



Financial Viability of Conservation Agriculture Tillage Technologies in Bangladesh: Evidence from Two-Wheel Power Tiller-Operated Implements

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ABSTRACT

Conservation agriculture (CA) offers a sustainable alternative to intensive tillage, yet its adoption remains constrained by limited evidence on the profitability of CA technologies. This study evaluates the financial viability of two-wheel power tiller-operated CA implements, the Versatile Multi-crop Planter (VMP) and the Power Tiller-Operated Seeder (PTOS), among service providers in Bangladesh. Data were collected from 60 purposively selected service providers in Rajshahi and Rajbari districts and analyzed using discounted cash flow techniques over a seven-year period at an 11% discount rate. Both technologies proved financially viable, generating positive net present values (VMP: BDT 102,088; PTOS: BDT 74,723) and internal rates of return exceeding the prevailing bank interest rate (VMP: 35%; PTOS: 24%). VMP consistently outperformed PTOS across all financial indicators. Sensitivity analysis identified operation and maintenance costs and gross benefits as the key determinants of profitability. The findings support targeted financial incentives, improved credit access, and technical improvements to enhance CA technology adoption and sustainable mechanization in Bangladesh.

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1. INTRODUCTION

Land degradation and declining soil fertility constitute primary constraints on agricultural productivity in densely populated South Asian countries. Conventional tillage-intensive cropping systems, dependent on synthetic inputs and repeated mechanical soil disturbance, progressively compromise soil organic matter, aggregate stability, and water retention capacity collectively reducing farm profitability and ecological resilience (Srivastava et al., 2025). In Bangladesh, two-wheel power tillers (2-WPT) have become the predominant land preparation implement since the early 2000s; yet repeated full-rotary tillage, sometimes performed more than ten times per year, depletes soil organic carbon (SOC) and accelerates structural degradation (Jahiruddin & Jahangir, 2024). The consequences are compounded by climate change, which is measurably reducing crop yields, intensifying salinity intrusion in coastal zones, and disrupting rainfall patterns across the country, thereby threatening food security and rural livelihoods (Samira-Binte-Saif, 2025). Addressing these intersecting pressures through resource-conserving tillage methods has

acquired strategic importance as Bangladesh's smallholder farming systems confront the dual challenge of environmental vulnerability and rising input costs.

Conservation Agriculture (CA) is an evidence-based agroecosystem management approach premised on three mutually reinforcing principles: (i) minimal mechanical soil disturbance, (ii) permanent organic soil cover through crop residues and cover crops, and (iii) diversified crop rotations (FAO, 2011). Originating in the USA during the 1930s in response to catastrophic wind and water erosion, CA has since been adapted across diverse agronomic environments globally. Its adoption confers measurable economic benefits including reductions in fuel, labor, and irrigation water costs alongside agronomic and environmental gains such as improved water use efficiency, enhanced SOC sequestration, and lower greenhouse gas emissions (Srivastava et al., 2025; Hoque et al., 2023).

In Bangladesh, FAO initiated CA-based tillage trials from 2003 onwards through the Wheat Research Centre (WRC) in collaboration with the Bangladesh Agricultural Research Institute (BARI), covering four major districts (Rawson et al., 2007). Among the CA implements developed under this program, the Versatile Multi-crop Planter (VMP), developed by CIMMYT for the northwest region, and the Power Tiller-Operated Seeder (PTOS), a Chinese-origin one-pass seeder, represent the most widely disseminated two-wheel power tiller-compatible CA technologies in the country. Studies have demonstrated that VMP reduces water use by 41–43% compared with conventional tillage and consumes 65% less fuel under strip tillage mode (Islam et al., 2010). Conservation agriculture practices have been shown to improve both crop productivity and farm profitability among Bangladeshi smallholders in the Eastern Gangetic Plain (Miah et al., 2023), and empirical evidence from rice-based systems in the region confirms that CA technologies reduce production costs and improve gross margins (Islam et al., 2022).

