DEVELOPMENT OF A MECHANIZATION SELECTION SYSTEM FOR OIL PALM PLANTATIONS WITH ALTERNATIVE PLANTING PATTERNS

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ABSTRACT

This article describes a study on the conceptual design and development of the most efficient mechanization selection system for oil palm plantations with alternative planting patterns. The study was conducted by extrapolating various planting patterns based on the existing triangular pattern and comparing these with machine information based on a constant mechanization package made for a large and rather flat area. The comparison of machines was conducted in earlier studies based on a combination of various plantation operations like fertilizer application, weeding, harvesting, in-field collection and loose fruit collection. The results obtained suggest that the most efficient planting pattern is the triangular planting pattern. The findings from this study will help to determine the efficiency of each machine besides optimizing the cost of implementing the package.

Keywords: oil palm, mechanization selection system, planting pattern.

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INTRODUCTION

Planting pattern plays an important role in the overall productivity of the oil palm. Planting pattern must make optimum use of space per hectare and at the same time be of optimal economic density that would minimize competition between palms for light, as well as other factors like nutrients to ensure high productivity. The optimal economic density, taking into account planting cost and discount on returns, depends on the trends of yield and leaf area in relation to age and environment, but a density of 158 palms per hectare gives cumulative yield or profit within 1% of the maximum under any condition considered.

Planting should be divided into equal-sized blocks with straight boundaries to permit ease of in-field operations, especially for yield recording, output estimation, and leaf analysis. This would be difficult to achieve in hilly areas and in areas near river edges. For application of mechanical or animal-drawn fruit collection, the road construction should be minimized to decrease the required frequency of collection roads compared to areas where fruits are carried out manually (Turner and Gillbanks, 1974). This will allow for a slightly higher rate of land utilization for planting palms.

A few estates use a rail system to transport the fresh fruit bunches (FFB), either totally or partially. The lightly used railways are expensive to construct and maintain, thus it is usually combined with a road system which brings FFB to the main railway system.

The design of the drainage system should also be well-planned to ensure maximum land available for palm cultivation. Thus, knowledge in planting distance and pattern will be required, where a distance of 2 m should be allowed between a drain edge and a palm. The intensity of the drainage system depends on the soil characteristics; thus, soil through which water movement is rapid will require less drainage than one where percolation is impaired as in the case with soils like clay (Turner and Gillbanks, 1974).

The problem of optimal density for oil palm is a complex one. A number of studies have been

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carried out but no unified suggestions have emerged. Hartley (1967) reviewed the problem and concluded that "From the scanty information available……a density of about 29-30 ft triangular was suitable in Africa…..". In the Far East "…… it would be unwise……to reduce the stand much below 60 palms per acre" (Corley *et al.*, 1973).

Hartley's recommendations were for maximum cumulative yield over the life of the palms, but optimal density can be defined in several ways which include: the density giving the highest current yield in any given year; the density giving the highest cumulative yield over a given period; and the density giving the maximum cumulative profit, with or without a discount on returns, over a given period. Usually the second and third definitions are preferred where the period used is the economic life span of the palms which is 25-30 years (Corley *et al.*, 1973).

The existing planting pattern is triangular in which the palms planted in one row are positioned opposite the mid-points of the inter-palm space in adjacent rows. This gives a greater utilization of the land for crop nutrition and of available space and light for crown development (Turner and Gillbanks, 1974). It has been proven in Africa that a triangular planting pattern results in a higher yield than from a square pattern. This is achieved because the distance between the rows will be less than the planting distance between palms within a row, and the inter-row distance can be calculated by using the following formula:

- row distance = palm spacing in a row × 0.866.
- the angle from one palm to the nearest in an adjacent row = 180 ÷ 3 = 60°.

There are many factors influencing the growth of the palm and its yield, which include the planting density. During the young stage, there is less competition for nutrients and light between the palms but as they mature and develop canopies, the competition rises. The dense canopies result in reduced dry matter production, leading to a reduction in yield. Some factors affecting the young palms include initial vegetative conditions, standard of maintenance and level of fertilizer application, soil type, fertility, water availability, rainfall distribution and the amount of sunshine over the year as well as genetic differences (Turner and Gillbanks, 1974).

