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OIL PALM PLANTATION MECHANISATION IN TOTALITY

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ABSTRACT

Scarcities of labour and low labour productivity are seen to be the unending characters in the oil palm plantation industry in Malaysia. The two characters could be regarded as the pertinent push factors for an holistic implementation of a sustainable mechanisation programme in the oil palm plantation. A complete machinery package that adopts the concept of mechanisation in-totality has been designed, developed and evaluated to offer a solution to the problems. The package consists of a universal single chassis, 4WD, 4WS prime mover with selectable and easily mounted machine attachments for soil filling in polybags, seedling transplanting, VRT band fertilising, herbicide circle spraying, herbicide blanket spraying, and in-field fresh fruit bunch (FFB) collection-transportation. The prime mover design was such as to allow better control and comfort to the operator under the harsh field environment and at the same time give greater maneuverability and stability to the overall machine system under the rugged terrain condition. Good feature with the machine system is that the units are self-propelled and self-contained, completely integrated having a continuous once-over-operation, simple in construction and operation and at the same time economical and reliable to be adopted. This new and innovative technology has great potential in maintaining the country's oil palm industry competitive edge through alleviation of labor shortage and enhancement of labor productivity.

***Keywords**: oil palm cultivation, oil palm mechanisation, plantation machinery, machine system, tree crop machinery*

INTRODUCTION

Oil palm is an important crop in Malaysia because the income and activities related to the crop contributes significantly to the country's Gross National Income (GNI). The country produced more than 17 million tonnes of oil palm from the available planted area of 4,487,957 hectares in 2008. This accounts for 41.12 % of the world's total palm oil production and 45.84% of the world's palm oil exports. Likewise, it contributes 12.20% to the world's total oil and fats productions and 26.26% to the world's oils and fats export. By 2020, the oil palm industry is expected to generate RM178 billion income and 41,000 new employments for the country out of which 40% of the total employment will be for high-skilled workers having average monthly income of RM6,000 [1].

Currently, oil palm plantations in Malaysia adopt a low technology and high labour based production system. The industry for the past two decades had relied so much on foreign labours because the stigma of hard and uncomfortable working environment has discouraged the locals to work in the plantations. According to Dompok [2], there are about 491,339 foreign workers that make-up 76 % of total workforces in the oil palm plantation. However, the present shortage in supply of foreign workers is seen to be a bottle neck that will constrain the future competitiveness of the oil palm industry. He reported a severe shortage of about 35,473 workers that currently exist in the oil palm plantations. Thus, there is an urgent need for a paradigm shift in the oil palm industry from heavy dependency on foreign labour to that of mechanisation. In relation to this, Veloo and Hitam [3] stated that there are about 194,000 hectares of oil palm plantation areas in Malaysia that have been identified as suitable for the complete adaptation of mechanisation.

Mechanisation advancement in the oil palm plantations has been at very slow pace since the beginning of the industry in the country. Veloo and Hitam [3] reported that the current practice of mechanised activities in the oil palm plantation was only 30% of the total 194,000 hectares of plantation area that have been identified as suitable for the implementation of mechanisation. Such low percentage of mechanised activities was highlighted by the labour to hectarage ratio of 1: 8 as compared to the projected ratio of 1:12 to15 if the whole 194,000 hectares is to be mechanised. Such a slow advancement of mechanisation was also indicated by the country's tractor to agricultural worker ratio of 1:42 as compared to the ratio 1:1.3 in Japan and ratio of 2:1 in United States of America [4].

High usage of human energy in most of the oil palm field cultivation operations was reported by Pebrian et. al [5]. As indicated in table 1, only six field operations out of the total 21 field operations (i.e about 19 % of total field operations) could be classified as light work on the basis of the strenuous levels by Christenson [6]. The field operations that were categorized as light work include planting germinated seeds in small polybag, spraying at nursery, tractor assisted holing, mainline transportation, tractor assisted in-field FFB collection-transportation and tractor assisted pest control. The remaining field operations were categorised under heavy to moderate work and the operations involved are conducted manually without the support of machines. Pebrian et al [7] also reported that the typical total annual human energy inputs in oil palm cultivation was about 1.61 times greater than the typical total annual human energy inputs in rice cultivation which indirectly indicate that the status of mechanisation in rice is slightly better than that of oil palm in Malaysia.