Despite these documented agronomic benefits, adoption of CA-based implements among Bangladeshi smallholders and service providers remains limited (Akter et al., 2021). A critical barrier identified in the literature is the absence of robust financial appraisal evidence to demonstrate the commercial viability of investments in CA machinery from the perspective of agricultural service providers, a category of actor whose role in custom-hire markets is pivotal for technology diffusion among resource-constrained farm households (Quayum & Ali, 2012). Evidence from comparable agricultural technology adoption studies in South Asia consistently demonstrates that high initial investment costs, inadequate institutional support, and limited policy incentives are the primary constraints restricting the diffusion of productivity-enhancing technologies, including those in the renewable energy and mechanization domains (Ashfaq & Tehreem, 2025). Previous studies on CA in Bangladesh have largely focused on tillage system performance, machinery design, and agronomic outcomes, while systematic financial analysis of CA implement investments from the service provider perspective remains sparse.

This study addresses that evidence gap by conducting a discounted cash flow analysis of 2-WPT-operated VMP and PTOS investments using primary data collected from service providers in Rajshahi and Rajbari districts of Bangladesh. The objective is to determine BCR, NPV, and IRR for both technologies under baseline conditions and a range of sensitivity scenarios, and to derive actionable policy recommendations to promote financially sustainable CA mechanization in Bangladesh.

2. MATERIALS AND METHODS

Study Area and Sampling

The study was conducted in Rajbari and Rajshahi districts of Bangladesh, both recognized as pioneering regions for CA adoption. Within Rajbari district, Baliakandi Upazila was selected on account of its early and sustained adoption of PTOS-based CA since 2000. Within Rajshahi district, Durgapur Upazila was selected as a site where VMP has been in operational use since 2015. These districts were chosen purposively to capture differential experiences across technology types and adoption maturity. Lists of registered 2-WPT-operated CA service providers were obtained from the Department of Agricultural Extension (DAE), from which a total of 60 service providers were randomly selected 30 VMP operators from Durgapur and 30 PTOS operators from Baliakandi.

Primary data were collected from February to May 2017 through structured household interviews using pre-tested interview schedules. To establish rapport and ensure data quality, researchers personally explained the study objectives to each respondent prior to data collection. Investment costs, operation and maintenance (O&M) expenditures, service charges, and area coverage were recorded through direct interview, supplemented by case studies and field observations.

Analytical Framework: Project Appraisal Technique

The financial viability of investments in 2-WPT-operated PTOS and VMP was assessed using discounted cash flow analysis, following the project appraisal methodology described by Gittinger (1972). Three standard indicators were computed over a seven-year project life at an 11% discount rate, consistent with the prevailing opportunity cost of capital in Bangladesh:

Benefit-Cost Ratio (BCR)

BCR is the ratio of the present worth of the benefit stream to the present worth of the cost stream. A BCR greater than unity (>1) indicates financial acceptability; $BCR = 1$ represents a neutral decision; $BCR < 1$ renders the project unacceptable.

$$BCR = [\sum B_n / (1+i)^n] / [\sum C_n / (1+i)^n]$$

where B_n = benefits in year n ; C_n = costs in year n ; i = discount rate; n = project year.

Net Present Value (NPV)

NPV represents the difference between the present value of the benefit stream and the present value of the cost stream. A positive NPV (>0) confirms that a project generates surplus returns above the discount rate; $NPV = 0$ indicates equality of costs and benefits; $NPV < 0$ implies financial non-viability.

$$NPV = \sum [(B_n - C_n) / (1+i)^n]$$

Internal Rate of Return (IRR)

IRR is the discount rate at which NPV equals zero, representing the average earning power of invested capital over project life. A project is financially acceptable when IRR exceeds the opportunity cost of capital (OCC). IRR was computed through linear interpolation between two trial discount rates producing positive and negative NPV values:

$$IRR = r_1 + [(NPV_1 / |NPV_1 - NPV_2|) \times (r_2 - r_1)]$$

where r_1 and r_2 are the lower and upper trial discount rates, and NPV_1 and NPV_2 are the corresponding net present values.