Plants planted at higher than their optimum density show overcrowding symptoms such as reduced light intensity and less inter-row vegetation, fronds from neighbouring palms interlock and overlap reducing photosynthesis and vegetative matter production, as well as other factors. In Ivory Coast, an extensive trial to assess the optimum density, where the same density was retained throughout the life span of the palms, showed that a figure of 139 palms per hectare was most suitable (Turner and Gillbanks, 1974). Results from the Congo were similar, and it was concluded that a range of 138-148 palms per hectare was the most suitable single-density planting. An experiment in Sumatra showed that by the 12th year, a reduction to 96 palms from its original 120 palms per hectare resulted in no yield loss. Thus, it seems that in the long run, a lower density gives the highest overall yield.

High-density planting can be carried out in the initial few years, before the palms start to enter the stage of inter-palm competition. This indicates that the effect would be minimized at an intermediate spacing where there is high maintenance. The time of thinning is critical, because one of the effects of competition at high densities is to induce a high rate of male inflorescence formation; thus, delayed thinning leads to yield loss (Turner and Gillbanks, 1974).

Should double intensity planting be envisaged, it would require a hexagonal planting design which would give a triangular pattern after thinning. A trial in Malaysia proved triangular planting to be superior over hexagonal planting. Some of the advantages of high-density planting are increased productivity of the land from the time of bearing onwards, and earlier and fuller use of capital investment in a factory, while the disadvantages of high-density planting are higher costs of establishment, planting and harvesting, and so on.

For effective and efficient FFB transport, in-field mechanization is used. These machines are used to transport the harvested FFB safely and with minimal damage in order to produce high quality oil (Teo *et al*., 1993). Some of the machines used in many plantations in Malaysia are the mechanical *Grabber*, the compact transporter, the mechanical harvester, the motorcycle trailer, the general-purpose vehicle, the mechanical loose fruit collector; the air-assisted loose fruit separator, the *Crabbie* mechanical loader, the half-track machine, the mechanical buffalo, the *Rambo* and the *Taltrac* (Helena *et al.*, 2009).

From studies conducted earlier (Helena *et al.*, 2009), Package A which was a combination of a spreader with a mini tractor (40 hp) for fertilizer application, a tanker sprayer (600 litres) with a mini tractor (40 hp) for weeding, a motorized cutter for harvesting, the *Wakfoot*; a single chassis-machine for low ground pressure was used for in-field collection, and an air-assisted fruit separator for loose fruit collection was suitable for a rather flat large area, especially in the big estates. Subsequently, Package B which is a combination of a spreader with a mini tractor (40 hp) and lower ground pressure (LGP) tyres for fertilizer application, a tanker sprayer (600 litres) with a mini tractor (40 hp) and LPG tyres for weeding, a motorized cutter for harvesting, a half-track machine for in-field collection, and an air-assisted fruit separator for loose fruit collection was found to be suitable for areas with soft soil to reduce further compaction and yet be able to maintain high productivity. Package C, a combination of a spreader with a mini tractor (40 hp) for fertilizer application, a tanker sprayer (600 litres) with a mini tractor (40 hp) for weeding, a motorized cutter for harvesting, an iron horse with a capacity of 500 to 600 kg which is suitable to work at terraced area due to its small structure was used for in-field collection, and an air-assisted fruit separator for loose fruit collection, was suitable for hilly and terraced areas. Next, Package D which is a combination of a spreader with a mini tractor (40 hp) for fertilizer application, a tanker sprayer (600 litres) with a mini tractor (40 hp) for weeding, a motorized cutter for harvesting, *Rambo*; a 4×4 skid steer driven machine fitted with the a Scanmech *Grabber* model RS/FFB20 that has maximum reach of 2.7 m and lifting capacity of 100 kg with a slewing angle of 360° was used for in-field collection, and an air-assisted fruit separator for loose fruit collection was recommended for flat coastal plantations. Lastly, a combination of a spreader with a mini tractor (40 hp) for fertilizer application, a tanker sprayer (600 litres) with a mini tractor (40 hp) for weeding, a motorized cutter for harvesting, Wu-Chart with a productivity of 14 t per day was used for in-field collection, and an air-assisted fruit separator for loose fruit collection, or Package E, was a special package that offered the lowest machine prices (that were less that RM 10 000 for each operation) with high productivity. This package is best applied on flat land and in small plantations.

This article describes a study on the conceptual design and development of the most efficient mechanization selection system for the oil palm plantation with alternative planting patterns, including a database designed for optimum yield. The specific objective was to provide a combination of mechanization systems that would be efficient with alternative planting patterns.

