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Terrain, Learning and Unit Cost in Mechanised In-Field Evacuation of Oil Palm Fresh Fruit Bunches: A Seven-Month Operational Record of a Mini Platform Collection System in Kedah, Malaysia

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ABSTRACT

Mechanisation of in-field fresh fruit bunch (FFB) evacuation is central to reducing the dependence of the Malaysian oil palm sector on manual field labour, yet published performance figures come mostly from short trials rather than routine commercial operation. This study analysed 175 machine-days of operating records from a single mini platform collection (MPC) unit working ten blocks of a commercial oil palm estate in Sungai Petani, Kedah, from 1 January to 31 July 2026. Daily throughput, output per harvester served and unit operating cost were tested against terrain class and elapsed operating time. The unit evacuated 3,552.4 t of FFB, averaging 20.30 t per machine-day (SD 5.62). Terrain class had no significant effect on machine throughput ($F = 0.71$, $p = 0.491$), but output per harvester served differed sharply ($F = 32.46$, $p < 0.001$), falling from 6.21 t on undulating blocks to 2.95 t on hilly blocks, where gangs averaged 7.4 workers against 3.3. Throughput rose from 14.86 t per day in January to 25.69 t in June, the second half of the record exceeding the first by 27.9 per cent. Operating cost averaged RM 84.91 per machine-day, 86 per cent of it the operator wage, giving a unit cost of RM 4.18 per tonne. The terrain penalty of platform-dependent evacuation falls on harvesters, not on the machine.

1. INTRODUCTION

The Malaysian oil palm industry entered 2026 from a position of record physical output. Planted area stood at 5.70 million hectares in 2025, crude palm oil production reached 20.28 million tonnes, the national fresh fruit bunch (FFB) yield recovered to 17.77 t ha-1 and the oil extraction rate averaged 19.74 per cent [1]. With planted area effectively capped by land-use policy and by the pace of replanting, the competitive position of Malaysian estates is now determined far less by the area they hold than by the cost at which they can move a tonne of FFB from the palm to the mill ramp.

Within that cost structure, in-field evacuation is the operation most exposed to labour supply. Harvesting and the associated movement of cut bunches from the palm circle to a collection point account for the largest single share of estate field labour, and the sector has long operated below the land-to-labour ratio it considers efficient.

The ideal ratio for Malaysian oil palm estates has been placed at 10:1, against the 8:1 requirement applied to estates employing foreign workers, and mechanised assistance has been shown to raise output per worker from 0.99 t per day to 2.24 t per day in harvesting operations [2]. Persistent shortages of plantation labour, the concentration of that labour in a narrow foreign-worker cohort and the reputational exposure this creates in export markets have made mechanisation a strategic rather than merely an operational question [3], [4].

Machine development has responded. The Malaysian Palm Oil Board has commercialised a family of in-field transport machines including the Hydra-Porter, the grabber and the Beluga [5], [7], and plantations combining a scissor-lift trailer

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with an FFB grabber have been reported to collect an average of 27.5 t of FFB per day [5]. Two functionally distinct machine families are now common on Malaysian estates. The mini platform collection (MPC) unit is platform-dependent: harvesters carry cut bunches to an in-field platform and the machine lifts and hauls only from that platform. The mini tractor grabber (MTG) is platform-independent: its hydraulic grabber recovers bunches left scattered at the palm base, eliminating the manual carry step, but traction and manoeuvring constraints confine it to flat blocks. The two machines therefore solve different halves of the same problem, and the choice between them is a terrain decision before it is an economic one.

The evidence base for that decision remains thin in one specific respect. Published productivity figures are drawn predominantly from designed trials of limited duration under supervised conditions, whereas the figures that determine an estate's investment decision are those generated by routine operation over months, by ordinary operators, across the whole range of blocks the estate actually harvests. Estates maintain daily machine registers precisely for this purpose, yet these records are seldom analysed beyond monthly totals. The scale of the opportunity is not in doubt: in-field mechanisation is reported by fewer than 10 per cent of estate firms in Malaysia and Indonesia, and harvesters have been observed to spend under 30 min of an eight-hour day actually cutting bunches, with the balance absorbed by walking, locating ripe fruit and negotiating uneven ground [6]. Three questions consequently remain open. First, whether difficult terrain degrades machine output or simply displaces the burden onto the harvesting gang. Second, how long a newly commissioned machine takes to reach steady-state output, and how severely an evaluation conducted before that point misstates performance. Third, what a tonne of mechanically evacuated FFB costs once the full operating record, rather than a trial week, is used as the denominator.

This study addresses those questions using the complete daily operating record of a single MPC unit on a commercial estate in Sungai Petani, Kedah. The objectives were: (i) to quantify daily FFB throughput of the unit under routine commercial operation; (ii) to test whether terrain class affects machine throughput and output per harvester served; (iii) to quantify the change in throughput over seven months of continuous operation; (iv) to compute unit operating cost and its sensitivity to capital charge; and (v) to position the measured MPC performance against published MTG and manual benchmarks in order to derive a fleet deployment rule. The contribution is an operationally grounded account of what platform-dependent mechanisation delivers, and of where its costs are actually incurred.