Sensitivity Analysis

Sensitivity analysis was conducted to assess how changes in key financial parameters specifically, O&M costs ($\pm 10\%$ and $\pm 20\%$) and gross benefits (-10% and -20%) affect the financial performance of VMP and PTOS investments. This approach is consistent with standard project appraisal practice for agricultural technology investments in developing countries (Gittinger, 1972; Tebeje et al., 2024).

3. RESULTS AND DISCUSSION

Investment Costs

Total investment costs, inclusive of government subsidy, amounted to BDT 132,000 for VMP and BDT 136,550 for PTOS, representing the combined acquisition cost of the 2-WPT and the respective planter implement. Both technologies carry an assumed service life of seven years. The relatively high capital requirement represents a significant financial barrier for smallholder farmers and custom-hire service providers in rural Bangladesh (Hehlangki et al., 2022). The literature consistently identifies investment cost as a primary adoption constraint for CA mechanization in developing countries, and this pattern holds equally for other agricultural technologies in the region: a study of solar-powered irrigation system adoption among rice farmers in Pakistan published in this journal found that high initial investment costs and inadequate institutional support were the dominant barriers to technology diffusion, despite clear evidence of economic viability (Ashfaq & Tehreem, 2025). Subsidies and targeted credit arrangements are essential instruments for improving affordability and enabling large-scale CA technology diffusion (Renaud, 1997; Akter et al., 2021).

Operation and Maintenance Costs

Average annual O&M costs were BDT 46,983 for VMP and BDT 54,850 for PTOS (Table 1). O&M cost profiles differed markedly between technologies, reflecting differences in age, mechanical complexity, and field application scope, consistent with the observation that locale-specific and environmental factors account for inter-owner variance in conservation technology running costs (Scott & Farquharson, 2004).

Fuel Cost

Fuel (diesel and lubricant) accounted for 49% and 44% of total O&M costs for VMP and PTOS, respectively, with average annual expenditures of BDT 22,874 and BDT 24,388. These proportions are consistent with findings from comparable mechanized tillage contexts: fuel represents approximately 45% of total operational costs in mechanized tillage systems in Ethiopia (Tebeje et al., 2024) and 40–50% of on-farm operational costs across diverse tillage implements in Pakistan (Shah et al., 2016). The relatively lower fuel burden for VMP users reflects the technology's design advantages in strip tillage mode, which requires substantially less fuel per unit area compared with conventional full-rotary tillage (Islam et al., 2010).

Spare Parts and Repair Costs

Given that VMP was newly introduced in the study area with a maximum operating history of three years at data collection, no spare parts or repair costs were incurred by VMP operators during the study period; the implementing agency also provided replacement parts during this phase. In contrast, PTOS operators, whose machines had been operational for five or more years, incurred average spare parts costs of BDT 1,055 per year (2.52% of total O&M) and average repair costs of BDT 2,410 per year (5.75% of total O&M). This age-dependent cost escalation is well-documented in the mechanized agriculture literature; spare parts requirements and repair costs increase substantially with machine age for soil tillage implements, particularly those subjected to high field loading (Renaud, 1997; Tebeje et al., 2024). These findings underscore the importance of accounting for lifecycle maintenance costs in financial appraisals of CA technology investments.

Labor and Other Operating Costs

Driver wages constituted the second largest cost component, representing 48% (BDT 22,560) and 46% (BDT 25,200) of total O&M costs for VMP and PTOS, respectively. Most service providers personally operated their machines, engaging hired operators only when they needed to serve multiple clients simultaneously. Shed costs were minimal, BDT 703 (VMP) and BDT 810 (PTOS), as the majority of operators stored machines in domestic verandas rather than purpose-built facilities. Interest on operating capital, calculated at the prevailing lending rate, contributed BDT 846 (VMP) and BDT 987 (PTOS), approximately 2.3% of total O&M costs for both technologies. The role of interest on working capital as a determinant of financial viability in agricultural machinery investments has been documented for smallholder contexts across Sub-Saharan Africa (Onduru et al., 2013).

