	1147.44	208.33	1355.77
0	CP_{60} + RHB_{40}	451.76	730.00	186.06	911.88	208.33	1120.21
0	CP_{40} + SD_{40} + 20% SHB_{20}	451.76	726.67	186.06	909.66	208.33	1117.99
0	CP_{60} + RH_{40}	451.76	640.00	186.06	851.88	208.33	1060.21

Cost of using different soilless media and deficit fertigation during the dry season

The costs associated with using different soilless media and deficit fertigation during the dry season is shown in table 5. The provision of irrigation, media formulation, and fertilizer application constituted the variable costs for each treatment.

For a deficit fertigation of 40%, the total variable cost for using 100% Cocopeat was GH₵ 1001.37, while the cost for the 60% Cocopeat and 40% Rice husk biochar (60% CP+40% RHB) treatment was lower. As the deficit fertigation decreased to 20%, the total variable costs increased. At 0% DF, the costs further escalated (Table 5).

The cost of media was highest for the 100% Cocopeat treatment, while the substitution of 40% of cocopeat with rice husk biochar significantly reduced the overall costs (Table 5). The cost of fertilizer remained constant across all treatments.

Additionally, the discounted cost of the greenhouse facility was GH₵ 1250 for the dry season cropping which was partitioned into GH₵ 104.17 per treatment. The total costs for the various treatments ranged from GH₵809.98 to GH₵ 1208.94 (Table 5).

Table 5: Cost of using different soilless media and deficit fertigation during the dry season

Deficit Fertigation	Media Composition	Cost of Irrigation (GH₵)	Cost of Media (GH₵)	Cost of Fertilizer (GH₵)	Total Variable Cost (GH₵)	Discounted cost of greenhouse (GH₵)	Total Cost (GH₵)
40	CP_{100}	271.06	1083.33	186.06	1001.37	104.17	1105.54
40	$CP_{60} + RHB_{40}$	271.06	730.00	186.06	765.81	104.17	869.98
40	$CP_{40} + SD_{40} + SHB_{20}$	271.06	726.67	186.06	763.59	104.17	867.76
40	$CP_{60} + RH_{40}$	271.06	640.00	186.06	705.81	104.17	809.98
20	CP_{100}	361.41	1083.33	186.06	1053.07	104.17	1157.24
20	$CP_{60} + RHB_{40}$	361.41	730.00	186.06	817.52	104.17	921.69
20	$CP_{40} + SD_{40} + SHB_{20}$	361.41	726.67	186.06	815.29	104.17	919.46
20	$CP_{60} + RH_{40}$	361.41	640.00	186.06	757.52	104.17	861.69
0	CP_{100}	451.76	1083.33	186.06	1104.77	104.17	1208.94
0	$CP_{60} + RHB_{40}$	451.76	730.00	186.06	869.22	104.17	973.39
0	$CP_{40} + SD_{40}$ + 20% SHB_{20}	451.76	726.67	186.06	867.00	104.17	971.17
0	$CP_{60} + RH_{40}$	451.76	640.00	186.06	809.22	104.17	913.39

Benefit-Cost Analysis of producing tomatoes in a greenhouse during the wet season

Table 6 derived from tables 3 and 4 presents the Benefit-Cost Analysis (BCA) of different soilless media combinations at various deficit fertigation during the wet season.

Based on the BCR values, several treatments were identified as favourable, with a BCR above 1.0, indicating that the benefit exceeded the cost. The treatment involving 60% Cocopeat and 40% Rice husk consistently produced the lowest BCR under all the fertigation deficits. In contrast, the combination of 60% Cocopeat and 40% Rice husk biochar (60% CP+40% RHB) at 40% deficit fertigation achieved a BCR of 1.44 exceeding that of the greenhouse industry recommended medium, the 100% Cocopeat.

The analysis further revealed that as the deficit fertigation decreased, the BCR generally improved across most treatments. For instance, the treatment 60% Cocopeat+40% Rice husk biochar at 0% deficit fertigation achieved a BCR of 1.93, a rise from 1.44 when deficit fertigation was 40% (Table 6).