2. Materials and Methods

2.1 Study Site

The study was conducted on a commercial oil palm estate in the Sungai Petani district of Kedah, Malaysia, in the northern peninsular planting region. The estate name and ownership are withheld at the request of management, and block identifiers are reported in the estate's own numbering with the estate prefix removed. The site experiences an equatorial climate with a bimodal rainfall distribution and no pronounced dry season, and the planting material, palm age profile and harvesting interval were unchanged over the observation window.

Ten harvesting blocks were served by the machine during the study period. Terrain was classified from the estate's topographic records into three classes. Blocks 20A, 21A and 23A are hilly; blocks 12A, 12B and 13A are undulating; all remaining blocks are flat. Block 20A received no machine-days during the observation window and is therefore absent from the analysis. The resulting sample comprises five flat blocks (01A, 08B, 09A, 10A, 14B), three undulating blocks (12A, 12B, 13A) and two hilly blocks (21A, 23A).

2.2 Evacuation Systems Compared

The machine under observation was a mini platform collection (MPC) unit comprising a 45 hp mini tractor fitted with a hydraulically actuated grabber and towing a tipping trailer (Fig. 2). In this configuration harvesters cut the bunches and carry them to an in-field platform, where they are stacked in heaps beside the harvesting path; the grabber lifts the accumulated crop from the platform into the trailer, which is then hauled to the roadside collection point for onward lorry transport to the mill. The machine does not enter the interrow to recover individual bunches. Because the platform, rather than the palm circle, is the interface between worker and machine, the MPC can be deployed on flat, undulating and hilly blocks alike; the manual carry step, however, is retained in full.

The comparator system, the mini tractor grabber (MTG), reverses this trade-off. A hydraulically actuated grabber recovers bunches left scattered at the palm base and along the interrow, so no platform is required and the manual carry step is eliminated. The penalty is terrain: traction, stability and turning-circle constraints restrict the MTG to flat blocks. Table 1 sets out the functional comparison and Fig. 1 represents the three evacuation configurations as process flows, distinguishing manual from machine steps. No MTG operating records were available for the study estate over the observation window; MTG performance is therefore treated throughout as a published benchmark and is explicitly identified as such wherever it appears.

2.3 Data Source and Screening

Data were extracted from the estate's daily machine productivity register, a routine operational record maintained by field staff and not created for research purposes. Each row records the date, machine type, vehicle, block worked, number of harvesters served, hectares covered, tonnes of FFB evacuated, machine running cost and operator daily rate. The register was screened to retain only rows with a recorded machine type and a non-null tonnage, which yielded 175 valid machine-days between 1 January and 31 July 2026. A single MPC unit, a single vehicle and a single designated operator were involved throughout, so machine and operator learning effects cannot be separated in this dataset; this is treated as a limitation rather than corrected. The nominal field day ran from 07:00 to 16:30, giving a working span of 9.5 h, which was used uniformly as the denominator for hourly rates.

2.4 Derived Variables

Four variables were derived from each machine-day record. Daily throughput Qd is the tonnage of FFB evacuated by the unit in one machine-day. Output per harvester served qh normalises throughput by the number of harvesters the machine supported on that day, and is the measure most closely related to field labour productivity:

$$qh = Qd / H \quad (1)$$

where H is the number of harvesters served. The hourly evacuation rate r is given by:

$$r = Qd / T \tag{2}$$

with T = 9.5 h. Unit operating cost Cu is the sum of machine running cost Cm and operator cost Co per machine-day, divided by that day's throughput:

$$Cu = (Cm + Co) / Qd \tag{3}$$

2.5 Cost Basis

Machine running cost was taken as booked by the estate and covers fuel, consumables and the maintenance allocation applied to the unit; it ranged from RM 4.61 to RM 14.40 per machine-day over the period. The operator was paid on a daily basis at rates between RM 72.38 and RM 73.58 per day. Capital cost was not disclosed by the estate and is therefore excluded from the primary unit-cost calculation; its effect is examined separately as a sensitivity analysis in Section 3.5. All monetary values are in Malaysian Ringgit at 2026 prices. The manual comparator used in Section 3.6 applies published per-worker collection rates to the estate's own daily wage; it is indicative and is not a measurement made at this site.

2.6 Statistical Analysis

Machine running cost was taken as booked by the estate and Descriptive statistics were computed as means, standard deviations and coefficients of variation. Differences in daily throughput and in output per harvester between terrain classes were tested by one-way analysis of variance, with the Kruskal-Wallis test reported alongside as a distribution-free check given the unequal group sizes. The temporal contrast between the first and second halves of the record was tested with Welch's unequal-variance t test, and the trend in daily throughput against elapsed operating days was estimated by ordinary least squares regression. The significance threshold was set at 0.05. All computation was performed in Python 3.11 using pandas and SciPy.

