Journal of Oil Palm Research Vol. 37 (2) June 2025 p. 312-323
DOI: https://doi.org/10.21894/jopr.2024.0014

MECHANISATION STATUS OF OIL PALM NURSERY AND FIELD CULTIVATION IN WEST MALAYSIA

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ABSTRACT

*Implementation of mechanisation has been the prime need for the Malaysian palm oil industry in order to reduce its foreign labour dependency. Mechanisation Index (MI) was used in this study to quantify the current mechanisation status in both oil palm seedling production and oil palm field cultivation. It was computed according to the expression of the ratio of machine energy to the total human and machine energy utilised in conducting the involved operations. The obtained average overall MI based on the 10 common clusters of operations in the oil palm FFB production was 0.43. The average overall MI for nursery operation was slightly lower than that of field cultivation operation (*i.e.*, MI values of 0.36* vs. *0.41). The three most critical operations for mechanisation in the oil palm field cultivation operation were the FFB harvesting, which included pruning operation (0.08), rat control operation (0.06) and loose fruit infield collection operation (0.09). The MI values approaching zero reflect the extent of human labour dependency on the method used in the field operations, signifying their seriousness. In general, the obtained MI values provide useful information for developing a workable mechanisation strategy that aligns with the specific circumstances of crop production.*

Keywords: crop production, mechanisation indicator, oil palm.

Received: 30 May 2023**; Accepted:** 27 November 2023**; Published online:** 9 February 2024.

INTRODUCTION

The oil palm plantation industry is one of the economic sectors in Malaysia that is still highly dependent on labour. International Organization for Migration (2023) reported that about 80% of the current plantation workforce are foreign labourers. The working condition in the plantations has been associated by the young locals with the 3Ds stigma - dangerous, dirty and difficult, the conditions which discourage them from working in the plantations (Parveez, 2022). To attract more locals working in the oil palm plantation industry, this sector must be modernised and mechanised. Introducing mechanisation is not meant to displace the presence of the labour force with machines in field operations but rather to reduce the total dependency on the labour force in conducting field operations. Additionally, its implementation in plantations is in line with the government's policy of encouraging the locals to be involved in this field, with the aim to gradually reduce the country's dependency on foreign labours. The ultimate objective is to equip the labourers with proper hand tools or machines in some selected field operations that require significant human effort and energy. Whilst, the field operations that could easily be conducted and consume less human energy are done using proper hand tools.

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Therefore, using mobile machines, instead of hand tools for less demanding field operations, would only increase the cost of field operations. For any application of mechanisation to be effective, as mentioned by Johari *et al.* (2020), it is essential to utilise machines that can increase land and labour productivity, meet the field operation timelines and enhance the rate of work output.

Earlier attempts in the 1980s used land to labour ratio as the means to measure the productivity of plantation workers in terms of machine usage. The overall land to labour ratio of 6:1 to 7:1 in the 1980s increased to 10:1 to 12:1 in 2013. Today, in some oil palm plantations with appropriate adaptation of mechanisation, labour productivity has reached 20:1 (Khalid *et al*., 2013).

Nawi *et al.* (2012) directly measured the workers' energy expenditures while doing various field operations in an attempt to rank the critical field operations of the crop production system. The human energy expenditure was measured based on the intensity and duration of the workers' activity, age, gender, and body weight (Westerterp, 2001). Pebrian *et al.* (2014) proposed a method of prioritising mechanisation based on workers' workload and productivity in conducting oil palm field operations. However, in this study, an attempt to systematically evaluate human energy expenditure and field operational capacity was done for complete field operations involved in producing oil palm seedlings at an oil palm nursery and oil palm fresh fruit bunches (FFB). Hence, a methodology was used to measure the nursery and field plantation mechanisation level, with the main objectives to identify, prioritise and eventually to design and develop appropriate machines for the most critical tasks within the field operations. Hence, in general, this study can significantly contribute to the development of a viable mechanisation strategy under the specified crop production scenario.

MATERIALS AND METHODS

A field study was conducted to explore, assess and determine the existing practices in the oil palm seedling production centre at Pusat Penyelidikan Pertanian Tun Razak (PPPTR), Jerantut, Pahang, Malaysia, under FELDA Agricultural Services Sdn. Bhd. (FASSB). The oil palm field cultivation was conducted at Ladang Felda Kechau 3, 8 and 10, Kuala Lipis, Pahang, Malaysia, under FELDA Global Ventures Plantations (M) Sdn. Bhd. The palm seedling production at PPPTR employed two-stage nursery techniques, which comprised pre-nursery and main nursery. In the pre-nursery stage, two methods of palm seedling production were used, *i.e*., closed (indoor field) and open field techniques. Open field technique involved the planting of germinated seeds in an open area on the ground, while the closed (indoor) technique involved the planting of germinated seeds in planting trays filled with peat moss. The seeds were soaked in a liquid medium to expedite the germination process and enhance the percentage of successfully sprouted seeds prior to planting. Soaking aims to sort out viable from non-viable seeds. If the seeds sink, they are still viable. On the contrary, if they float, it is advisable to discard them as they are less likely to germinate. Meanwhile, peat moss together with NPK fertiliser was crushed and smashed to get the fine particles for better growth of the seeds. The trays planted with the germinated seeds were then placed on a bench above the soil covered with a shelter made of ultraviolet (UV) resistant plastic. A total of 50 field operations were involved; 35 at the oil palm nursery and 15 at the oil palm plantation. Detailed descriptions of the work done in the nursery and field operations are given in *Table 1* and *2*, respectively.