Table 6: Benefit-cost analysis of using different soilless media at different deficit fertigation during the wet season

Deficit fertigation	Media Composition	Total Cost (GH₵)	Revenue or Benefit (B) (GH₵)	Benefit-Cost Ratio
40	CP_{100}	1235.30	1433.69	1.16
40	$CP_{60} + RHB_{40}$	999.74	1443.34	1.44
40	$CP_{40} + SD_{40} + SHB_{20}$	999.52	1052.60	1.06
40	$CP_{60} + RH_{40}$	939.74	980.24	1.04
20	CP_{100}	1295.53	1823.47	1.41
20	$CP_{60} + RHB_{40}$	1059.98	1733.75	1.64
20	$CP_{40} + SD_{40} + SHB_{20}$	1057.76	1102.77	1.04
20	$CP_{60} + RH_{40}$	999.98	1303.45	1.30
0	CP_{100}	1355.77	1995.21	1.47
0	$CP_{60} + RHB_{40}$	1120.21	2159.22	1.93
0	$CP_{40} + SD_{40}$ + 20% SHB_{20}	1117.99	1823.47	1.63
0	$CP_{60} + RH_{40}$	1060.21	1521.45	1.44

Benefit-Cost Analysis of using different soilless media at different deficit fertigation during the dry season

The benefit-cost analysis of different soilless media under three deficit fertigation levels during the dry season is shown in table 7. The economic performance varied considerably across fertigation regimes and media compositions, as reflected in total production costs, revenue, and benefit-cost ratios (BCR). At 40% deficit the 60% Cocopeat + 40% Rice husk biochar medium recorded the highest BCR indicating profitability under severe deficit fertigation (Table 7).

In contrast, 100% CP, 60%CP + 40%RH and the media containing 40% CP + 40% SD + 20% SHB produced BCR values below 1.0. Under 20% deficit fertigation, all media recorded BCR values greater than 1.0, demonstrating improved profitability relative to 40% DF.

The highest BCR was observed for the 60% CP + 40% RHB medium, followed by 60% CP + 40% RH. 100% CP and 40% CP + 40% SD + 20% SHB produced similar BCR. Similar trend among the media was seen at full fertigation (0% DF). The BCR values were highest across all media types. The 60% CP + 40% RHB treatment again recorded the maximum BCR of 2.20, while other media combinations achieved BCR values ranging from 1.78 to 1.85 (Table 7).

Table 7: Benefit-Cost Analysis of using different soilless media at different deficit fertigation during the dry season

Deficit Fertigation (DF)	Media Composition	Total Cost (GH₵)	Revenue or Benefit (B) (GH₵)	Benefit-Cost Ratio
40	CP_{100}	1105.54	1047.72	0.95
40	CP_{60} + RHB_{40}	869.98	1112.63	1.28
40	CP_{40} + SD_{40} + SHB_{20}	867.76	715.68	0.82
40	CP_{60} + RH_{40}	809.98	621.73	0.77
20	CP_{100}	1157.24	1693.44	1.46
20	CP_{60} + RHB_{40}	921.69	1848.67	2.01
20	CP_{40} + SD_{40} + SHB_{20}	919.46	1329.55	1.45
20	CP_{60} + RH_{40}	861.69	1436.20	1.67
0	CP_{100}	1208.94	2155.10	1.78
0	CP_{60} + RHB_{40}	973.39	2138.98	2.20
0	CP_{40} + SD_{40} + 20% SHB_{20}	971.17	1738.8	1.79
0	CP_{60} + RH_{40}	913.39	1689.41	1.85

Benefit-Cost Ratio of different deficit fertigation at both wet and dry seasons

The results showed that in both wet and dry seasons, the BCR increased with decreasing deficit fertigation (Figure 1). At 40% DF, BCR for wet season was nominally higher than that of the dry season, the BCR for the dry season did not break even. However, from 20% to 0% DF the dry season BCR did not only become profitable but overtook that of the wet season.