MATERIALS AND METHODS

A variety of planting patterns was studied to estimate a more efficient use of machinery to obtain a better yield. Studies were carried out on the different kinds of planting patterns, such as the triangular, rectangular, square and even the hexagonal shapes, to calculate the most efficient use of space and to determine the effects of the soil texture as well as nutrient absorption in the production of the best FFB yields.

Based on the existing triangular planting pattern, an extrapolation of the square, rectangular and hexagonal planting patterns was derived. *Figures 1* to *4* show the projection of a minimum distance of 8.2 m between palms. This was shown on an area of 1 ac which is equivalent to 0.405 ha in the dimensions of 90 m × 45 m. There were around 55 palms in the square pattern (*Figure 1*), 66 palms in the equilateral triangular pattern (*Figure 2*), around 56 palms in the hexagonal pattern (*Figure 3*), and 50 palms in the rectangular pattern (*Figure 4*).

The alternative planting patterns discussed were combined with the mechanization system for various terrains, and thus the machine cost, operational cost and productivity were estimated together with the coverage per acre of each machine. This was then produced in templates for the estate manager to use for achieving optimum yield.

Table 1 shows a proposed machine combination for alternative planting patterns, where the machines for carrying out the operations of fertilizer application, weed control and harvesting have been made constant while machines for in-field transportation and loose fruit collection are varied according to the different planting patterns as given in *Tables 2* to *5*.

Calculation According to Planting Pattern

Unit conversion. Unit conversion was done from the coverage area obtained by calculation as

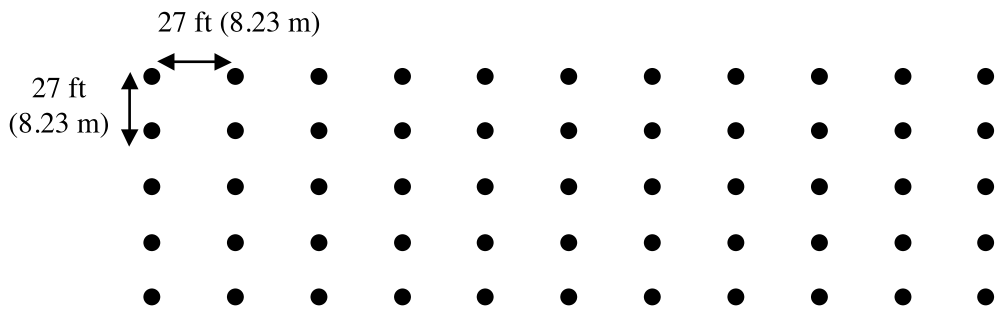

Figure 1. Square planting pattern.

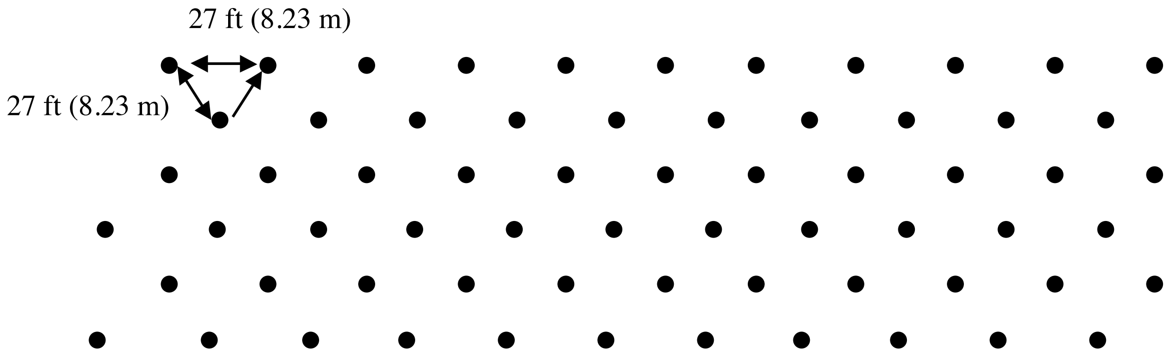

Figure 2. Triangular planting pattern.