A total of 100 subjects consisting of 49 for the oil palm nursery and 51 for the oil palm field were randomly selected as participants by using a probability sampling approach. The subjects were field workers. They were healthy males and females who were familiar with the oil palm cultivation activities. The age, weight, and height of the subjects were in the range of 18-54 years old, 37-99 kg and 143-182 cm, respectively. The selected subjects represented a typical sample of the workforce in the oil palm plantations. Three or four workers were involved in each operation and the whole data collection was repeated for at least three full working days with a duration of eight working hr day^{-1}. Time motion and energy expenditure measurements were taken on the assigned workers while conducting the nursery or field operations.

Digital stop watches were used to record the timing of all the tasks carried out by the subjects during the operations. Body Media Armbands were attached to the right arm of each subject to measure the energy expenditure while conducting the stated operations. Detailed technical specifications of the tools, equipment, or machinery used by the subjects in conducting the operations were recorded, as well as technical specifications, crop inputs and other consumable materials used in the operation. After completing the operations, work outputs from the conducted operations were counted and the data recorded by the Body Media Armbands were downloaded into a computer for analysis. The workers' field operational capacities were computed by dividing the quantity of work outputs by the corresponding time required for completing the operations. A value of 110 palms ha^{-1} to represent a typical planting density for a plantation with a hilly terrain similar to that of the study area was used throughout the calculations of operation capacity and energy expenditure. Machinery energy refers to tool, equipment or machinery/tractor using energy (J palm^{-1}) at each stage of oil palm nursery or field operations estimated by using Equation (1) (Board on Science and Technology for International Development, 1981), as follows:

$$ME = \frac{CEE \times WT}{TP} \times 10^6 \quad (1)$$

where *ME* is machinery energy (J palm^{-1}), *CEE* is the coefficient of energy equivalent of machinery, equipment, or tool (MJ hr^{-1}), *WT* is working time (hr), and *TP* is total palms, dimensionless. The energy equivalent coefficient serves as an indicator of an object or system's mass when quantifying its energy content in Joules (J) or Mega Joules (MJ). Working time is the period of time that a machinery uses in a day.

Machinery energy could also be calculated from its known weight in terms of J palm^{-1} which was calculated using Equation (2) (Board on Science and Technology for International Development, 1981):

$$ME = \frac{CEE \times W}{TP} \times 10^6 \quad (2)$$

where *ME* is machinery energy (J palm^{-1}), *CEE* is the coefficient of energy equivalent of machinery, equipment or tool (MJ kg^{-1}), *W* is weight (kg) and *TP* is total palms, dimensionless.

TABLE 1. FREQUENCY, EQUIPMENT AND MATERIAL USAGE AND WORKERS' INVOLVEMENT IN THE OIL PALM NURSERY OPERATIONS

Operation	Equipment and material	Number of workers
Pre-nursery		
Filling peat moss in trays	Peat moss (Klasmann-Deilmann TS 3) **Open technique:** Nursery bed, tray (24 seeds per tray), canvas, nursery bed cover (Silvershine) **Closed technique:** Tray (50 seeds per tray), scissors, table, wheelbarrow	**Open technique:** 5 **Closed technique:** 4
Planting oil palm germinated seeds in trays	Tray filled with Klasmann, oil palm germinated seeds, Scissors, small plastic chair (open technique)	1
Fertilising oil palm seedlings in trays	**Open technique:** Agroblen@SK Cote Precise Fertiliser, pail, hole punch, spoon, small plastic chair **Closed technique:** Fertiliser system, Felda Liquid Fertiliser 8, water	1
Pest and disease control of oil palm seedlings in trays	**Open technique:** Conventional Knapsack Sprayer (CKS), container, Zagro, Dithane, Argi-dex, Bayfolan, water **Closed technique:** Engine and pump, container, Zagro, Dithane, Argi-dex, Bayfolan, water	**Open technique:** 1 **Closed technique:** 2
Watering oil palm seedlings in trays	**Open technique:** Engine pump, pipe line (mist irrigation system), gasoline fuel, diesel fuel, water **Closed technique:** Irrigation system, water	1
Main-nursery		
Filling soil in large polybags	Pile/stalk, funnel, big scoop plastic polybags (15" x 18"). Cable wire 12G with 20 points by distance of 0.9 m, top soil	3
Transplanting oil palm seedlings from the trays to large polybags	60 kW 4WD Kubota tractor with 2 t trailer, diesel fuel, small scoop, wooden rod, Agroblen@SK Cote Precise Fertiliser, Rock Phosphate Fertiliser, oil palm seedlings from trays in basket, 15" x 18" polybags filled with soil, pail, spoon	3
Mulching fibres around the oil palm seedlings in large polybags	Oil palm seedlings in large polybags, basket, the mulching fibres from oil palm EFB fibres	1
Fertilising oil palm seedlings in large polybags	Pail, Scoop, Agrenas fertiliser, FPM compound fertiliser	1
Clearing grass in large polybags	Polybag, scissor	1
Watering oil palm seedlings in large polybags	3 kW Engine-pump set, pipe line (drip irrigation system), gasoline fuel, diesel fuel, water	1
Weeding oil palm seedlings in large polybags	Conventional Knapsack Sprayer (CKS), sodium chlorate (99%), Agri-dex, Dual G 960, Basta 15, water, container	1
Pest and disease control of oil palm seedlings in large polybags	Conventional Knapsack Sprayer (CKS), Zagro, Dithane, Bayfolan, Dithane, water, container	1