3. RESULTS

3.1 Overall Operating Performance

Over 175 machine-days the unit evacuated 3,552.4 t of FFB, a mean of 20.30 t per machine-day with a standard deviation of 5.62 t and a coefficient of variation of 27.7 per cent (Table 2). Median throughput was 20.14 t, closely matching the mean, and daily values ranged from 2.52 t to 32.06 t. Expressed against the 9.5 h field day the unit averaged 2.14 t h^{-1}. Twenty-eight machine-days, or 16.0 per cent of the record, fell below 15 t; inspection showed these to be concentrated in the opening months of operation rather than distributed across the period.

3.2 Effect of Terrain Class

The machine worked 80 machine-days on flat blocks, 67 on undulating blocks and 28 on hilly blocks, corresponding to 45.7, 38.3 and 16.0 per cent of the record respectively. Mean daily throughput was 19.92 t on flat blocks, 20.30 t on undulating blocks and 21.39 t on hilly blocks. The differences are not statistically significant, either by one-way ANOVA ($F = 0.71$, $p = 0.491$) or by the Kruskal-Wallis test ($H = 1.43$, $p = 0.488$). Machine throughput is, in other words, effectively invariant to terrain across the range of conditions worked on this estate.

Output per harvester served behaves in the opposite way. It averaged 5.20 t on flat blocks and 6.21 t on undulating blocks, but only 2.95 t on hilly blocks, and the difference is highly significant ($F = 32.46$, $p < 0.001$; Kruskal-Wallis $H = 58.65$, $p < 0.001$). The explanation lies in gang size: hilly blocks were worked with an average of 7.4 harvesters per machine-day, against 4.0 on flat blocks and 3.3 on undulating blocks, and the machine was allocated a larger area on hilly blocks (5.00 ha) than on flat (3.65 ha) or undulating (3.84 ha) blocks. Crop recovered per hectare was correspondingly lower on hilly blocks at 4.28 t ha^{-1} against 5.60 t ha^{-1} on undulating blocks. Table 3 summarises performance by terrain class and Fig. 3 shows the contrasting distributions; block-level detail is given in Table 4.

3.3 Change in Throughput over the Operating Period

Throughput increased markedly with accumulated operating experience. Monthly means rose from 14.86 t per day in January to 18.06 t in February and 19.78 t in March, fell to 16.26 t in April, then rose again to 23.33 t in May, 25.69 t in June and 24.23 t in July (Fig. 4). Regression of daily throughput on elapsed operating days gives a slope of 0.052 t per day per day ($R^2 = 0.34$, $p < 0.001$); fitted to monthly means the trend explains 75 per cent of the variance. Comparing the first half of the record with the second, mean throughput rose from 17.76 t to 22.70 t per machine-day, an increase of 27.9 per cent that is highly significant (Welch $t = 6.49$, $p < 0.001$). The peak month exceeded the first month by 72.9 per cent.

The April interruption to this trend coincided with the smallest mean gang size of the period, 3.7 harvesters per machine-day against 4.5 in the adjacent months, and with a rise in the share of machine-days worked on flat blocks. The register does not record the reason for the reduced gang deployment, and the interpretation offered here is therefore provisional.

3.4 Operating Cost

Mean total operating cost was RM 84.91 per machine-day, comprising RM 11.95 of machine running cost and RM 72.96 of operator wage. The operator wage therefore accounted for 85.9 per cent of the daily operating cost of the unit. Weighted across the full record, unit operating cost was RM 4.18 per tonne of FFB evacuated. Because daily cost is close to fixed while throughput rose steeply, unit cost tracked the learning curve in reverse, falling from a monthly mean of RM 6.26 per tonne in January to RM 3.48 per tonne in June (Fig. 5). Unit cost was lowest on hilly blocks (RM 4.22 per tonne) and highest on flat blocks (RM 4.92 per tonne), a direct consequence of the throughput pattern in Section 3.2 rather than of any cost advantage in hilly working.

3.5 Sensitivity to Capital Charge

Extrapolating the observed mean throughput over a 312-day working year gives an annual capacity of approximately 6,330 t for the unit. Applying straight-line depreciation over a seven-year service life, a capital cost of RM 60,000 adds RM 1.35 per tonne and a capital cost of RM 120,000 adds RM 2.71 per tonne, giving total unit costs between RM 5.53 and RM 6.89 per tonne (Table 5). The capital charge is thus material but not dominant, and it is diluted by exactly the throughput gains documented in Section 3.3: at the January throughput rate the same capital charge would be 73 per cent higher per tonne than at the June rate.