The increase of BCR when deficit fertigation decreased from 40% DF to 20% DF was lower than from 20% DF to 0% DF in the wet season. However, in the dry season it was different, the increase of BCR when deficit fertigation changed from 40% DF to 20% DF was higher than from 20% DF to 0% DF (Figure 1). In the dry season, 40% deficit fertigation gave the least BCR.

Benefit–Cost Ratio of different soilless media

The results showed that 60% Cocopeat+40% Rice husk biochar emerged as the best medium in terms of economic returns (Figure 2). The 100% Cocopeat yielded BCR which was similar to that of 60% Cocopeat + 40% Rice husk biochar.

When Sawdust and Sorghum haulm biochar were added to 40% Cocopeat the BCR was similar to the addition of uncharred rice husk to 60% Cocopeat (Figure 2). The BCR of the dry season was bigger than that of the wet season though the standard error of mean of the treatments showed that they were similar in magnitude.

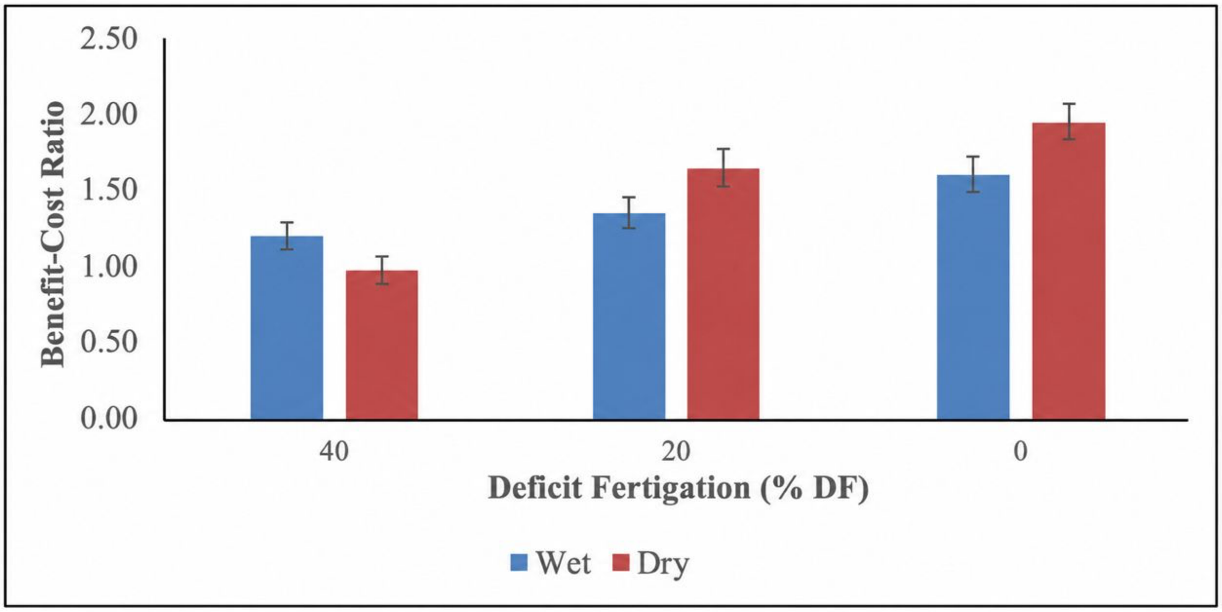

Figure 1: Benefit-cost analysis for different deficit fertigation in the wet and dry seasons. Error bars represent Standard error of mean.