TABLE 2. FREQUENCY, EQUIPMENT AND MATERIAL USAGE AND WORKERS' INVOLVEMENT IN THE OIL PALM FIELD OPERATIONS

Operation	Equipment and material	Number of workers
Clearing old palm trees – cutting and chipping	110 kW Kobelco Yutani excavator, diesel fuel, chipping bucket for chipping, 3 kW generator and sharpening machine for chipping bucket, gasoline fuel	1
Clearing weeds	Mist blower, measuring container, water, Garlon 250, gasoline fuel	1
Lining for planting	Wooden pegs survey tape	1
Holing for planting	37.28 kW 4WD tractor EUROSTAR 4540 with fully mounted post hole digger with 35.6 cm diameter auger bit, diesel fuel	1
Planting ground cover crops	CIRP fertiliser (30 g per each drill at oil palm inter-row), hoe, legume cover crops (LCC)	3
Seedling delivery from nursery to field	3 t bin lorry, diesel fuel, oil palm seedlings, rope	2
Planting oil palm seedlings	CIRP fertiliser (500 g per palm), hoe, wheelbarrow, oil palm seedling	1
Circle weeding	**Immature palm:** Conventional Knapsack Sprayer (CKS), herbicides **Mature palm:** Controlled Droplet Applicator (CDA) with battery 6V, herbicides	1
Fertilising	**Immature palm:** Fertiliser pail, NPK fertiliser **Mature palm:** Fertiliser pail, SOA fertiliser	1
Rat control	Fertiliser pail, *butik* S Rat Bait	1
Loose fruit infield collection	50 kg capacity sacks, rake	1
FFB harvesting including pruning	Harvesting sickle, loading spike, *parang*	2
FFB infield collection transportation	60 kW 4WD Kubota tractor and 2-t trailer, loading spike, collection bin, diesel fuel	2
FFB mainline transportation	8 t bin lorry with 96 kW hook-lift system, canvas or net, diesel fuel	1

Energy consumption by fuel used in terms of J palm^{-1} could be calculated using Equation (3) (Board on Science and Technology for International Development, 1981), as follows:

$$IE = \frac{CEF \times Q}{TP} \times 10^6 \quad (3)$$

where *IE* is input energy (J palm^{-1}), *CEF* is the coefficient of energy equivalent of fuel (43.3 MJ L^{-1} for diesel and 39.7 MJ L^{-1} for gasoline), *Q* is quantity (L), and *TP* is total palms, dimensionless. Energy consumption by water for irrigation used in terms of J palm^{-1} could be calculated using Equation (4) (Board on Science and Technology for International Development, 1981):

$$IE = \frac{CEI \times Q}{a \times TP} \times 10^6 \quad (4)$$

where *IE* is input energy (J palm^{-1}), *CEI* is the coefficient of energy equivalent of water for irrigation (0.63 MJ m^{-3}), *Q* is quantity (L) and *TP* is total palms, dimensionless and *a* is constant (1,000 L m^{-3}).

The value of fuel energy consumption in terms of J palm^{-1} for the tractor used in the infield FFB collection transportation operation was computed using Equation (5) (Board on Science and Technology for International Development, 1981):

$$IE = \frac{CEH \times A}{TP} \times 10^6 \quad (5)$$

where *IE* is input energy (J palm^{-1}), *CEH* is the coefficient of energy equivalent of harvesting tractor (1,323.15625 MJ ha^{-1}), *A* is area (ha) and *TP* is total palms, dimensionless.

The coefficient of energy is equivalent for different operational inputs for the oil palm nursery and field cultivation operations was used in the calculation (Canakci & Akinci, 2006; Chaichana *et al*., 2008; De *et al*., 2001; Fluck, 1992; Ozkan *et al*., 2004; Pimentel, 1992; Strapatsa *et al*., 2006; Singh, 2002).

MI is expressed as the ratio of machine energy to the total human and machine energy utilised in conducting the field operations. Machine energy includes machinery and tractor energy, fuel energy consumption and energy consumption by water for irrigation. The MI value could be calculated using Equation (6) (Isaak *et al*., 2020):

$$MI = \frac{MCE}{MCE + HE} \quad (6)$$

where *MI* is mechanisation index, dimensionless, *MCE* is machine energy (MJ ha^{-1}) and *HE* is human energy expenditure (MJ ha^{-1}).

Duncan's Multiple Range Test (DMRT) was used to compare significant differences in the subjects' mean energy expenditure, mean quantity of work output, mean machine energy, mean human energy, and mechanisation index (MI) in the palm nursery and field operations.

RESULTS AND DISCUSSION

Field Capacity and Energy Expenditure in the Oil Palm Nursery Operation

Table 3 presents the measured field capacities and the human energy expenditures of individual operations in oil palm nursery operations. Any operation with the highest field operational capacity could be considered an expeditious operation where the involved work is normally referred to be very quick, efficient and productive to accomplish. During the field pre-nursery stage under the open field nursery system, the pest and disease control of oil palm seedlings in trays was the most expeditious level of operation, with the highest field operational capacity of 120,000 seedlings hr^{-1}. Similarly, during the indoor pre-nursey stage under the closed field nursery system, the pest and disease control of oil palm seedlings in trays was the most expeditious level of operation, with the highest field capacity of 6,000 seedlings hr^{-1}. During the field main-nursery stage for both the open and closed field nursery systems, the pest and disease control of oil palm seedlings in large polybags was the most expeditious level of operation, with the highest field capacity of 6,667 seedlings hr^{-1}, while filling soil in large polybags was the least expeditious level of operation with the lowest field capacity of 108 seedlings hr^{-1}.

Any field operation with the highest energy could be considered as an exhausting operation where the work involved are commonly referred to as backbreaking, taxing and tough to accomplish. During the field pre-nursery stage under the open field nursery system, planting oil palm seeds in trays was the most exhausting level of operation with the highest energy expenditure of 976.28 J $seed^{-1}$. On the other hand, the pest and disease control of oil palm seedling in the tray was the least exhausting operation with the lowest field energy expenditure of 10.60 J $seedling^{-1}$. During the indoor pre-nursey stage under the closed field nursery system, filling peat moss in trays was the most exhausting level of operation with the highest energy expenditure of 935.96 J $seedling^{-1}$, while the pest and disease control of oil palm seedling in tray was stated as the least exhausting operation with the lowest energy expenditure of 18.42 J $seedling^{-1}$.