3.6 Benchmark Comparison

Table 6 places the measured MPC performance alongside published figures for grabber-based mechanised collection and for manual collection. The MPC unit averaged 20.30 t per machine-day over the full record and 25.69 t in its best month, against the 27.5 t per day reported for a scissor-lift trailer and FFB grabber combination [5]. Manual collection rates of 0.99 to 2.24 t per worker-day [2] imply that the measured MPC output is equivalent to the collection capacity of roughly 9 to 21 workers. Applying the estate's own daily wage of RM 72.58 to those manual rates gives an indicative manual collection cost of RM 32 to RM 73 per tonne, against RM 4.18 per tonne measured for the MPC on an operating basis and RM 5.53 to RM 6.89 per tonne once a capital charge is included.

4. DISCUSSION

4.1 The Terrain Penalty Falls on Labour, Not on the Machine

The clearest result of this study is also the least intuitive: terrain class had no measurable effect on how much FFB the machine moved per day, but a very large effect on how much each harvester contributed. This follows directly from the platform-dependent architecture of the MPC. Because the machine lifts only from the platform, the difficulty of the terrain is absorbed upstream, in the manual carry from palm circle to platform, before the machine is engaged at all. The estate compensated in the only way available to it, by deploying larger gangs on hilly blocks, and the compensation is visible as a 52.5 per cent collapse in output per harvester relative to undulating blocks.

This has a direct measurement implication for estate management. Where mechanisation performance is monitored on machine tonnes per day, as it commonly is, the terrain penalty is invisible: the hilly blocks in this dataset returned the highest mean machine throughput of the three classes. The penalty appears only when throughput is normalised by the number of harvesters the machine supports. Estates evaluating platform-dependent equipment should therefore treat output per harvester served, not machine tonnes per day, as the primary key performance indicator, since it is the measure that tracks the labour cost the mechanisation was purchased to reduce.

4.2 Fleet Configuration: Where MTG and MPC Belong

The functional difference between the two machines maps onto this result with unusual clarity. The MTG eliminates the manual carry step entirely, recovering bunches from the palm base without a platform, but cannot operate on undulating or hilly ground. The MPC operates on any terrain but preserves the carry step in full. The awkward consequence for this estate is that the blocks where the manual carry burden is heaviest, and where per-harvester output is therefore lowest, are precisely the blocks the MTG cannot enter.

The deployment rule this implies is straightforward. On flat blocks the MTG should be preferred wherever it is available, because it removes the labour step that the MPC leaves intact; the flat blocks in this dataset carried 45.7 per cent of machine-days and returned an intermediate per-harvester output of 5.20 t, which an in-field grabber would be expected to raise further. On undulating and hilly blocks the MPC is the only mechanised option of the two, and the management lever available there is not machine choice but platform density and siting, since platform spacing determines the length of the carry that remains manual. Reducing the mean carry distance on hilly blocks is likely to yield a larger productivity gain per Ringgit than any further investment in machine capacity, given that machine throughput on those blocks was already the highest recorded.

4.3 Commissioning Effects Dominate the First Two Quarters

The 27.9 per cent improvement between the first and second halves of the record, and the 72.9 per cent gap between the first and the peak month, are larger than any terrain or block effect measured in this study. Because a single operator worked the unit throughout, the improvement combines operator skill acquisition, route and platform learning, and the progressive adjustment of gang deployment to the machine's rhythm; the present data cannot apportion it among these. What the data do establish is the magnitude and the time scale, and both matter for how mechanisation is evaluated.

An estate that trials a new evacuation machine for one month and compares the result against published benchmarks would, on the evidence here, record 14.86 t per day against a benchmark of 27.5 t per day and conclude that the machine underperforms by 46 per cent. The same machine, assessed in month six, returns 25.69 t per day, within 7 per cent of that benchmark. Unit cost moves in step, from RM 6.26 to RM 3.48 per tonne. Evaluation windows shorter than one quarter therefore carry a systematic downward bias, and investment appraisals built on them will understate the return and may lead to premature abandonment of equipment that is in fact performing normally for its stage of commissioning. A minimum four-month assessment period, with the first quarter reported separately as a commissioning phase, is the practical recommendation arising from this study.

4.4 Unit Cost is a Throughput Problem, Not a Fuel Problem

The cost structure recorded here is unambiguous: the operator wage accounted for 85.9 per cent of daily operating cost and machine running cost for the remaining 14.1 per cent. Since the operator is paid by the day rather than by the tonne, daily cost is effectively fixed and unit cost is determined almost entirely by the tonnage moved. A 10 per cent improvement in daily throughput reduces unit cost by approximately 9 per cent, whereas a 10 per cent reduction in fuel and maintenance spend reduces it by about 1.4 per cent. Management attention directed at throughput determinants, namely gang synchronisation, platform siting, route sequencing and the elimination of machine idle time waiting for crop, is worth roughly six times more than an equivalent proportional saving on running cost.