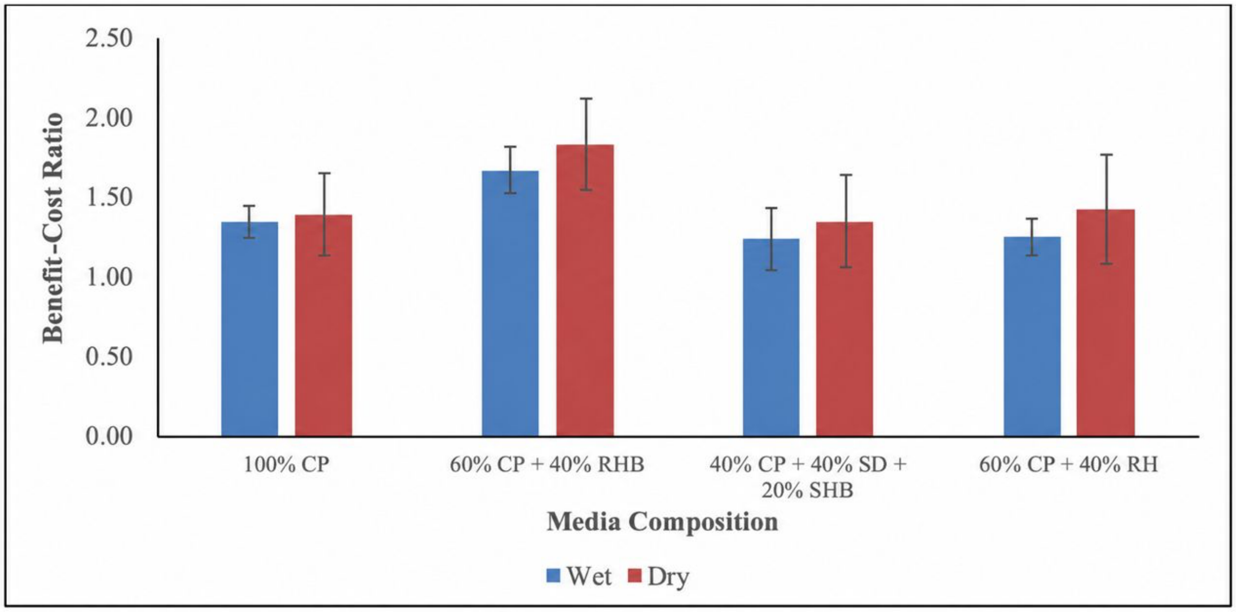

Figure 2: Benefit-cost analysis for the different soilless media composition during the wet and dry seasons. Error bars represent Standard error of mean.

Partial Budget Analysis of tomato production in greenhouse during wet and dry seasons

The partial budget analysis of the treatments applied to greenhouse tomato planted in a wet season is shown in table 8. The data were arranged based on the increasing total variable cost of the treatments. The analysis entails the computation of the net benefits derived from each treatment.

Based on the net benefit, six deficit fertigation and media combination were discarded as they were dominated, i.e., they resulted in greater additional costs with lesser net benefits. The use of 100% Cocopeat in all the deficit fertigation were dominated and were among the six treatments discarded. At 40% deficit fertigation, 40% Cocopeat + 40% Sawdust + 20% Sorghum haulm biochar resulted in higher marginal total variable cost (ΔTVC) than marginal net benefit (ΔNB) so the return on investment was low (Table 8). When the media was changed to 60% Cocopeat + 40% Rice husk biochar under the same deficit fertigation, marginal total variable cost was very small but the corresponding marginal net benefit was high resulting in huge MRR. When the deficit fertigation was reduced to 20% for the same media, the marginal Total Variable Cost went higher therefore the MRR reduced substantially (Table 8). At 0% deficit fertigation, a shift of media from 40% Cocopeat + 40% Sawdust + 20% Sorghum haulm biochar to 60% Cocopeat+40% Rice husk biochar resulted in small marginal Total Variable Cost and high marginal Net benefit producing high MRR.

In the dry season, six treatments resulted in greater additional costs with lesser net benefits and were discarded as dominated treatments (Table 9). Two other treatments that resulted in negative net benefit were also discarded (Table 9). None of the 40% deficit fertigation was profitable in the dry season. 60% Cocopeat+40% Rice husk posted a positive MRR only when it was irrigated at 0% deficit fertigation. 60% Cocopeat+40% Rice husk biochar posted a huge MRR when mild deficit fertigation of 20% was applied. A shift from 20 to 0% DF for the same media, 60% Cocopeat+40%Rice husk biochar, produced higher marginal TVC resulting in reduced MRR (Table 9).