TABLE 3. FIELD CAPACITY AND HUMAN ENERGY EXPENDITURE OF OIL PALM NURSERY OPERATION

Oil palm nursery operation	Field capacity*		Human energy expenditure*
	95% confidence intervals $seed^{-1}$	Seeds hr^{-1} or seedlings hr^{-1}	95% confidence interval, J $palm^{-1}$
Field pre-nursery stage			
Filling peat moss in trays	1.70 ± 0.12	$2,118^{d}$	598.49 ± 155.12^{e}
Planting oil palm germinated seeds in trays	3.87 ± 0.27	930^{b}	976.28 ± 102.04^{c}
Fertilising oil palm seedlings in trays	3.00 ± 0.21	$1,200^{c}$	592.16 ± 69.98^{e}
Pest and disease control of oil palm seedlings in trays	0.03 ± 0.002	$120,000^{i}$	10.60 ± 2.40^{j}
Watering oil palm seedlings in trays	0.07 ± 0.003	$51,429^{h}$	14.92 ± 0.15^{i}
Indoor pre-nursery stage			
Filling peat moss in trays	2.66 ± 0.26	$1,353^{c}$	935.96 ± 18.70^{c}
Planting oil palm germinated seeds in trays	3.75 ± 0.15	960^{b}	735.46 ± 136.98^{d}
Fertilising oil palm seedlings in trays	0.37 ± 0.009	$9,730^{f}$	85.25 ± 3.83^{g}
Pest and disease control of oil palm seedlings in trays	0.06 ± 0.005	$60,000^{h}$	18.42 ± 1.64^{i}
Watering oil palm seedlings in trays	0.11 ± 0.0003	$32,727^{d}$	25.98 ± 0.71^{h}
Field main-nursery stage			
Filling soil in large polybags	33.30 ± 1.53	108^{a}	$11,439.72 \pm 2,674.05^{a}$
Transplanting oil palm seedlings from the trays to large polybags	23.58 ± 0.89	153^{a}	$7,555.30 \pm 1,011.15^{b}$
Mulching fibres around the oil palm seedlings in large polybags	20.22 ± 1.48	178^{a}	$6,060.43 \pm 717.14^{c}$
Fertilising oil palm seedlings in large polybags	2.91 ± 0.003	$1,237^{c}$	638.70 ± 25.71^{d}
Clearing grass in large polybags	1.03 ± 0.096	$3,495^{d}$	243.58 ± 24.76^{f}
Watering oil palm seedlings in large polybags	0.79 ± 0.008	$4,557^{e}$	221.36 ± 9.65^{f}
Weeding oil palm seedlings in large polybags	1.96 ± 0.28	$1,837^{c}$	555.65 ± 97.12^{e}
Pest and disease control of oil palm seedlings in large polybags	0.54 ± 0.036	$6,667^{e}$	165.50 ± 12.17^{f}

Note: *Superscripts with different letters are considered significantly different at 0.001 level.

During the field main-nursery stage under both the open and closed field nursery systems, filling soil in large polybags was the most exhausting level of operation with the highest energy expenditure of 11,439.72 J seedling^{-1}, while the pest and disease control of oil palm seedlings in large polybags was the least exhausting level of operation, with the lowest energy expenditure of 165.50 Joule seedling^{-1}. Meanwhile, the human energy expenditure of the workers in conducting the field operation was extremely affected by the nature of work of individual operation, whereby a low field capacity operation was normally and generally associated with high energy expenditure.

Figure 1 is the column chart graphical representation of the critical level of the individual operation involved in the open field nursery and closed field nursery systems. The critical level values were computed based on the ratio of the ranking levels of the field operational capacity and energy expenditure obtained for each field operation. The field operation having a critical level of 1.0 was categorised as the most critical field operation to be mechanised, while the field operation showing a critical level of 0.00 was categorised as the least critical field operation to be mechanised. As observed, the three most critical operations in both the open and closed field nursery systems, based on the highest hierarchy order, were filling soil in large polybags operation, transplanting oil palm seedlings from tray to large polybags operation, and mulching fibres around oil palm seedlings in large polybags. However, the three least critical operations based on the lowest hierarchy order in both the open and closed nursery systems were watering oil palm seedlings in trays, fertilising oil palm seedlings in trays, and planting oil palm germinated seeds in trays.

Field Capacity and Energy Expenditure in the Oil Palm Field Cultivation Operation

At the immature crop stage, rat control operation in the plantation field was categorised as the most expeditious operation, with the highest field capacity of 472 palms hr^{-1} (*Table 4*). The rat control operation requires workers to walk carrying a pail containing the rat baits along the harvesting path in the plantation field while distributing the rat baits at the targeted spots. Such a task was easy to conduct in the field even though it required frequent refilling of the rat baits in the pail at predetermined filling