One of the main factors that hinder the advancement of mechanisation in the oil palm plantation is the unavailability of suitable prime mover to meet the requirements of the plantation terrains. Pebrian and Yahya [8] mentioned that the plantations do not have much choices of prime mover to use other than the imported 2WD and 4WD wheeled tractors. Both of these tractors have much limitation in carrying out the field cultivation operations with the available implements on the challenging hilly and undulating plantation terrains. Generally, up to 50% of the total land area in Peninsular Malaysia and Sabah is categorised as hilly terrain, while in Sarawak, it is more than 70% of the total land areas. The plantation area that is meant for tractor use need to be well-prepared and free from obstructions of old timbers, fallen trees or palms, gullies, potholes and mounds. Furthermore, these imported wheeled tractors and the available implements were designed to meet the farming requirements of arable field crops and not for plantation tree crops like oil palm. As a result, adaptation of these tractors and their implements for the oil palm plantations will not be justifiable in terms of performances with respect to work efficiency and quality.

Table 1 : Field capacity and energy expenditure for individual oil palm operation at nursery and field stages

Stage[1]	Operation	Effective field capacity (bags/h/man or ha/hr/man)	Energy expenditure (kcal/h/man)
Nursery	Holing in large polybags	130	673.20
	Seedlings delivering	304	444.80
	Soil toping in large polybags	53	297.80
	Transferring large polybags	32	287.10
	Soil fillings in large polybags	15	238.30
	Soil fillings in small polybags	118	216.70
	Seedlings planting in large polybags	136	202.8
	Spraying	242	85.50[d]
	Planting germinated seeds in small polybags	458	59.20
Field	Lining	0.49	399.10
	In-field loose fruit collection	0.56	319.30
	Seedlings delivering	0.65	294.00
	Immature palm fertilising	0.72	287.90
	Seedlings planting	0.71	284.60
	Mature palm fertilising	5.13	250.80
	Circle spraying	0.55	226.40
	Harvesting	0.87	156.30
	Holing	0.59	48.49
	Mainline transportation	1.50	39.88
	In-field FFB collection- transportation	1.49	5.34
	Pest control	4.39	3.34

[1]Units for effective field capacities for the nursery stage operations are in bags/h/man while for the field stage operations are in ha/hr/man

Source : Pebrian et. al (5)

This paper introduces a complete machinery package that has been designed and developed based on the concept of mechanisation in-totality for the oil palm plantation in Malaysia. The field performances and

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economic evaluation of the individual machine system are presented and compared with the currently employed methods in the oil palm plantation.

MATERIALS AND METHOD

Overall Machines Concept for Mechanisation In-Totality

The configuration of machinery package for oil palm plantation mechanisation in totality consists of a universal four wheel drive (4WD), four wheel steer (4WS) prime mover that is efficiently able to traverse the soft and hilly terrains and with a number of individual machine attachments that have been specially designed for the various critical oil palm field cultivation operations. The individual machine attachments are for soil bagging, seedling transplanting, variable rate technology (VRT) band fertilising, herbicide circle spraying, herbicide blanket spraying, and in-field FFB collection-transportation operations.

The following criteria were considered in the formulation of universal prime mover for the machinery package:

- Simple in design, construction and operation with affordable initial and maintenance cost.
- Completely mechanised system for better operator's comfort and machine output capacity.
- Single chassis type with articulating axles, four-wheel drive, four-wheel steering for better traction and better mobility on undulating plantation terrain.
- Optimum machine total mass with respect to the wheel-ground contact area for better floatation and minimum soil compaction on the plantation terrain.
- Optimum wheelbase and width based on the standard plantation field layout for good in-field manoeuvrability and headland cornering.
- Low centre of gravity for good machine stability on inclined plantation terrain.
- Robust in construction for good machine durability against the roughness of the plantation terrain.
- Wide-open space main chassis with sufficient mounting points and hydraulic power auxiliary points for mounting various machine attachments.

4WD Universal Prime Mover

The 4WD 4WS universal prime mover shown in figure 1 runs on a 51 kW water-cooled Kubota V-3300 diesel engine with a rated speed of 2600 rpm that is directly coupled to a Sauer Danfoss Series 40 hydrostatic pump with a displacement of 46 cm^3/rev at continuous pressure of 210 bar. The engine size selection of the prime mover was made based on established traction equations developed by Wong [9] and Bekker [10]. Pertinent soil and machine parameters summarized in table 2 were used in the calculations involved. The prime mover tyres were considered rigid since the terrain was sufficiently soft and the tyre has little deflection. On the basis of calculation, the selected engine power was found to be more than sufficient to run the prime mover for the respective field operations at the speed of 6.7 km/h on the worst mineral soil terrain condition that might exist in the oil palm plantation.