Table 1: Average Annual Operation and Maintenance Costs of VMP and PTOS (BDT/Year)

Cost Item	VMP Cost (BDT)	VMP % of Total	PTOS Cost (BDT)	PTOS % of Total	Combined (BDT)	Combined %
Fuel cost	22,874	49.0	24,388	44.0	22,760	45.0
Spare parts	0	0.0	1,055	2.52	528	1.43
Repairs	0	0.0	2,410	5.75	1,205	3.27
Storage/shed	703	2.20	810	1.93	755	2.05
Driver wages	22,560	48.0	25,200	46.0	23,880	48.0
Interest on operating capital	846	2.37	987	2.28	901	2.28
Total O&M Cost	46,983	100.0	54,850	100.0	53,964	100.0

Source: Authors' own estimation based on field survey data (2017). BDT = Bangladeshi Taka.

Benefits from VMP and PTOS Operations

Service provider revenues are derived from two sources: service charges collected from farmer-clients on a per-acre basis, and the residual (salvage) value of the implement at the end of the seven-year asset life, estimated at 5% of initial investment value.

Average annual service charges were BDT 96,400 for VMP (BDT 1,200/acre $\times$ 80.33 acres) and BDT 83,200 for PTOS (BDT 1,575/acre $\times$ 52.25 acres). The higher unit service charge for PTOS reflects its narrower operational niche in irrigated systems, whereas VMP's lower per-acre fee is offset by its greater seasonal coverage area. Salvage values were BDT 6,600 (VMP) and BDT 6,827 (PTOS), yielding gross annual benefits of BDT 103,000 and BDT 90,027, respectively (Table 2). The custom hiring model where service providers supply CA seeding services to smallholder farm households is a well-established pathway for CA technology diffusion in South Asia (Quayum & Ali, 2012; Miah et al., 2023).

Table 2: Annual Benefits from VMP and PTOS Operations

Technology	Avg. Area (acre)	Service Charge/acre (BDT)	Total Service Charge (BDT)	Salvage Value (BDT)	Gross Benefit (BDT)
VMP	80.33	1,200	96,400	6,600	103,000
PTOS	52.25	1,575	83,200	6,827	90,027
Combined	66.29	1,388	89,800	6,714	96,514

Source: Authors' own estimation based on field survey data (2017).

Financial Analysis of CA Tillage Technologies

At an 11% discount rate over a seven-year investment horizon, both VMP and PTOS generated positive NPVs and BCRs exceeding unity, and IRRs above the prevailing bank lending rate (Table 3). VMP yielded NPV = BDT

102,088, BCR = 1.38, and IRR = 35%, compared with NPV = BDT 74,723, BCR = 1.26, and IRR = 24% for PTOS. These results confirm that both technologies represent financially sound investment options from the perspective of individual service providers.

VMP's superior financial performance reflects its broader operational scope, larger area coverage per season, lower age-related maintenance costs during the study period, and greater fuel efficiency. These findings align with evidence from the Eastern Gangetic Plain, where CA-based crop establishment systems have consistently demonstrated higher profitability compared with conventional tillage across a range of crop types and soil conditions (Miah et al., 2023; Islam et al., 2022; Hoque et al., 2023). The positive financial returns from CA technology investment are similarly corroborated by cost-benefit analyses in sub-Saharan African contexts; in a study of climate-smart agricultural practices across five African countries, conservation agriculture investments consistently demonstrated positive NPVs and BCRs exceeding 1.0 at discount rates of 10–13.5% (Ng'ang'a et al., 2022). A cost-benefit analysis of CA zero tillage in Nepal also confirmed positive NPVs and IRRs under comparable smallholder conditions at a 12% discount rate (Bhusal et al., 2024). The climate vulnerability context that intensifies the economic case for CA in Bangladesh is empirically documented: Samira-Binte-Saif (2025), publishing in this journal, provides econometric evidence that climate change is significantly reducing agricultural performance in Bangladesh, creating an urgent and evidence-based rationale for transitioning from resource-intensive conventional tillage to CA-based systems.