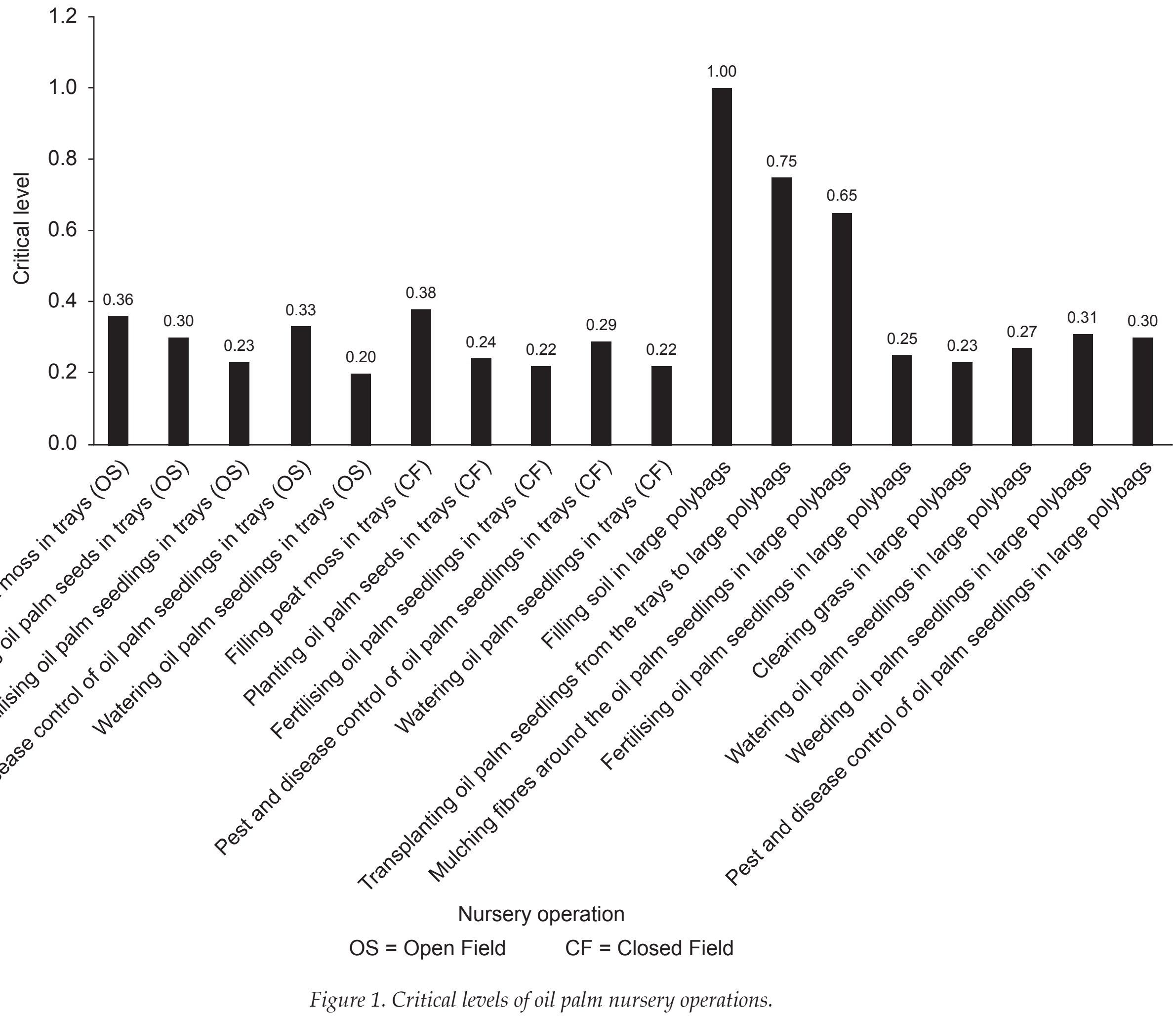

Figure 1. Critical levels of oil palm nursery operations.

points in the plantation field. On the other hand, planting oil palm seedlings in the plantation was the least expeditious operation as the workers had to manually complete the task of removing plastic polybags from the seedling soil body mass, lifting to place the seedlings into available prepared holes on the ground, filling space around the planted seedlings with available soil mass around the planting holes, and finally compacting the filled soil around the planted seedlings. On top of these, the workers had to walk carrying a hoe from one planting hole to the next adjacent planting hole along the planting row in the plantation field to complete the operation for the day. The next least expeditious level operation was the clearing of old palm trees operation, with the rated field operational capacity of 18 palms hr^{-1}. Even though the task was machine-assisted, it was time-consuming and demanding due to the cutting and chipping of old palm trees.

At the mature crop stage, rat control operation in the plantation field was once again the most expeditious level of operations. However, the loose fruit infield collection operation was categorised as the least expeditious level of operations with the lowest field capacity of 8 palms hr^{-1}. The loose fruit infield collection operation requires the workers to carry a sack and a rake while walking along the harvesting path and stopping at every location where a significant amount of loose fruits are found on the ground. The task was to manually rake and collect all the scattered loose fruits on the ground and load them into the sack. The ultimate task was to gather the most amount of loose fruits and minimise the number of uncollected loose fruits left on the ground. The next least expeditious operation that was close to the loose fruit in the field collection operation was the FFB harvesting. The FFB harvesting including pruning had a field capacity of 16 palms hr^{-1}. The operation requires the workers to walk along the harvesting path while carrying a harvesting pole. Among others, the task was to identify any ripe FFB on the palm, cut the frond underneath it and the identified FFB, and relocate the cut fronds to the nearby frond stack.

At the immature crop stage, planting oil palm seedlings in the plantation field was categorised as the most exhausting level of operations with the highest human energy expenditure of 80,285.32 J hr^{-1}. The next exhausting level operation was delivering the seedlings from the nursery to the field with the energy expenditure of 72,693.54 J hr^{-1}. To complete both operations requires a number of tasks to be done manually with a substantial effort by the workers. The tasks of placing the seedlings in the planting hole, covering them with the surrounding soil and then compacting the filled soil around the planted seedlings in the planting oil palm seedlings operation were done manually with the use of hands. In the seedling delivery operation, much of the manual effort involved lifting individual