Fig. 1: Prototype universal prime mover.

Table 2: Pertinent soil and machine parameters

Design consideration	Parameters	Unit
Soil	Pressure sinkage parameter due to soil cohesiveness	1.87 kN/m^{n+1}
	Pressure sinkage parameter due to soil friction angle	98.08 kN/m^{n+2}
	Soil deformation exponent	0.4
	Soil cohesiveness	9.07 kPa
	Soil angle of internal shearing resistance	37 degrees
	Soil shear deformation modulus	0.065 m
Machine	Prime mover total weight	22.95 kN
	Maximum total weight of prime mover with the designed machine attachment with payload	41.59 kN
	Prime mover wheel base	2.25 m
	Prime mover centre gravity height	0.88 m
	Prime mover maximum operating speed (ASABE, 2008)	4 to 11 km/h
	Tyre radius	0.425 m
	Tyre width	0.31 m
	Tyre cornering stiffness	47.82 kN

On the basis of calculation, the selected engine power was found to be more than sufficient to run the prime mover for the respective field operations at the speed of 6.7 km/h on the worst mineral soil terrain condition that might exist in the oil palm plantation. The Sauer Danfoss Series 40 main pump runs two units of Eaton Char-Lynn Series 2000 hydraulic motors with a displacement of 245 cm^3/rev at continuous pressure of 205 bar in the close loop system to enable the prime mover to be propelled in either series or parallel drive modes.

Tubular ladder structural frame was adopted on the prime mover main chassis to support the engine and hydrostatic transmission, axles and drive wheels, driver compartment and controls, and implement attachment as per requirement for the field operations. The main chassis is equipped with two oscillating axles with each axle having a pair of spring suspensions and a pair of 12-16.5 tyre sizes. The chassis beams are provided with mounting point for the individual machine attachments to be used.

Soil Bagging Machine Attachment

The soil bagging machine attachment shown in figure 2 was developed for the universal prime mover for the purpose of mechanising the mixing and filling the soil medium into the seedling polybags at the oil palm nursery. The machine attachment configuration consists of the soil hopper, soil agitator, screw delivery auger, auxiliary power unit, and detachable loading trays and trolley. The soil hopper could accommodate about 1.5 tons of planting medium at one time and able to produce about 1071 seedling polybags for every filing operation with the 15.3 cm X 23.8 cm size seedling polybag. The hopper is trapezoidal in shape with its inclined side walls equipped with 4 miniature hydraulic cylinders which are used to collapse the sides wall inwards to overcome the soil clogging soil problems on the hopper side walls. The soil agitator was designed to break the soil clods and at the same time to mix the soil in the hopper. The auxiliary hydraulic system provides the fluid power to run all the available functional machine elements of the whole machine attachment. A screw type delivery auger was designed to deliver the soil from the screw feeder auger at the required flow rate to fill the polybag through the outlet chute. A seat was provided at the back of the soil hopper for the operator to seat while performing the soil filling operation. The tray support platforms were located at both sides in front of the operator to place the detachable trays for accommodating the soil filled polybag. Soil agitator had 4 blades and was designed to break the small clods of soil and at the same time to mix the soil in the soil hopper.. The operation of the auger motor is controlled by pressing switch that is located at a close vicinity to the machine operator seat. Special wooden tray of 610 mm wide X 610 mm length and 150 mm height with side handles were designed to carry eight polybags filled with planting medium. The trays are located on the available tray platforms at both sides of the operator seat for the machine. Prior to the actual soil filling in polybag operation, soil hopper had to be filled with the soil to its load capacity using a front mounted loader. While loading the soil in the hopper, the soil agitator was set to rotate to break the soil clogs and thoroughly mix the soil content in the hopper. This agitation operation was set run for an extended duration even after the completion of the filling operation. Two operators are needed to conduct the soil filing operation in polybags; one as a driver and also an operator to conduct the soil filling operation and another operator to transfer the wooden boxes with soil filled polybags to the arrangement location using the special made trolley. The filling operator collects the outgoing soil from the hopper by placing the polybag at the mouth of the delivery chute. Once the polybag is filled with soil, he releases the foot control pedal of the delivery auger and at the same time lifts the soil filled polybag into the wooden tray at his sides. He continues by putting a new polybag at mouth of the delivery chute and stepping on the foot control pedal of the delivery auger to allow the soil to come out and fill the new empty polybag. The other operator loads three wooden trays with soil filled polybags on the specially made trolley to transfer the soil filled polybags to a close-by seedling arrangement location. He returns the empty wooden tray to the machine system and places the trays on the tray platform of the machine before taking another set of wooden trays with soil filled polybags for the next transferring task. These activities would be repeated until the targeted number of soil filled polybags for the day's operation with the machine system has been achieved.