The comparison with manual collection reinforces the point while requiring care in interpretation. On an operating basis the measured RM 4.18 per tonne is an order of magnitude below the RM 32 to RM 73 per tonne implied by published manual collection rates at this estate's wage level, and it remains far below that range once a capital charge of RM 1.35 to RM 2.71 per tonne is added. That comparison should not be read as a measured saving, however, because the manual rates are taken from the literature rather than observed at this site, and because the MPC does not replace the manual carry step; the harvesters counted in the denominator of the per-harvester measure are still performing it. The correct statement is narrower: mechanised lifting and hauling from platform to roadside is very cheap per tonne relative to the labour it displaces, and the residual manual carry is where the remaining cost sits.

Table 1. Functional comparison of the two mechanised in-field FFB evacuation systems

Attribute	**Mini platform collection (MPC)**	**Mini tractor grabber (MTG)**
Configuration observed	45 hp mini tractor, hydraulic grabber, tipping trailer	Mini tractor with hydraulic grabber
Crop pick-up point	In-field platform only	Palm base and interrow, scattered
Platform required	Yes	No
Manual carry step	Retained in full	Eliminated
Terrain suitability	Flat, undulating and hilly	Flat blocks only
Principal constraint	Carry distance to platform	Ground condition and manoeuvring space
Status in this study	Measured, 175 machine-days	Published benchmark only

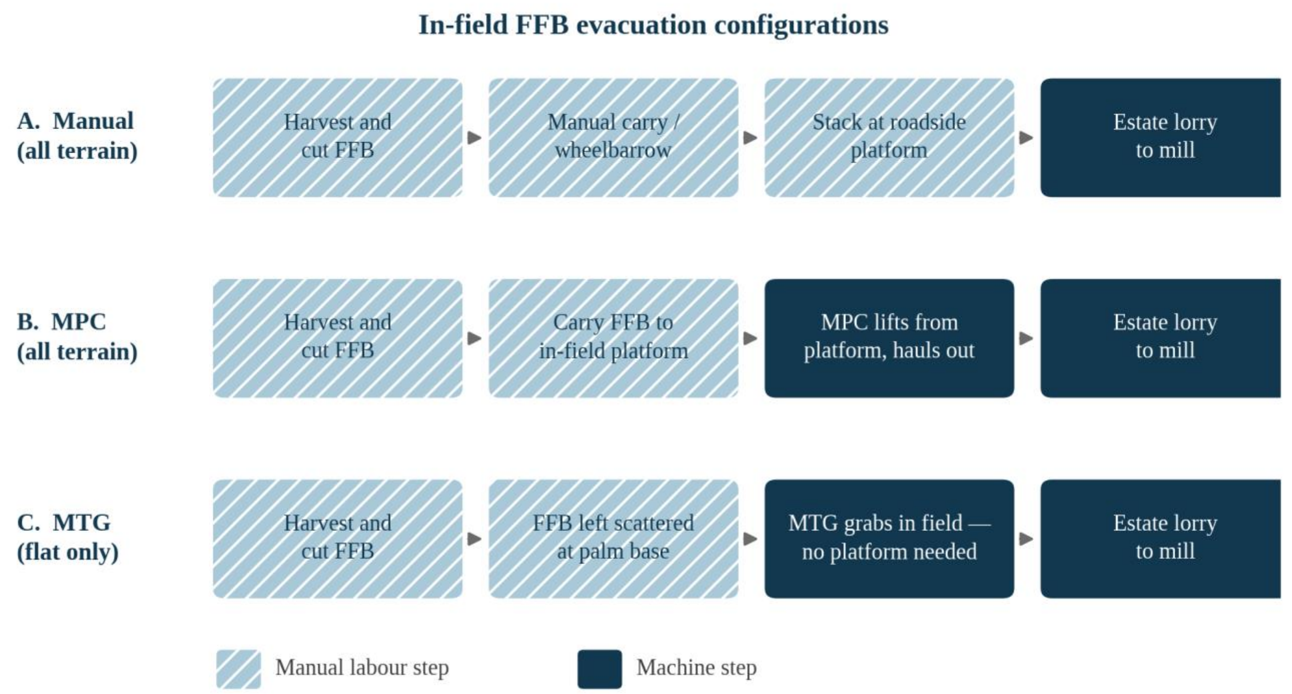

Fig. 1. Process flows for the three in-field FFB evacuation configurations. Hatched steps are performed manually; solid steps are performed by machine

Table 2. Daily operating performance of the MPC unit over the full record (n = 175 machine-days, 1 January to 31 July 2026)

Indicator	**Value**
Total FFB evacuated (t)	3,552.4
Mean daily throughput (t machine-day^{-1})	20.30
Standard deviation (t)	5.62
Coefficient of variation (%)	27.7
Median daily throughput (t)	20.14
Minimum, maximum (t)	2.52, 32.06
Mean hourly rate (t h^{-1}, 9.5 h day)	2.14
Mean harvesters served (workers day^{-1})	4.29
Mean output per harvester (t harvester^{-1} day^{-1})	5.23
Mean area covered (ha day^{-1})	3.94
Machine-days below 15 t (n, %)	28, 16.0