TABLE 4. FIELD CAPACITY AND ENERGY EXPENDITURE OF THE OIL PALM FIELD CULTIVATION OPERATION

Oil palm field operation	Field capacity*		Human energy expenditure*
	95% confidence intervals $palm^{-1}$	Palms hr^{-1}	95% confidence interval (J $palm^{-1}$)
Immature crop stage			
Clearing old palm trees – cutting and chipping	194.61 ± 11.78	18^{a}	39,457.56 ± 299.90^{c}
Clearing weeds	57.49 ± 0.32	63^{d}	12,131.49 ± 437.10^{f}
Lining for planting	53.28 ± 2.20	68^{d}	16,276.13 ± 141.52^{e}
Holing for planting	79.26 ± 0.39	45^{c}	24,308.07 ± 169.68^{d}
Planting ground cover crops	55.65 ± 0.64	65^{d}	17,491.88 ± 335.44^{e}
Seedling delivery from nursery to field	129.97 ± 4.65	28^{b}	72,693.54 ± 1,971.68^{b}
Planting oil palm seedlings	265.66 ± 1.18	14^{a}	80,285.32 ± 2,773.37^{a}
Circle weeding by using CKS	44.58 ± 0.03	81^{e}	11,865.82 ± 683.17^{f}
Fertilising	38.62 ± 3.54	93^{f}	10,451.81 ± 1,204.80^{g}
Rat control	7.63 ± 0.85	472^{g}	1,926.09 ± 212.62^{h}
Mature crop stage			
Circle weeding by using CDA	39.49 ± 0.98	91^{c}	10,632.16 ± 468.69^{d}
Fertilising	33.63 ± 1.68	107^{d}	8,416.04 ± 890.69^{e}
Rat control	7.63 ± 0.85	472^{g}	1,926.09 ± 212.62^{g}
Loose fruit infield collection	464.02 ± 59.92	8^{a}	107,656.25 ± 16,502.23^{a}
FFB harvesting including pruning	221.53 ± 19.16	16^{b}	70,865.81 ± 20,025.98^{b}
FFB infield collection transportation	22.86 ± 0.79	157^{e}	16,859.50 ± 1,350.76^{c}
FFB mainline transportation	16.58 ± 1.33	217^{f}	7,233.77 ± 1,149.83^{f}

Note: *Superscripts with different letters are considered significantly different at 0.001 level.

seedlings onto the trailer of the tractor at the nursery site, unloading at the field site, and carrying them to the nearest available planting holes in the field. On the other hand, the rat control operation was the least exhausting level of operation with the energy expenditure of 1,926.09 J hr^{-1}, followed by the fertilising operation with the energy expenditure of 10,451.81 J hr^{-1}. The fertiliser operation requires the workers to walk along the harvesting path in the field carrying a pail containing granular type of fertilisers. In this task, the workers would grab a cup-full of fertilisers from the pail and toss them into a smaller cup to the targeted cut palm front heap row next to the palm row. Just like the rat control operation, this task was fairly easy and consumed less amount of time in the field even though frequent refilling of the granular fertilisers was required at the earlier predetermined filling point in the field.

At the mature crop stage, loose fruit infield collection operation had the most exhausting level of operation with the highest energy expenditure of 107,656.25 J hr^{-1}. The rat control operation was once again the least exhausting level of operation with energy expenditure of 1,926.09 J hr^{-1}, followed by the FFB mainline transportation with the energy expenditure of 7,233.77 J hr^{-1}. Not much of the manual handling of the FFB was done in the FBB mainline transportation because 8 t bin main transporter lorry was equipped with a mechanical hydraulically-assisted hook-lift system for pulling the fully loaded bin of the harvested FFB onto the chassis.

Figure 2 shows the column chart graphical representation of critical levels of the individual operations involved in the oil palm field cultivation operations. The top three most critical level of oil palm field cultivation operations in the highest hierarchy order were loose fruit infield collection operation (0.77), planting oil palm seedlings and seedling delivery from nursery to field operations (0.58 and 0.57), and oil palm FFB harvesting and frond pruning operation (level of 0.53). However, the three least critical oil palm field cultivation operations in the lowest hierarchy order were rat control operation (0.13), clearing weeds (0.17) and fertilising operation (0.18).

MI of the Oil Palm Nursery and Field Cultivation

Table 5 and *6* present the computed MI for the open field system and closed field system in the oil palm nursery operations. The overall MI for the oil palm nursey operations was 0.31 for the open nursery system and 0.30 for the closed nursery system.

With the open nursery system, the average MI of the open field nursery operation and closed field nursery was very close to each other (*i.e.*, 0.31 *versus* 0.36). The main critical operations were filling peat moss in trays operation and planting oil palm seedlings in tray operation at the field pre-nursery stage (0.00) and filling soil in large polybags operation at the field main nursery stage (0.06). Meanwhile, watering oil palm seedlings in tray operation at field pre-nursery stage and watering oil palm seedlings