Table 3: Baseline Financial Analysis of VMP and PTOS (11% Discount Rate, 7-Year Project Life)

CA Technology	BCR (at 11%)	NPV at 11% (BDT)	IRR (%)
VMP	1.38	102,088	35%
PTOS	1.26	74,723	24%

Source: Authors' own estimation based on field survey data (2017).

Sensitivity Analysis

Sensitivity analysis was conducted to determine the robustness of financial performance under four adverse scenarios: 10% decline in gross benefits, 20% decline in gross benefits, 10% increase in O&M costs, and 20% increase in O&M costs.

Effect of a 10% Decrease in Gross Benefits

Under a 10% reduction in gross benefits, both technologies retained positive NPVs (VMP: BDT 64,961; PTOS: BDT 48,186), BCRs above unity, and IRRs exceeding the bank rate (VMP: 21%; PTOS: 19%), confirming continued commercial viability (Table 4). VMP maintained a higher IRR under this scenario. Analogous reductions in gross benefit in comparable conservation investment contexts in Kenya caused non-structural practices (e.g., trash lines) to experience IRR declines from approximately 27% to 17–18% with BCRs around 1.2, though viability was maintained (Onduru et al., 2013).

Table 4: Financial Analysis Under a 10% Decrease in Gross Benefit

CA Technology	BCR (at 11%)	NPV at 11% (BDT)	IRR (%)
VMP	1.24	64,961	21%
PTOS	1.10	48,186	19%

Source: Authors' own estimation based on field survey data (2017).

Effect of a 20% Decrease in Gross Benefits

A 20% reduction in gross benefits materially eroded PTOS profitability, reducing its BCR to near unity (1.02) and IRR to 12%, barely exceeding the bank rate, while producing an NPV of only BDT 5,035 (Table 5). VMP remained financially viable (NPV: BDT 27,888; BCR: 1.15; IRR: 16%), though with a considerably narrowed margin. These results indicate that PTOS adopters are particularly exposed to demand-side risk and market price volatility. Shahzad et al. (2017) similarly observed that CA bed-sowing systems in Pakistan retained profitability under adverse yield scenarios only when realized yield gains were sufficiently large to compensate for cost pressures, a condition that may not consistently obtain for PTOS users in Bangladesh.

Table 5: Financial Analysis Under a 20% Decrease in Gross Benefit

CA Technology	BCR (at 11%)	NPV at 11% (BDT)	IRR (%)
VMP	1.15	27,888	16%
PTOS	1.02	5,035	12%

Source: Authors' own estimation based on field survey data (2017).

Effect of a 10% Increase in O&M Costs

A 10% increase in O&M costs modestly reduced financial performance for both technologies while preserving viability (Table 6). NPVs of BDT 87,056 (VMP) and BDT 54,964 (PTOS), BCRs of 1.31 and 1.16 respectively, and IRRs of 29% and 17% confirm that moderate cost escalation can be absorbed without compromising the investment case for either technology. This resilience is consistent with evidence from similar CA technology analyses in South Asia, where operating cost increases of up to 10% typically do not eliminate financial viability given the cost-competitiveness of CA implements relative to conventional tillage options.

Table 6: Financial Analysis Under a 10% Increase in O&M Cost

CA Technology	BCR (at 11%)	NPV at 11% (BDT)	IRR (%)
VMP	1.31	87,056	29%
PTOS	1.16	54,964	17%

Source: Authors' own estimation based on field survey data (2017).