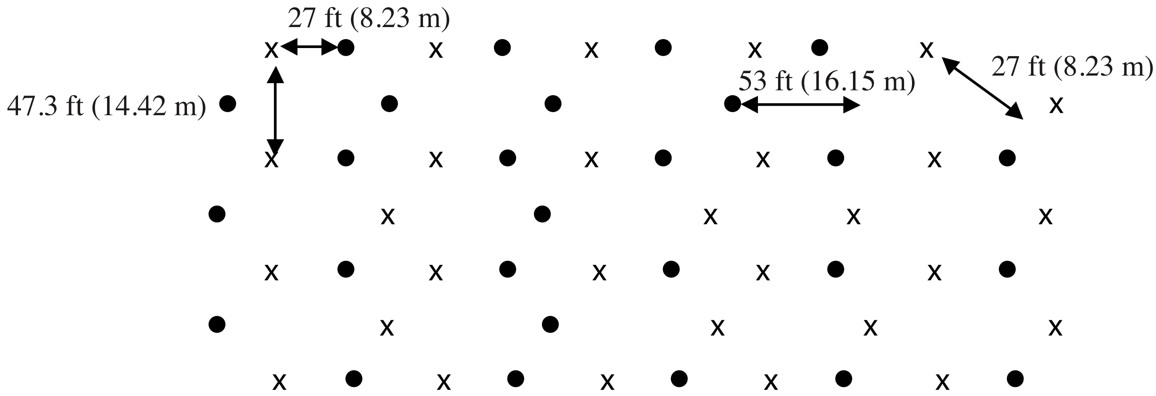

Figure 3. Hexagonal planting pattern.

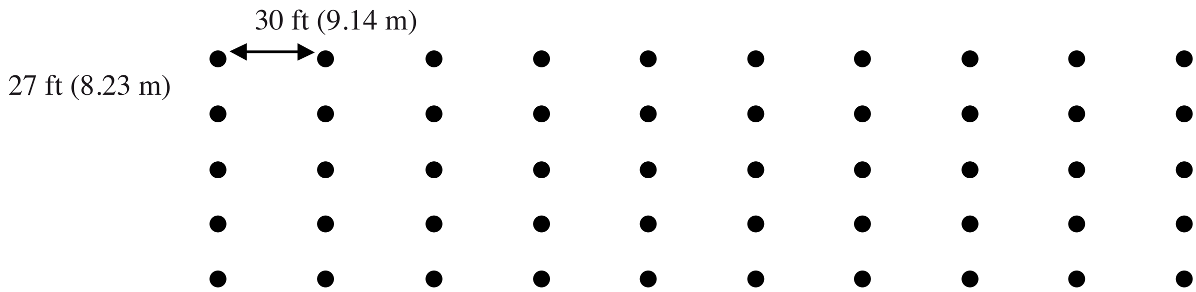

Figure 4. Rectangular planting pattern.

TABLE 1. PROPOSED COMBINATION OF ALTERNATIVE PLANTING PATTERNS

No.	Planting pattern	Mechanization of various operations				
		Fertilizer application	Weed control	Harvester	In-field transporter	Loose fruit collector
1.	Triangular	*	*	*	-	-
2.	Rectangular	*	*	*	-	-
3.	Hexagonal	*	*	*	-	-
4.	Square	*	*	*	-	-

Note: *Shows constant mechanised operations.

follows:

$$\text{Productivity} = \text{day ha}^{-1} \times \text{t day}^{-1} = \text{t ha}^{-1} \quad (1)$$

$$\text{Operation cost} = \text{RM t}^{-1} \times \text{t ha}^{-1} = \text{RM ha}^{-1} \quad (2)$$

For the triangular planting pattern:
Total number of palms per acre = 66 palms
Movement of machine:

1-row distance = 21 × 8.23 m = 172.82 m
3-row distance = 172.82 m × 3 = 518.46 m
Inter-row distance = 2 × 8.23 m = 16.46 m

Total distance a machine can move per acre is 534.92 m.

The extrapolation for the square, rectangle and hexagonal planting patterns is described in *Appendix 1*.

Productivity was essentially based on the number of palms, assuming the other factors like genetics, fertilization regime and light intensity to be constant. So the productivity of the other planting patterns was interpolated based on the known productivity of the triangular planting pattern and the projected coverage of the respective planting patterns, using the same method of calculation for all the other planting patterns.

Conceptual Design

The mechanization and alternative planting pattern management system was run over a wide area network. The network was to connect the client group with the server group. The server group would be accessed by the administrator with full privileges. The system and the database management installed in the server would be the main access point. An example of the main page of the system described is shown in *Figure 5*. In addition, system architecture provided a conceptual framework for organizing and compartmentalizing the software system to better coordinate its evolution and better monitor its development. The database management system which was used for the enhanced mechanization and alternative planting pattern management system was MySQL. *Figure 6* shows the hexagonal planting pattern tested using this system.