Fig. 2. The MPC unit in routine operation on the study estate: (a) the 45 hp mini tractor with mounted hydraulic grabber and tipping trailer positioned alongside an in-field platform, the vehicle registration masked for anonymity; (b) the grabber lifting bunches from a platform heap into the trailer; (c) a bunch in the grabber jaws being placed into the loaded trailer; (d) a fully loaded trailer at a collection point on a flat block. Photographs taken by the author during the observation period

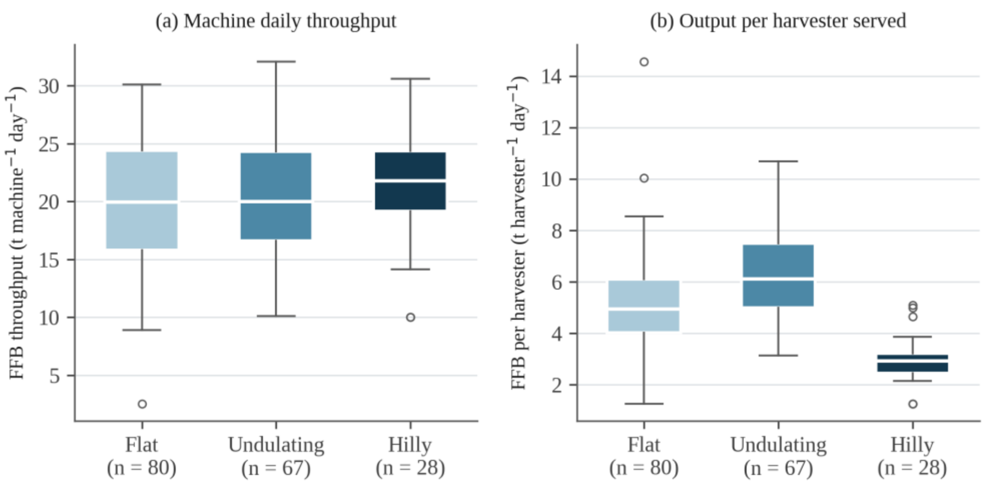

Fig. 3. Distribution of (a) machine daily throughput and (b) output per harvester served, by terrain class. Boxes span the interquartile range, whiskers extend to 1.5 times that range and circles mark values beyond it

Table 3. MPC performance by terrain class, with tests of difference between classes

Indicator	Flat	Undulating	Hilly	Test statistic	p
Machine-days (n)	80	67	28	-	-
Share of record (%)	45.7	38.3	16.0	-	-
FFB evacuated (t)	1,593.3	1,360.1	599.0	-	-
Daily throughput (t day^{-1})	19.92	20.30	21.39	F = 0.71	0.491
Standard deviation (t)	5.88	5.54	5.07	-	-
Harvesters served (n day^{-1})	3.99	3.33	7.43	-	-
Output per harvester (t day^{-1})	5.20	6.21	2.95	F = 32.46	< 0.001
Area covered (ha day^{-1})	3.65	3.84	5.00	-	-
Crop per hectare (t ha^{-1})	5.49	5.60	4.28	-	-
Unit operating cost (RM t^{-1})	4.92	4.53	4.22	-	-

Table 4. Block-level summary of MPC operations, ordered by terrain class

Block	Terrain	Machine-days	Area (ha day^{-1})	Harvesters	Throughput (t day^{-1})	Per harvester (t day^{-1})	Total FFB (t)
01A	Flat	2	3.00	3.0	13.60	4.54	27.2
08B	Flat	6	3.17	2.2	13.97	6.63	83.8
09A	Flat	31	4.00	5.0	21.40	4.28	663.3
10A	Flat	22	3.91	4.0	20.85	5.21	458.7
14B	Flat	19	3.00	3.0	18.96	6.32	360.2
12A	Undulating	28	5.00	3.0	20.93	6.98	585.9
12B	Undulating	17	3.00	3.0	19.27	6.42	327.6
13A	Undulating	22	3.00	4.0	20.30	5.07	446.6
21A	Hilly	20	5.00	8.0	20.70	2.59	414.0
23A	Hilly	8	5.00	6.0	23.13	3.85	185.0