Fig.2: Prototype universal prime mover with soil bagging attachment.

Seedling Transplanting Machine Attachment

The seedling transplanting machine attachment shown in figure 3 was developed for the universal prime mover for the purpose of mechanising the planting of oil palm seedlings in the field plantation. The machine attachment configuration consists of a seedling bin, support sleeves, planting assembly, operator compartment and auxiliary hydraulic system [11]. The seedling bin was designed to accommodate a maximum of 28 palm seedlings per machine trip which will cater for the number of available planting points within a planting row in any standard oil palm plantation layout having 18 to 24 seedlings per planting row. The support sleeves allow for vertical movements of the planting assembly and tilting position adjustments of the planting assembly to the terrain slope. The seedling planting assembly was made-up of drilling unit and placement-covering unit. The drilling unit functions to prepare the planting hole while the placement-covering functions to deliver seedling into the prepared hole, cover seedling in the hole using the available drilled out soil, and lastly compact soil around the planted seedling. The operator compartment provides the work space for the operator to perform all functional operations of the transplanting machine that are involved in the planting activities of the seedling. The auxiliary hydraulic system provides the fluid power to run all the available functional machine elements of the whole machine attachment. The whole operation involves two operators; one as the driver for the prime mover and the other as the operator for the seedling transplanting attachment on the prime mover. This machine system is able integrate all the individual activities within a single planting operation in one machine pass. The activities include adjusting the vertical drilling position in sloppy terrain, preparing the planting hole, delivering the seedling into the prepared hole, covering the seedling in the prepared hole, and compacting the soil around the planted seedling. Prior to the planting operation, identifying and marking of the planting points in the field was carried out using a portable hand held Real Time Kinematic Global Positioning System (RTK GPS) unit. The transplanting operation begins with loading 24 seedlings into the seedling bin and filling 50 kg of CIRP fertiliser inside the fertiliser plastic container on the seedling bin. Once it is ready, the driver drives the machine system to the location of the first planting point in the first planting row to plant the seedlings. Whenever the seedling bin has become empty, he drives the machine to the seedling supply point to reload the next 24 seedlings into the bin for planting for the next planting row. These activities would be repeated until the assigned field area for the day's operation with the machine system had been planted.

Fig. 3: Prototype universal prime mover with seedling transplanting attachment.

VRT Band Fertilising Machine Attachment

The VRT band fertilising machine attachment shown in figure 4 was developed for band application of granular fertiliser at both sides within the targeted location where the cut fronds are stacked in the field plantation [12]. The machine configuration comprises of a 1.2 ton fertilizer bin, screw conveyor, two rotary valve metering units and two centrifugal turbo blowers. Components of the variable rate system for the machine include long range UHF RFID reader/tag, compactRIO embedded system, control computer system, rotary valve electric motors and 2 kVA generating set. The screw conveyor and the turbo blowers are powered by hydraulic motors with supply from the hydraulic power outlets of the prime mover. The fertilizer inside the bin is transferred by the screw conveyor to the rotary valves which meter the precise amount of fertilizer that is blown out by the centrifugal blowers. One passive RFID tag is attached to an oil palm tree for each fertilizer dosage required for each section of the plantation. Prior to fertiliser application, a prescription table that contains plane coordinates, RFID tag ID and required fertiliser dosage is prepared and stored in the control computer system. As the VRT applicator moves in the plantation, the RFID tag ID is read by the RFID reader and sent to the computer system. The compactRIO embedded system in conjunction with the computer system adjusts the rotary valve speed to meter the precise amount of fertilizer according to the prescription table. Hence, the metered fertilizer is blown to the stack of cut fronds at the target area of 4 to 12 metres on either side of the machine path.

Fig. 4: Prototype universal prime mover with VRT fertilising attachment.