Interface design is the process of defining how the users interact with the system, and the nature of the inputs and outputs which the system will accept and generate. The new system uses the Macromedia Dreamweaver as the tool to design the graphical user interface. The main purpose of a perfect interface design is to provide a communication tool between the user and the system to convince the estate managers with an accurate and reliable system. If the web is sloppily built with poor visual design and low editorial standards, it will not inspire confidence among the estate managers. A good user interface design can make a product easy to understand and use, which will result in greater user acceptance.

RESULTS AND DISCUSSION

The triangular planting pattern combination of machines is shown in *Table 2*. The fertilizer application machine is a spreader plus a mini tractor (40 hp); weed control is by a tractor-drawn

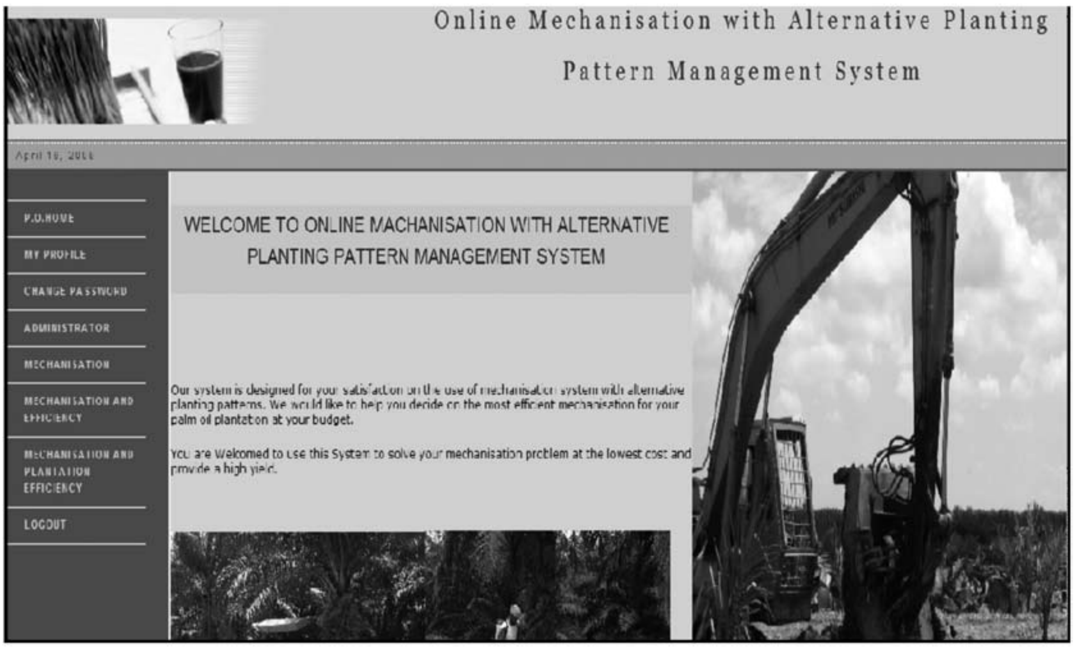

Figure 5. System's main page.

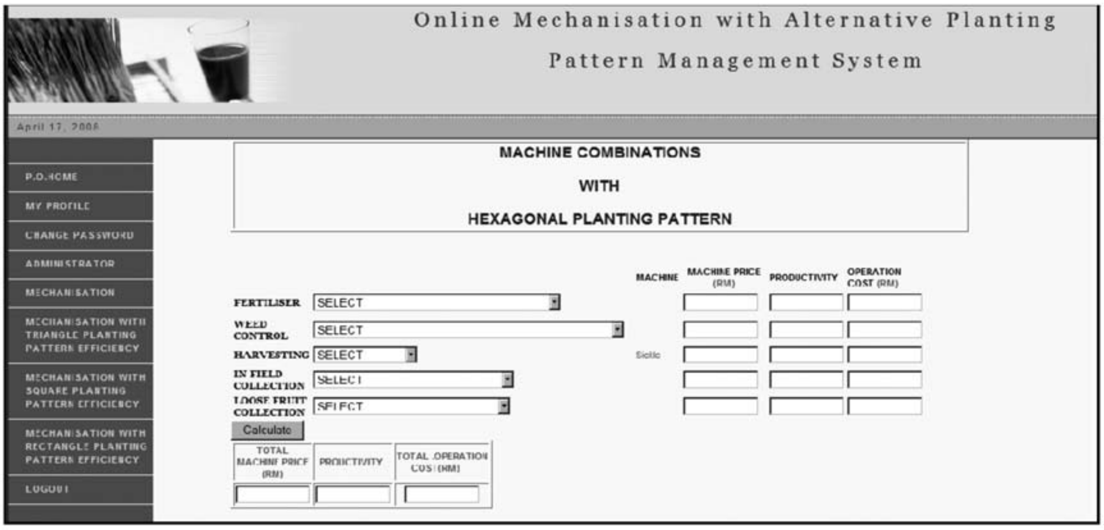

Figure 6. Mechanization with hexagonal planting pattern.