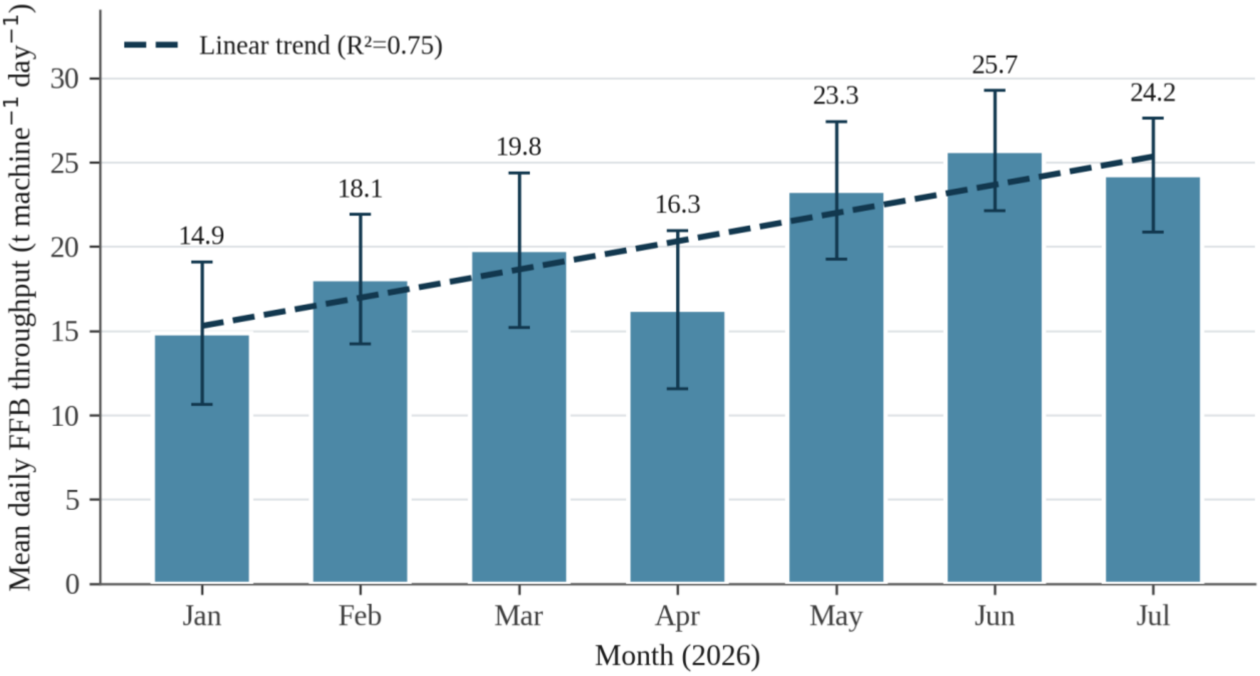

Fig. 4. Mean daily FFB throughput by month with standard deviation bars and fitted linear trend, January to July 2026

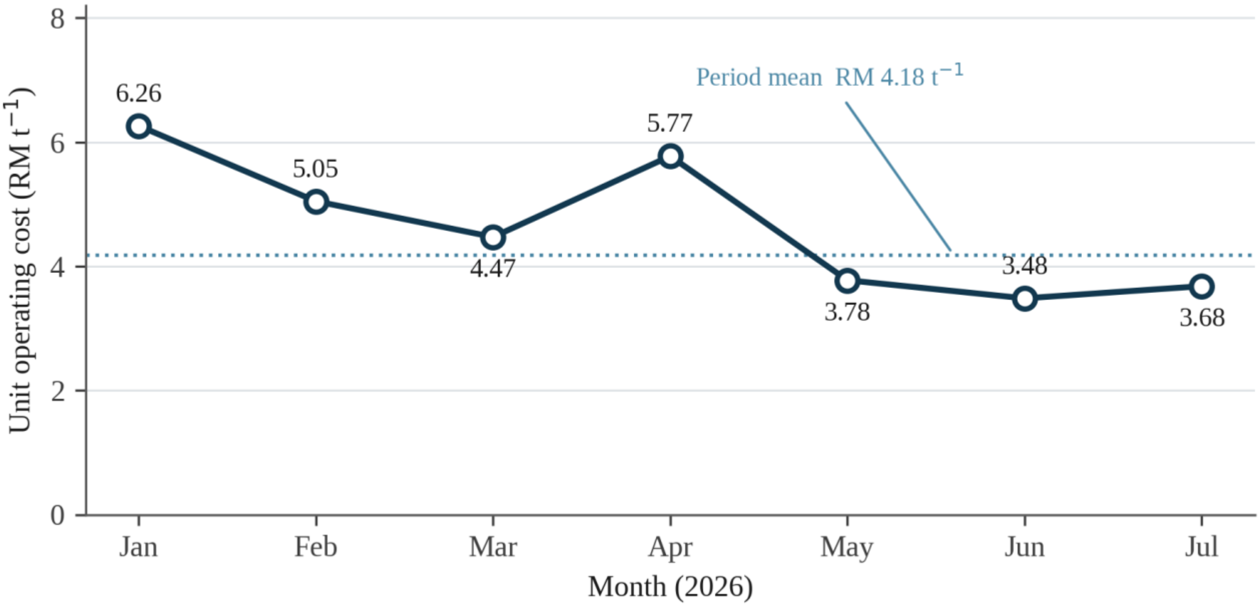

Fig. 5. Monthly mean unit operating cost of mechanised FFB evacuation, January to July 2026