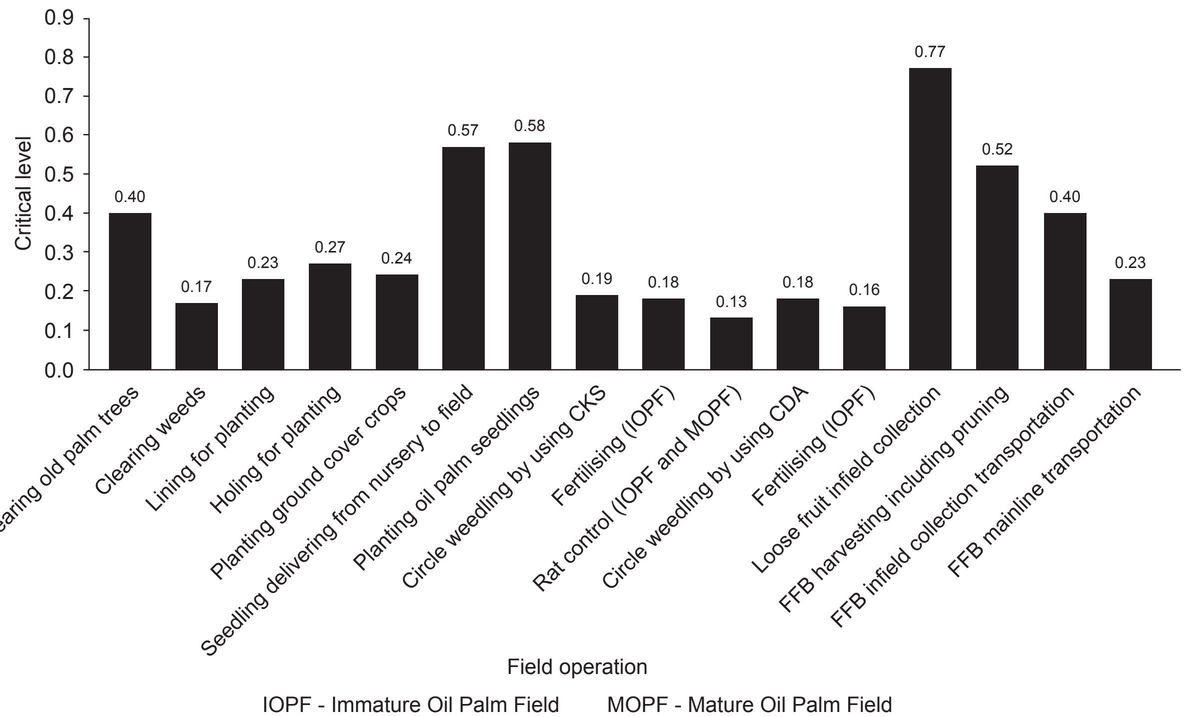

Figure 2. Critical levels of oil palm field cultivation operations.

in large polybags operation at the field main nursery showed the highest MI of 0.76 and 1.00, respectively.

With the closed nursery system, the MI of indoor pre-nursery was slightly higher than the field main nursery stages (*i.e.*, 0.44 *versus* 0.30). Similarly, for the open nursery system, the main critical operations were filling peat moss in trays operation and planting oil palm germinated seeds in tray operation at the field pre-nursery stage (0.00) and filling soil in large polybags operation at the field main nursery stage (0.06).

Once again, watering oil palm seedlings in tray operation at the field pre-nursery stage and watering oil palm seedlings in large polybags operation at the field main nursery showed the highest mechanisation levels with MI of 0.75 and 1.00, respectively. There were still a number of operations in both the open and closed nursery systems with the MI values of below 0.50, indicating significant human labour involvement instead of proper machines in performing the operations.

Table 7 presents the average MI value for the immature stage of oil palm cultivation, which was slightly higher than the average MI for the mature stage of oil palm cultivation (*i.e.*, 0.44 *versus* 0.37). The overall average MI for the field cultivation operation was slightly higher than the overall average MI for both the open and closed field nursery operations (*i.e.*, 0.41 *versus* 0.31 and 0.36). This reflects a slightly higher level of machinery used at the field level compared to the nursery level in the current oil palm cultivation in Malaysia.

At the immature crop stage, the most critical operations were planting oil palm seedlings and planting ground cover crops operations (0.00) and rat control and fertilising operations (0.08). The four field operations that include clearing old palm trees – Cutting and chipping, clearing weeds and holing for planting could be classified to be fully mechanised.

At the matured crop stage, the most critical field operations to be mechanised was FFB harvesting that included pruning operation with the MI of 0.00. This was followed by two critical field operations rat control and loose fruit infield collection operations with MI of 0.08 and 0.09, respectively. Generally, the mechanisation levels with the most involved field operations were relatively very low (0.00 to 0.28), with the exception of FFB infield collection-transportation operation and FFB mainline transportation operation (1.00 and 0.97). Such low values generally indicated that the techniques currently employed in the operations required more human labour involvement in conducting and completing the field operations.

TABLE 5. MECHANISATION INDEX FOR THE OIL PALM OPEN FIELD NURSERY SYSTEM

Oil palm nursery operation	Labour energy ($J\ palm^{-1}$)	Machinery energy ($J\ palm^{-1}$)	Mechanisation index	Level
Field pre-nursery stage				
Filling peat moss in trays	598.49	-	0.00	4[d]
Planting oil palm germinated seeds in trays	976.28	-	0.00	4[d]
Fertilising oil palm seedlings in trays	592.16	798.24	0.57	2[b]
Pest and disease control of oil palm seedlings in trays	10.60	3.10	0.23	7[c]
Watering oil palm seedlings in trays	14.92	48.06	0.76	1[a]
Average			**0.31**	
Field main-nursery stage				
Filling soil in large polybags	11,439.72	793.48	0.06	5[f]
Transplanting oil palm seedlings from the trays to large polybags	7,555.30	13,551.20	0.64	2[b]
Mulching fibres around the oil palm seedlings in large polybags	6,060.43	477.32	0.07	5[f]
Fertilising oil palm seedlings in large polybags	638.70	68.74	0.10	4[d]
Clearing grass in large polybags	243.58	5.87	0.02	6[e]
Watering oil palm seedlings in large polybags	221.36	155,647.41	1.00	1[a]
Weeding oil palm seedlings in large polybags	555.65	206.47	0.27	3[c]
Pest and disease control of oil palm seedlings in large polybags	165.50	57.29	0.26	3[c]
Average			**0.30**	
Overall			**0.31**	

Note: [1]Decreasing order and superscripts with different letters are considered significantly different at 0.001 level.