Herbicide Circle Spraying Machine Attachment

The herbicide circle spraying machine attachment shown in figure 5 was developed for herbicide application around the palm circumference in the plantation to reduce nutrients competition between the palms and weeds and at the same time to facilitate effective fertilising, harvesting, and in-field loose fruit collection-transportation [13]. The configuration of the herbicide circle spraying attachment consists of the hexagonal curved spray boom, lifting arm, opening-tilting mechanism unit, 600 L storage tank, spray pump, solid cone nozzles, and associate hydraulic system. The hexagonal curved spray boom for circle spraying comes in 2 sizes; the boom with 72.50 cm side length for immature palms and the boom with 97.50 cm side length for mature palms. Both of these hexagonal curved booms have been designed to accommodate a circle spraying radius of 100 cm and 175 cm at the nozzle height position of 60 cm from the ground for immature and mature palms, respectively. The whole operation involves one operator who acts both as the driver for the prime mover and the operator for the circle spraying attachment on the prime mover. The operator drives the machine system along the machine path and stop at each individual palms on both sides of the planting rows in a zig-zag manner to do the circle spraying of the individual palms. When the machine system is close to the palm to be sprayed, he actuates the control lever to adjust the lifting arm of the spraying unit to the required spraying height before actuating the other control lever to enclose the hexagonal curved spray boom arms around the palm trunk. He triggers the toggle switch below the steering wheel to operate the pump for the nozzles that spray on the targeted weed area around the palm. Once spraying is completed, he actuates the control lever to open the hexagonal curved spray boom arms and drive the prime mover rearwards to clear pass the palm trunk before driving forward to the next palm in the other side of the palm row. The same operation is repeated for all the palms that are available on both sides of the machine path. Cornering has to be made at the headland before he drives the machine system to enter the next machine path to proceed with the circle spraying operation.

Fig. 5: Prototype universal prime mover with herbicide circle spraying attachment.

Herbicide Blanket Spraying Machine Attachment

The herbicide blanket spraying machine attachment shown in figure 6 was developed for conducting blanket spraying of herbicide along both sides of the palm rows. The operation is normally an optional operation over herbicide circle spraying operation in the plantation and conducted when total weed control along the palm row and machine path is needed to allow unimpeded access for maintenance operations, fertiliser application and general supervision. The configuration of the proposed blanket spraying attachment consists of the collapsible spray boom, 600 L storage tank, spray pump, fan air nozzles, and associated hydraulic systems. The collapsible spray boom has a 10 m full length but could be collapsed rearward at 6 meters from both ends for overcoming the palms and at the same time folded forwards at 3.70 meters from both ends for easy on-road movements and headland cornering of the machine system. Two separate cylinders were used for folding and unfolding the side boom wings while another two separate cylinders were used for raising and lowering the side boom wings. Two helical tension springs were provided to the side boom wings to return back to its initial position after hitting the palms on either row side during the spraying operation. The collapsible spray boom was designed to fulfil the plantation layout with minimum planting row distance of 7.63 m under a standard triangular planting having a density of 148 palms/ha. Similar to circle spraying, the whole operation involves one operator who acts both as the driver for the prime mover and the operator for the blanket spraying attachment on the prime mover. The operator initially operates the control lever to run the spraying pump when he is ready to move the machine system in the field for the blanket spraying operation. He drives the machine system along the machine path at recommended travel speed of 3 to 6.50 km/hr with the nozzles on the spray boom continuously on the targeted weed area. He operates the relevant control levers whenever necessary to raise the side boom wings to overcome the presence of any ground obstacles or uneven ground terrain as he drives the machine system along the machine path.

Fig. 6: Prototype universal prime mover with herbicide blanket spraying attachment.

In-field FFB Collection-transportation Machine Attachment

The in-field FFB collection-transportation machine attachment shown in figure 7 was developed for in-field evacuations of oil palm FFB in the plantation field. Mechanising in-field FFB collection transportation operation is highly recommended to allow minimum delay in transporting the cut fruit bunches to the nearby oil palm mill. The configuration of the in-field FFB collection transportation attachment consists of the clamping jaws, lifting arm, opening-tilting mechanism unit, storage bin, pivot frame, and associated hydraulic system. The lifting arm with the opening-tilting mechanism unit in the circle spraying attachment is also used in the picking assembly of the in-field FFB collection-transportation attachment. The clamping jaws are used with the opening-tilting mechanism here instead of the hexagonal curved spray boom as in the circle spraying attachment. The available miniature hydraulic cylinders on the opening-tilting mechanism permit the clamping jaws to be wide open at 180 degrees and fully tilted at 45 degrees below the horizon. The collection assembly is made-up of the storage bin and the pivot frame. The bin is trapezoidal in shape which is capable of accommodating bunches to a total capacity of 1500 kg. The bin is designed with 45 degrees inclined floor at its rear end to facilitate for easy flowing of the fruit bunches into the collection bin of the mainline transporter during dumping. The frame is used to provide the mounting support for storage bin on the prime mover chassis and the fulcrum point for rear tipping of the storage bin. This fulcrum point on the pivot frame was set to be at 2.80 m height from ground level when the complete collection assembly is mounted on the chassis of the prime mover. It was designed as such so that during full tipping position, the rear end of inclined storage bin bottom is slightly above the collecting bin of a 5 ton lorry which has been commonly used as the mainline transporter in the oil palm plantations in Malaysia. The whole collection transportation operation involves one operator who acts both as the driver for the prime mover and the operator for the in-field FFB collection transportation attachment on the prime mover. The operator then drives the machine system forward to the bunch location and conduct the picking and loading of the fruit bunch on to its storage bin.