Table 5. Sensitivity of total unit cost to undisclosed capital cost, assuming straight-line depreciation over seven years and an annual throughput of 6,330 t

Capital cost (RM)	Annual capital charge (RM)	Capital component (RM t^{-1})	Total unit cost (RM t^{-1})
60,000	8,571	1.35	5.53
80,000	11,429	1.80	5.98
100,000	14,286	2.26	6.44
120,000	17,143	2.71	6.89

Table 6. Benchmark comparison of in-field FFB evacuation systems. Only the MPC row was measured in this study; the remaining rows are published values reproduced for comparison

System	Output	Unit cost (RM t^{-1})	Source
MPC, full record	20.30 t machine-day^{-1}	4.18 operating	This study
MPC, best month	25.69 t machine-day^{-1}	3.48 operating	This study
MPC with capital charge	20.30 t machine-day^{-1}	5.53 to 6.89	This study
Scissor-lift trailer with FFB grabber	27.5 t day^{-1}	Not reported	[5]
Manual collection, assisted	2.24 t worker-day^{-1}	32.4 indicative	[2]
Manual collection, unassisted	0.99 t worker-day^{-1}	73.3 indicative	[2]

4.5 Implications for Labour, Certification and Sustainability Reporting

At the measured throughput, a single MPC unit performs the platform-to-roadside movement that manual methods would require in the order of 9 to 21 workers to accomplish, on the published rates cited above. For an estate operating below the 10:1 land-to-labour ratio considered efficient [2], this is a material easing of the binding constraint rather than a wholesale displacement of labour, since the released capacity is typically redeployed to harvesting and upkeep rather than removed from the payroll. The ergonomic dimension is equally relevant: repetitive manual handling of bunches weighing 10 to 25 kg over uneven ground is a recognised source of work-related musculoskeletal disorder among plantation workers [8], and any reduction in carry distance and carried mass has occupational safety and health value independent of its productivity effect.

These outcomes connect directly to certification and disclosure obligations. Malaysian Sustainable Palm Oil certification places explicit requirements on safe working conditions and worker welfare, and the certification literature identifies implementation cost and capability as the principal barriers to Operational records of the kind analysed here provide auditable evidence for both the safety and the labour-productivity dimensions of that reporting, at no additional data-collection cost, since the register already exists. Estates seeking to substantiate environmental, social and governance claims about working conditions would gain more from analysing the registers they already maintain than from commissioning new studies.

4.6 Limitations

Five limitations bound these conclusions. First, the study observed a single machine operated by a single operator, so machine capability and operator skill are confounded and the results should not be read as a population estimate for MPC units generally. Second, no MTG operating records were available for the estate; all MTG figures in this paper are published benchmarks and the fleet deployment rule proposed in Section 4.2 is a hypothesis derived from machine architecture, not a measured comparison. Third, capital cost was not disclosed and has been handled by sensitivity analysis rather than by measurement. Fourth, terrain was classified categorically from estate records rather than measured as slope gradient, which prevents any dose-response analysis of terrain severity. Fifth, the register records tonnage evacuated but not bunch losses, loose fruit recovery or crop quality at the ramp, so the analysis addresses the quantity of crop moved and not the quality with which it was moved.

5. Conclusion

Analysis of 175 consecutive machine-days of routine operating records from a mini platform collection unit on a Kedah oil palm estate produced three findings of operational consequence. Machine throughput averaged 20.30 t per machine-day and was statistically invariant to terrain class, but output per harvester served fell by more than half on hilly blocks, showing that the terrain penalty of platform-dependent evacuation is borne by the harvesting gang rather than by the machine. Throughput rose 27.9 per cent between the first and second halves of the record and 72.9 per cent between the first and the peak month, so that evaluation windows shorter than one quarter systematically understate performance and overstate unit cost. Operating cost was RM 4.18 per tonne, of which the operator wage constituted 86 per cent, making unit cost a function of throughput rather than of running expenditure.

Three recommendations follow. Estates evaluating platform-dependent evacuation equipment should adopt output per harvester served as the primary performance indicator, since machine tonnes per day conceal the terrain penalty entirely. Machine assessments should run for a minimum of four months with the first quarter reported separately as a commissioning phase. On flat blocks, where an in-field grabber can operate, the MTG configuration should be preferred because it removes the manual carry step that the MPC retains, while on undulating and hilly blocks the productive lever is platform density and siting rather than machine capacity.

The priority for further work is a matched-block comparison of MTG and MPC operating on the same estate under the same crop and gang conditions, with slope measured as a continuous variable and with bunch loss and loose fruit recovery recorded alongside tonnage. Such a design would convert the deployment rule proposed here from an architecture-based hypothesis into a measured decision rule, and would allow the residual manual carry cost, which this study identifies as the location of the remaining inefficiency, to be quantified directly.

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