Table 8: Partial budget analysis showing marginal rate of return for different media composition and deficit fertigation during wet season tomato production in greenhouse. The Net benefit of treatments highlighted were dominated and were excluded in subsequent marginal analysis

Deficit Fertigation (% DF)	Media	TVC/m^2	Revenue/m^2	NB	ΔTVC	ΔNB	MRR (%)
40	CP60+RH_{40}	731.413	980.24	248.82			
40	CP_{40} + SD_{40} + SHB_{20}	789.193	1052.60	263.40	57.78	14.58	25.2336
40	CP_{60}+RHB_{40}	791.413	1443.34	651.93	2.22	388.52	17501.1
20	CP_{60}+RH_{40}	791.648	1303.44	511.80			
20	CP_{40} + SD_{40} + SHB_{20}	849.428	1102.77	253.34			
20	CP_{60}+RHB_{40}	851.648	1733.75	882.10	60.2353	230.17	382.117
0	CP_{60}+RH_{40}	851.883	1521.49	669.61			
0	CP_{40} + SD_{40} + 20% SHB_{20}	909.663	1823.47	913.81	58.0153	31.71	54.6599
0	CP60+RHB_{40}	911.883	2159.22	1247.34	2.22	333.53	15023.9
40	CP100	1026.97	1433.69	406.73			
20	CP100	1087.2	1823.47	736.27			
0	CP100	1147.44	1995.21	847.77			

Table 9: Partial Budget Analysis showing marginal rate of return for different media composition and deficit fertigation during dry season tomato production. The Net benefit of treatments highlighted were dominated and were excluded in subsequent marginal analysis

Fertigation Deficit (% DI)	Media	TVC/m2	Benefit (B)N	NB	ΔTVC	Δ NB	MRR (%)
40	CP60 + RH$_{40}$	705.81	621.734	-84.08			
40	CP$_{40}$ + SD$_{40}$ + SHB$_{20}$	757.52	1436.2	678.68			
40	CP$_{60}$ + RHB$_{40}$	763.59	715.68	-47.91			
20	CP$_{60}$ + RH$_{40}$	765.81	1112.63	346.82			
20	CP$_{40}$ + SD$_{40}$ + SHB$_{20}$	809.22	1689.41	880.19	51.70	201.51	389.749
20	CP$_{60}$ + RHB$_{40}$	815.29	1329.55	514.26			
0	CP$_{60}$ + RH$_{40}$	817.52	1848.67	1031.16	8.30	150.97	1819.3
0	CP$_{40}$ + SD$_{40}$ + 20% SHB$_{20}$	867.00	1738.8	871.80			
0	CP60+RHB$_{40}$	869.22	2138.98	1269.76	51.70	238.60	461.495
40	CP100	1001.37	1047.72	46.35			
20	CP100	1053.07	1693.44	640.37			
0	CP100	1104.77	2155.1	1050.33			

DISCUSSION

The Benefit-Cost Analysis (BCA) and Partial Budget Analysis carried out in the wet and dry seasons on the soilless media and three deficit fertigation provide important information about the economic feasibility of greenhouse tomato production.

The BCA shows that the cost of inputs, yield outputs, and the ensuing benefit-cost ratios (BCR) have a substantial impact on the economic viability of a venture. Based on the data, farmers have more cost-effective options since some combinations of soilless media and deficit fertigation produce higher profit. It was observed that BCR increased with decreasing deficit fertigation. Decreasing deficit fertigation having impact on yield has been reported by Bian et al. (2024) who indicated that increasing irrigation volume improved water use efficiency by 6.57% to 28.89% and significantly enhanced maize yield by 16.96% to 39.24%, demonstrating the importance of optimizing fertigation practices for better agricultural outcomes. It has been demonstrated that lower deficit fertigation enhances crop yield and growth. For example, research on radicchio showed that low deficit fertigation increased yield by 12% when compared to high-deficit regimes (Bortolini and Tolomio, 2019).