TABLE 6. MECHANISATION INDEX FOR OIL PALM CLOSED FIELD NURSERY SYSTEM

Oil palm nursery operation	Labour energy (J palm^{-1})	Machinery energy (J palm^{-1})	Mechanisation index	Level
Indoor pre-nursery stage				
Filling peat moss in trays	935.96	-	0.00	3[c]
Planting oil palm germinated seeds in trays	735.46	-	0.00	3[c]
Fertilising oil palm seedlings in trays	85.25	254.32	0.75	1[a]
Pest and disease control of oil palm seedlings in trays	18.42	41.60	0.69	2[b]
Watering oil palm seedlings in trays	25.98	76.92	0.75	1[a]
Average			**0.44**	
Field main-nursery stage				
Filling soil in large polybags	11,439.72	793.48	0.06	7[g]
Transplanting oil palm seedlings from the trays to large polybags	7,555.30	13,551.20	0.64	2[b]
Mulching fibres around the oil palm seedlings in large polybags	6,060.43	477.32	0.07	5[f]
Fertilising oil palm seedlings in large polybags	638.70	68.74	0.10	4[e]
Clearing grass in large polybags	243.58	5.87	0.02	6[g]
Watering oil palm seedlings in large polybags	221.36	155,647.41	1.00	1[a]
Weeding oil palm seedlings in large polybags	555.65	206.47	0.27	3[c]
Pest and disease control of oil palm seedlings in large polybags	165.50	57.29	0.26	3[c]
Average			**0.30**	
Overall			**0.36**	

Note: [1]Decreasing order and superscripts with different letters are considered significantly different at 0.001 level.

TABLE 7. MECHANISATION INDEX FOR OIL PALM FIELD CULTIVATION OPERATION

Oil palm field operation	Labour energy (J palm^{-1})	Machinery energy (J palm^{-1})	Mechanisation index	Level[1]
Immature crop stage				
Clearing old palm trees – cutting and chipping	39,457.56	15,239,407,027.30	1.00	1[a]
Clearing weeds	12,131.49	1,389,886.71	0.99	1[a]
Lining for planting	16,276.13	-	0.00	
Holing for planting	24,308.07	365,332,464.42	1.00	1[a]
Planting ground cover crops	17,491.88	6.18	0.00	5[e]
Seedling delivery from nursery to field	72,693.54	1,074,586.37	0.94	2[b]
Planting oil palm seedlings	80,285.32	29.54	0.00	5[e]
Circle weeding by using CKS	11,865.82	4,447.08	0.27	3[c]
Fertilising	10,451.81	911.88	0.08	4[d]
Rat control	1,926.09	175.77	0.08	4[d]
Average			**0.44**	
Mature crop stage				
Circle weeding by using CDA	10,632.16	4,167.71	0.28	3[c]
Fertilising	8,416.04	1,588.24	0.15	4[d]
Rat control	1,926.09	175.77	0.08	5[f]
Loose fruit infield collection	107,656.25	10,931.67	0.09	5[f]
FFB harvesting including pruning	70,865.81	16.10	0.00	6[g]
FFB infield collection transportation	16,859.50	9,918,308.35	1.00	1[a]
FFB mainline transportation	7,233.77	225,229.48	0.97	2[b]
Average			**0.37**	
Overall average			**0.41**	

Note: [1]Decreasing order and superscripts with different letters are considered significantly different at 0.001 level.

TABLE 8. AVERAGE MECHANISATION INDEXES AND FIELD CAPACITIES FOR 10 COMMON CLUSTER OPERATIONS IN OIL PALM CULTIVATION

Main operation	Average field capacity	Mechanisation index	Mechanisation status ranking
Seedling preparation	39.07 seedlings hr^{-1}	0.34	4
Land preparation	0.10 ha hr^{-1}	1.00	1
Seedling planting	0.68 ha hr^{-1}	0.39	3
Circle spraying	0.55 ha hr^{-1}	0.28	5
Fertilising	0.72 ha hr^{-1}	0.12	6
Rat control	2.05 ha hr^{-1}	0.08	8
Loose fruit infield collection	0.14 ha hr^{-1}	0.09	7
FFB harvesting including pruning	0.87 ha hr^{-1}	0.00	9
FFB infield collection-transportation	1.49 ha hr^{-1}	1.00	1
FFB main line transportation	1.50 ha hr^{-1}	0.97	2
Average		**0.43**	

Table 8 summarises the average MI and field capacities for the 10 common clusters of operations in oil palm cultivation. A common average MI of 0.43 was obtained in the cultivation of oil palm, which was slightly higher than the average MI of 0.31 for coconut and much lower than the average MI of 0.65 for all oilseed crops (Elsoragaby *et al.*, 2019). The three most critical operations for mechanisation in the oil palm field cultivation operation were the FFB harvesting including pruning operation (0.00), rat control operation (0.06), and loose fruit infield collection operation (0.09). This important information could be used by the government in setting up the R&D direction priorities in developing mechanisation and automation technologies for the oil palm cultivation plantation industries in the country. Additionally, it can aid the top management in the oil palm plantation industries to plan proper mechanisation programme for the oil palm plantations. The basis of their planning was to place the highest priority in the order of operations, *i.e.*, from the lowest rank in mechanisation status table. Secondly, for any new mechanisation and automation technology to be developed or used, the technology should give an average field capacity that is much higher than the given average field capacity for the said field operation.

CONCLUSION

This study has successfully demonstrated the use of MI in quantifying the overall mechanisation level of the oil palm FFB production, the mechanisation level of individual nursery, and the field operations in the oil palm FFB production. It was found that the MI values of the operations ranging from 0.00 to 1.00, whereby the operations with MI values close to zero require prompt mechanisation. An average MI of 0.43 was obtained for the 10 common clusters of operations in oil palm cultivation. The information obtained is useful in the preparation of a viable mechanisation programme under the specified crop production scenario. Besides that, the column chart has been shown to be useful in identifying the most critical operations or tasks within any operation that need to be improved to fulfil the overall crop production target. Future works are recommended to quantify the overall mechanisation level of the oil palm FFB production in the plantations in East Malaysia.

ACKNOWLEDGEMENT

The authors are very grateful to both the Pusat Penyelidikan Pertanian Tun Razak (PPPTR), Jerantut, Pahang under FELDA Agricultural Services Sdn. Bhd., and Kechau Oil Palm Plantations, Kuala Lipis, Pahang under FELDA Global Ventures Plantations (M) Sdn. Bhd., for giving the permission and administrative support to conduct this study, and also to Universit Putra Malaysia (UPM) for providing the research grant.

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