Fig. 7: Prototype universal prime mover with in-field FFB collection-transportation attachment.

Cornering is made at the headlands before he drives the machine system to enter the next machine path to continue with the in-field collection transportation operation. Whenever the storage bin has reached its payload capacity, he drives the machine to the road side to dump what is available in the storage bin into the available collection bin at the mainline collection point. Finally, he drives back the machine system with its storage bin empty into the location in the machine paths where he stops the collection operation before within block in the plantation. He repeats these activities until the collection operation for the whole assigned areas is completed.

Field performances and economics evaluation

Field evaluations were conducted to investigate the prime mover field performances with soil bagging attachment, seedling transplanting attachment, VRT band fertilising attachment, circle spraying attachment, blanket spraying attachment, and in-field FFB collection-transportation attachment. The field tests for circle spraying, blanket spraying and in-field collection-transportation operations were conducted at Sime Darby's New Labu Estate in Labu, Negeri Sembilan while for the soil bagging, seedling transplanting and VRT fertilizing operations were conducted at University Putra Malaysia's Agriculture Research Park in Serdang, Selangor. Time motion study was conducted while the actual field operations were conducted in the field and the expected field capacity of the machine systems for the various field operations were computed based on the standard eight working hours per day.

Economics evaluations on the machine systems for the respective field operations were hypothetically conducted based on typical oil palm plantation with 1005 hectares total area and with crop planted at a density of 148 palms/ha [14]. Out of the considered total area, about 80% or 804 hectares was considered to be productive while the remaining 15% or 201 hectares was under replanting or not productive. Table 3 shows that the typical average annual operating hours of the prime mover with the respective machine attachments for the considered plantation hectare area. The standard ASABE procedure [15] was employed to calculate the operating cost of the machine systems for the various field operations. The hypothetical estimates on the initial cost, economic life and annual operating hour of the individual machine system are summarized in table 4. The machine systems were assumed to have salvage values of 10% of its initial purchase price as suggested by Kepner et al. [14]. Tax, shelter, and insurance were considers to be 2% of the total initial costs of the machine systems in accordance to ASABE [15]. An interest rate on the higher extreme value of 10% was assumed under the present economic scenario in Malaysia. Common repair and maintenance factors *RF1* and *RF2* with values of 0.003 and 2.0 from ASABE [15] and common lubricant costs at 15% of the fuel costs as suggested by Kepner et al. [16] were considered for the individual machine system. Daily standard wage of USD12.78 per day for the tractor operator was used in the calculation based on personal communications made with the two plantation managers in the Selangor and Pahang states. Average fuel consumption of 4.73 L/h was considered for the machine system for the VRT band fertilizer application while an average value of 3.13 L/h was used for the machine system for the remaining field operations. These two values were obtained from the earlier conducted field performance test on the machine systems. Finally, the field workers were assumed to work 264 days in a year based on 22 available average working days in a month with an average of 8 committed working hours in a day.