The wet season BCR was generally higher than that of the dry season. In the wet season, increment in BCR when fertigation deficit was reduced from 40% deficit to 20% deficit was not as high as when deficit fertigation was reduced from 20% deficit to 0% deficit fertigation. It is economically feasible to irrigate at 0% deficit in the wet season when water is not scarce. The higher difference in BCR that was observed in the dry season when fertigation deficit was reduced from 40% to 20% deficit may be due to higher water demand by the crop occasioned by high evapotranspiration. Because of increased water consumption and expenses during dry seasons, the increase in BCR brought on by more irrigation may be less noticeable. Increment in BCR when fertigation deficit was reduced from 40% deficit to 0% deficit in the dry season did not bring appreciable increase in BCR when compared with a shift from 40% deficit to 20% deficit fertigation. In situations when water is scarce, the farmer can irrigate at 20% deficit since 0% deficit will not bring appreciable increase in BCR. Since the marginal benefits of raising irrigation to 0% deficit is negligible in situations of limited water availability, it might be more cost-effective to limit it to 20% deficit fertigation. This is consistent with the finding of Koech and Langat (2018) who revealed that, improving irrigation techniques can improve financial returns without using excessive amounts of water. Irrigation expenditures, however, need to be carefully evaluated against the revenue. These assessments are made possible by the BCA framework, which empowers farmers to decide on the best irrigation plans that complement their financial objectives. A study by Majdalawi et al. (2023) provides a comprehensive economic analysis of soilless culture systems, supporting the findings that, these systems can lead to higher profits and resource efficiency which is similar to the result recorded in this study

It is evident from the study that different soilless media-like cocopeat and rice husk biochar-have different costs and yield outputs. For example, using 60% Cocopeat with rice husk biochar produced a higher yield and revenue per season than other combinations of media, leading to a favourable BCR. Compared to other combinations, a 60% Cocopeat and rice husk biochar mixture produced higher revenue and a positive BCR but a study by Adekiya et al. (2022) reported less than 1 BCR for a similar composition. The horticulture industry is promoting cocopeat in Ghana greenhouse production. This study has shown that the use of 60% Cocopeat with rice husk biochar gives higher BCR than the known cocopeat. The use of rice husk in uncharred form with cocopeat (60% Cocopeat+ Rice husk) recorded lower BCR this aligns with a study by Adekiya et al. (2022) where lower BCRs were obtained (0.16) when uncharred rice husk was combined with cocopeat. The stellar performance of cocopeat as a soilless media is attributed to its high-water holding capacity, excellent porosity (Habib et al., 2024), and improved wettability, in our case, when mixed with rice husk biochar. Cocopeat has the ability to retain water and keep nutrients applied, which most likely led to greater yields and, ultimately higher profits (Habib et al., 2024). Biochar's porous structure and high surface area makes it an effective medium for nutrient retention and reduced leaching which can lead to improved crop efficiency and health of soilless medium. Biochar acts as a reservoir for nutrients, promoting their slow release and reducing the risk of leaching and nutrient runoff. This slow-release mechanism ensures a steady supply of nutrients to plants, enhancing soil fertility over time (Llovet et al., 2023). The rice biochar inclusion in the medium improved aeration making oxygen available to the roots. This observation is in line with the finding of Banitalebi et al. (2024) who indicated that biochar-based growth media exhibit superior aeration properties compared to traditional cocopeat mixtures. For instance, Rice husk biochar mixed with other materials demonstrated optimal oxygen diffusion coefficients, essential for root respiration. According to Sharma and Chhabra (2024), biochar enhances soil fertility and crop yields by improving nutrient retention through its high charge density and porous structure, which facilitates ion exchange and nutrient availability. This increased retention reduces nutrient leaching, allowing crops to access essential elements like nitrogen, phosphorus, and potassium more effectively. According to Ariningsih et al. (2023), the application of biochar can lead to a 4% increase in rice efficiency, attributed to improved moisture availability in soilless media, promoting plant growth and yield. Healthy root development depends on improved air-filled porosity, which is made possible by the porous structure of biochar (Chang et al., 2021). By increasing nutrient availability and soil fertility, the application of rice husk biochar not only enhances aeration and moisture retention but also raises crop yields and improves plant health in general (Li et al., 2023). The results of this study are consistent with previous research that highlights the advantages of using organic soilless media, which can improve plant growth and yield because of improved aeration and moisture retention (Kumar et al., 2020). The BCR for many treatments were quite good; for example, in the wet season, 60% Cocopeat+40% Rice husk biochar achieved a BCR of 1.93, meaning that benefits were returned to almost twice the same value for Cedi invested. The results of this research emphasize how crucial it is to choose the right soilless media and fertigation techniques in order to improve the economic viability of tomato production. The most economical approach is found when 60% Cocopeat+40% Rice husk biochar and 0% deficit fertigation are combined depending on the season.