Effect of a 20% Increase in O&M Costs

A 20% increase in O&M costs rendered PTOS financially inviable, with BCR falling below unity (0.87) and IRR declining to 10%, below the bank lending rate, while NPV contracted to BDT 5,587 (Table 7). VMP, by contrast, remained commercially viable (BCR: 1.24; IRR: 24%; NPV: BDT 65,079), demonstrating substantially greater resilience to cost-side shocks. This divergent outcome is attributable to PTOS's higher absolute O&M costs, primarily driven by spare parts and repair expenditures that escalate with machine age, and its lower gross benefit-to-cost margin. The result reinforces findings from structural conservation investment analyses; Onduru et al. (2013) documented that higher-cost structural soil conservation measures (e.g., infiltration ditches) in Kenya generated IRRs below 15% and became marginally cost-effective without subsidy support when costs escalated.

Table 7: Financial Analysis Under a 20% Increase in O&M Cost

CA Technology	BCR (at 11%)	NPV at 11% (BDT)	IRR (%)
VMP	1.24	65,079	24%
PTOS	0.87	5,587	10%

Source: Authors' own estimation based on field survey data (2017). Note: PTOS IRR of 10% falls below the 11% opportunity cost of capital, rendering this scenario financially non-viable for PTOS operators.

4. CONCLUSIONS AND POLICY RECOMMENDATIONS

This study confirms that both the Versatile Multi-crop Planter (VMP) and the Power Tiller-Operated Seeder (PTOS), two prominent 2-WPT-operated CA technologies, are financially viable investments for agricultural service providers in Bangladesh under baseline conditions. Both technologies generate positive NPVs and IRRs that substantially exceed the opportunity cost of capital, with VMP demonstrating markedly superior financial performance (IRR: 35%, BCR: 1.38) compared with PTOS (IRR: 24%, BCR: 1.26). Primary economic advantages include lower fuel consumption, reduced labor requirements, and the ability to cover larger seasonal areas per unit of variable cost input, consistent with the broader literature on CA mechanization benefits in the Eastern Gangetic Plain (Miah et al., 2023; Hoque et al., 2023). The urgency of transitioning to CA-based tillage is further underscored by the documented deterioration of agricultural performance under climate change in Bangladesh (Samira-Binte-Saif, 2025), which makes the adoption of more resource-efficient farming systems not merely economically desirable but environmentally imperative.

However, sensitivity analysis reveals a critical vulnerability for PTOS: when O&M costs increase by 20%, a scenario consistent with an aging equipment stock, or gross benefits decline by the same margin, PTOS investment becomes financially unviable. VMP sustains profitability under all tested stress scenarios, underscoring its superior resilience as a long-term investment proposition.

On the basis of these findings, the following policy measures are recommended to support the sustainable scaling of CA mechanization in Bangladesh:

First, national CA technology promotion programs should prioritize VMP over PTOS given VMP's demonstrated financial resilience and broader operational versatility. This prioritization should be reflected in subsidy allocation, extension programming, and commercialization support.

Second, PTOS machinery design should be revisited to reduce long-run maintenance and spare parts costs, which represents the primary driver of PTOS financial fragility. Collaboration between BARI, local manufacturers, and technology development partners (CIMMYT, ACIAR) to develop more durable PTOS components or locally fabricated replacements would extend economic viability.

Third, financial access interventions including targeted credit facilities, equipment loan guarantees, and machinery leasing schemes should be designed specifically for PTOS service providers and smallholder farmers seeking to enter custom-hire markets with high initial capital barriers. The analogy with solar-powered irrigation adoption is instructive: Ashfaq and Tehreem (2025) demonstrated in this journal that financial subsidies or credit facilities, technical training, and stronger institutional frameworks are the most effective policy levers for accelerating the adoption of economically viable but capital-intensive agricultural technologies in South Asian smallholder settings.

Finally, future research should extend the financial appraisal framework adopted here to incorporate social returns including environmental co-benefits (carbon sequestration, reduced soil erosion) and labor productivity gains to generate a more complete welfare analysis of CA technology adoption in the Bangladesh context.

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Declarations

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