Mathematically, the total operating cost for the individual machine system was calculated using the following equations :

$$TOP = \{[(D_p + I_p + TSI_p + C_{mp})/h_p] + (F_p + J_p + B_p)\}/N_a + \{[(D_a + I_a + TSI_a + C_{ma})/h_a] + B_p\} \quad (1)$$

Where :

TOP	=	total operating cost of machine system, USD/hr
D_p	=	depreciation cost of prime mover, USD/yr
D_a	=	depreciation cost of machine attachment, USD/yr
I_p	=	interests of investment cost of prime mover, USD/yr
I_a	=	interests of investment cost of machine attachment, USD/yr
TSI_p	=	tax, shelter, and insurance cost of prime mover, USD/yr
TSI_a	=	tax, shelter, and insurance cost of machine attachment, USD/yr
C_{mp}	=	accumulated repair and maintenance cost of prime mover, USD/yr
C_{ma}	=	accumulated repair and maintenance cost of machine attachment, USD/yr
F_p	=	fuel consumption cost of prime mover, USD/hr
J_p	=	lubricant cost of prime mover, USD/hr
B_p	=	operator cost of prime mover, USD/hr

B_a	=	operator cost of machine attachment, USD/hr
N_a	=	number of machine attachments, dimensionless
h_p	=	total operating hours of prime mover in a year, hr
h_a	=	total operating hours of machine attachment in a year, hr.

Table 3: Typical total required number of machine systems and their respective annual total operating hours for an average oil palm plantation size

Universal prime movers and its corresponding machine attachments	Frequency of operations in a year, dimensionless	Effective field capacity[1], ha/day or bags/day	Total required number of machine systems, dimensionless	Average annual operating hours for each machine systems[2], h
Universal prime mover	264	-	6	1148
Soil bagging machine attachment	1	1584	1	150
Seedling transplanting attachment	1	0.81	1	1985
VRT band fertilising attachment	3	61.68	1	313
Herbicide circle spraying attachment	4	7.89	2	1630
Herbicide blanket spraying attachment	4	30.61	1	841
In-field FFB collection-transportation attachment	26	14.16	6	1968

[1]Based on average values in bags/day for soil bagging machine operation and ha/day for other field operations.
[2]Calculation on total operating hours for each universal prime mover is made by dividing the total annual operating hour for all the field operations with the total required numbers of universal prime movers.

Table 4: Hypothetical estimates used on cost analysis of the individual machine system[1]

Parameters	Universal prime movers and its corresponding machine attachments						
	Universal prime mover	Soil bagging machine attach.	Seedling transplanting attach.	VRT band fertilising attach.	Circle spraying attach.	Blanket spraying attach.	In-field FFB collection and transportation attach.
Estimated initial cost, USD	19375	12500	6719	14062	1475	1703	707
Estimated economic life, years	14	8	7	8	5	6	5
Total operating hours in a year, hr	1148	150	1985	313	1630	841	1968

[1]Based on a currently rate of USD 1 = RM 3.20.

RESULT AND DISCUSSIONS

Table 5 shows the computed field capacity and the operating cost of the individual machine system for the respective field operations. All the machine systems were successfully able to conduct the intended field operations at the field site. Comparisons on the values obtained were made against the values obtained with the commonly employed method in the oil palm plantation. Table 6 describes the machinery, equipment, tools and manpower that are currently involved in the commonly employed method for the respective field operations in the oil palm plantation. As observed in table 5, the tested machine systems were able to show higher effective field capacity than the current employed methods in the respective oil palm field operation. Improvements in the effective field capacities ranging from 12% to 53.33% were obtained with this new mechanised system. The highest improvement was in the seedling transplanting operation and the lowest improvement was in the in-field FFB collection-transportation operation. The seedling transplanting with the new mechanised system allows the involved tasks of operations to be completed continuously within one single machine pass and to reduce the number manpower involvements from 5 to 3. Unlike with the current employed method, the tasks of preparing the planting hole, delivering seedling to planting hole and seedling planting in planting hole are completed in staggered operations within a certain period of time. Likewise, the soil filling in seedlings polybag operation and the herbicide circle spraying operations with the new mechanised system were able to reduce the labour dependency to complete the operations from 3 to 1 and 4 to 1, respectively. More manpower was utilised in these operations with the current employed method simply to accomplish the task within the allocated time durations for the operation as the current achievable field capacities were still too low. Subsequently, the new mechanised systems for herbicide blanket spraying, in-fielding FFB collection-transportation, and seedling transplanting operations shows reduction in the operation costs ranging from 26.2 to 58.7% with operating cost savings ranging from USD1.21/ha to USD1.32/ha over the current employed method. The highest operating cost reduction was with the herbicide blanket spraying while the lowest reduction was with the herbicide circle spraying operation. High effective capacity with herbicide blanket spraying as compared to herbicide circle spraying (i.e 30.61 ha/day/man compared to 7.89ha/day/man) justifies the much higher operating cost reduction with the new mechanised system over the current employed method in herbicide blanket spraying operation than the herbicide circle spraying operation.