Marginal rate of returns is influenced by production cost. Greenhouse tomato production often involves high initial investments, particularly for hydroponic and soilless cultivation systems (Al-Khateeb et al., 2024). However, these systems can lead to higher yields and better resource efficiency, potentially increasing the MRR. Yield and efficiency are directly related to MRR. Higher yields generally lead to higher returns, increasing the MRR. Greenhouse tomato production often results in higher yields compared to open-field production due to controlled environmental conditions and advanced cultivation techniques (Sagar and Singh, 2023; Al-Khateeb et al., 2024). In this study it emerged that MRR was influenced by media substrate efficiency, fertigation deficit and season of production. The Partial budget analysis shows that substitution of 40% of the Cocopeat with Rice husk biochar (60% Cocopeat+40% Rice husk biochar) presented the best marginal rate of return. 40% Cocopeat + 40% Sawdust + 20% Sorghum haulm biochar was the second-best media formulation that gave higher MRR. This demonstrates the significance of media substrate, deficit fertigation and season in influencing marginal rate of return. Assuming that every farmer expects 100 % return in addition to the interest on credit taken for farming, in Ghana about 45% at the time the study was done, then Marginal Rate of Return above 145% will be acceptable to farmers. For the non-dominated treatments, then Marginal Rate of Returns above 145% will be acceptable to farmers. Except 40% CP + 40% SD + 20% SHB, all the non-dominated treatments exceeded the expected 145% marginal rate of return. From the results it is clear that substitution of 40% Cocopeat in both seasons and 60% Cocopeat in the dry season with charred coarser materials leads to huge marginal rate of return above 145% Juxtaposing the BCA with Partial budget analysis, it can be seen that 0% deficit fertigation using 60% Cocopeat+40% Rice husk biochar presented the best BCR and MRR in the both seasons. In times of water scarcity which occurs in the dry season, 20% deficit fertigation using 60% Cocopeat+40% Rice husk biochar will still give huge MRR as well as good BCR.

CONCLUSION AND RECOMMENDATION

The Benefit–Cost Analysis (BCA) and Partial Budget Analysis (PBA) conducted across wet and dry seasons provide compelling evidence on the economic viability of greenhouse tomato production under different soilless media and deficit fertigation. The results clearly demonstrate that both substrate composition and fertigation scheduling are critical determinants of profitability, with their effects varying by season due to differences in water availability and production costs.
The inclusion of rice husk biochar to cocopeat (60% Cocopeat+40% Rice husk biochar) offered better economic returns with BCR of 1.93 and 2.20 in the wet and dry seasons respectively. This was higher than the popular Cocopeat which recorded BCR of 1.47 and 1.78 in the wet and dry seasons respectively. The Partial Budget Analysis (PBA) showed that, fertigation at 20% and 0% deficit in the wet season produced huge MRR. In the dry season, 20% deficit fertigation gave the

best MRR. The PBA also showed that, the use of 60%Cocopeat+40% Rice husk biochar produced the best MRR. The findings of this study highlight that using a soilless medium composed of 60% cocopeat and 40% rice husk biochar offers significant economic benefit. This combination not only enhanced tomato yield, water productivity, and fruit quality under both wet and dry conditions but also proved more cost-effective, yielding higher benefit–cost ratios and marginal rates of return than cocopeat alone. The inclusion of rice husk biochar, a locally available agricultural byproduct reduces production costs, promotes resource recycling, and supports sustainable waste management. Moreover, the use of biochar contributes to carbon sequestration and aligns with climate-smart agricultural practices. The study therefore recommends that, incorporating cocopeat and rice husk biochar at the ratio of 3:2 and 20-0% deficit fertigation should be used.

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