Table 5 : Comparisons on effective capacity and operating cost operations between the new system and current employed method with respective oil palm field operations.

Types of field operations	Effective field capacity			Operating cost		
	New system	Current Method	Difference, %	New system	Current Method	Difference, %
Soil filling in polybag	198 bags/ h/man	118 bags/ h/man	+40.4	USD0.09 /bag	USD0.02/ bag	+77.8
Seedling transplanting	120 seedlings/ day/man	56 seedlings/ day/man[1]	+53.3	USD0.28/ seedling	USD0.52/ seedling	-46.2
VRT band fertilising	61.68 ha/ day/man	37.04 ha/ day/man	+40.0	USD1.53/ha	USD1.10/ ha	+28.1
Herbicide circle spraying	7.89 ha/ day/man	4 ha/ day/man[2]	+44.2	USD3.41/ha	USD4.62/ ha	-26.2
Herbicide blanket spraying	30.61 ha/ day/man	20 ha/ day/man[3]	+34.7	USD0.93/ha	USD2.25/ ha	-58.7
In-field FFB collection-transportation	2.62 ton/ h/man	2.5 ton/ h/man[4]	+12.0	USD1.21/ton	USD2.62/ ton	-53.8

[1] Based on the published planting capacity by Pebrian and Yahya [17].
[2]Based on the published circle spraying capacity of Serena knapsack sprayer by Orme [18].
[3]Based on the claimed blanket spraying capacity of tractor with 10 m width fully mounted spray boom by a local manufacturer.
[4]Based on the published field capacity of tractor and 1 ton trailer with mechanical grabber by PORIM[19].

Table 6: Description of the commonly employed method in the respective oil palm field operation in Malaysia.

Types of field operations	Machinery, equipment and tool	Manpower
Soil filling in polybag	Hoe and plastic scoop	A gang of 3 workers
Seedling transplanting	67kW 4WD tractor with a fully mounted hole digger, 22kW 4WD tractor with a 3 ton trailer loaded with 40 palm seedlings, hoe, knife, and a plastic pail filled with CIRP fertiliser and a plastic cup	A gang of 5 workers
Band fertilising	Plastic pail filled with mineral fertilisers and plastic cup	1 worker
Herbicide circle spraying	Serena 16L Knapsack sprayer filled with herbicides	A gang of 4 workers
Herbicide blanket spraying	30kW 4WD tractor with a fully mounted sprayer boom filled with herbicides	1 operator
In-field FFB collection-transportation	30kW 4WD tractor and 1 ton mini trailer with attached mechanical trailer	1 operator

However, the soil filling in polybag and VRT band fertilising operations in the new mechanised systems resulted in an operation cost increase of 77.8% and 28.1% respectively over the currently employed method despite the reported high effective field capacity with the machine systems. In this case, the initial cost of the machine system has high implication on the calculated machine system operating cost even though the achievable effective field capacity in completing the operation was high. The higher operating cost with these two field operations could be due to the nature of the design and construction of the associated machine attachments which contributed to the increase in the initial cost of the associated machine attachments. It might be possible for the design and construction of these two machine attachments to be revisited for the purpose of reducing their overall costs while at the same time making performance of the machine systems better with much higher achievable effective field capacities. However, VRT band fertilising operation with the new mechanised system provides another inherent advantage where fertilisers can be applied at the precise amount and precise location in the plantation. Hence, fertiliser wastage and pollution of the plantation ecosystem could be eliminated.

CONCLUSIONS

A mechanisation in-totality machinery package for the Malaysian oil palm plantation has been successfully established and tested. The employed machine system concept in the package was introduced with the ultimate objective of looking at the implementation of mechanisation in a holistic way with an effort to reducing labour dependency and increasing labour productivity for the oil palm plantation industry. The conducted field tests proved that the available machine systems in the proposed package showed acceptable effective field capacities with improvements within the range of 12% to 53.3% over the currently employed methods in the plantations. Reductions in operating cost within the range of 26.2% to 58.7% were reported with machine systems for most of the oil palm field operations with the exception of the soil filling in polybag and VRT band fertilising operations. Simplifications on the present design and construction of the soil filling polybag and VRT band fertilising attachments might helps to reduce the initial cost of the machine systems and at the same reduce the operating costs of the machine systems. Additional machine attachments for pest control spraying and in-field looses fruit collection operations should be added to complete the current proposed mechanisation in-totality machinery package for the oil palm plantation industry in Malaysia.

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