TABLE 2. TRIANGULAR PLANTING PATTERN MECHANIZATION COMBINATION

No.	Operation	Machine	Machine cost (RM)	Operation cost (RM ha^{-1})	Productivity (t ha^{-1})	Coverage (ha day^{-1})
1.	Fertilizer application	Spreader + mini tractor (40 hp)	50 600	NA*	NA	NA
2.	Weed control	Tractor-drawn tanker sprayer (300 litres) + mini tractor (40 hp)	50 600	NA	NA	NA
3.	Harvesting	Motorized cutter	4 500	22.2	1.11	10.34
4.	FFB in-field evacuation & collection	*Wakfoot*	27 000	1.1	1.1	21
5.	Loose fruit collection	Air-assisted loose fruit separator	10 000	NA	NA	NA
	Total		145 100	23.3	2.21	31.34

Note: * NA = not available.

tanker sprayer of 300-litre capacity; a motorized cutter is used as the harvester; a *Wakfoot* for in-field collection; and finally an air-assisted loose fruit separator is used for loose fruit collection. All these machines were kept constant when the alternative planting patterns were studied.

These machines were selected because they have a larger coverage area compared to the cheaper machines but are also more affordable than other machines with larger coverage areas. For harvesting activities, the motorized cutter, also known as *Cantas*, was selected for its efficiency and high productivity – around 350% higher compared to the manual method – and minimum energy is required for handling it.

Wakfoot was selected as in-field collection machine due to its ability to work in difficult areas and varying topography. In addition to that, it has an average productivity of 18 to 25 t per day with an operation cost of only RM 1 t^{-1}. For loose fruit collection, the air-assisted loose fruit machine was selected because it has the highest productivity compared to other machines, while the machine cost is far cheaper than for the other machines with lower productivity.

This package is suitable for flat large areas of plantations. The total machine cost calculated for the package was RM 145 100 with a total productivity of 58.5 t per day. Thus, the package was made constant in this study for the extrapolated alternative planting patterns. For the triangular planting pattern, the total operational cost was RM 3.30 ha^{-1} with a productivity (capacity) of 2.21 t ha^{-1} and a coverage of 31.34 ha per day.

The combination of machines for the mechanization package for the square planting pattern is shown in *Table 3* with the entire operations kept constant as in the triangular planting pattern. The total machine cost for this planting pattern was RM 142 700, and the operational cost was RM 19.6 ha^{-1} with a productivity of 2.03 t ha^{-1} for a coverage of 24.7 ha.

For the rectangular planting pattern, the combination of machines is shown in *Table 4* with the fertilizer application machine of the spreader plus a mini tractor (40 hp), weed control with the tractor-drawn tanker sprayer of 300-litre capacity, the motorized cutter for harvesting, the *Wakfoot* for in-field collection and the air-assisted loose fruit separator kept constant. The total machine cost was RM 124 100, and the total operational cost was RM 17.30 ha^{-1} with a productivity of 1.88 t ha^{-1} over 21.9 ha per day.

The mechanization package for the hexagonal planting pattern is shown in *Table 5* with the machines for the operations of fertilizer application and weed control kept constant as in the triangular planting pattern. The total machine cost for this planting pattern was RM 142 700, and the operational cost was RM 20.6 ha^{-1} with a productivity of 2.08 t ha^{-1} for a coverage of 26 ha per day.

TABLE 3. SQUARE PLANTING PATTERN MECHANIZATION COMBINATION

No.	Operation	Machine	Machine cost (RM)	Operation cost (RM ha^{-1})	Productivity (t ha^{-1})	Coverage (ha day^{-1})
1.	Fertilizer application	Spreader + mini tractor (40 hp)	50 600	NA*	NA	NA
2.	Weed control	Tractor-drawn tanker sprayer (300 litres) + mini tractor (40 hp)	50 600	NA	NA	NA
3.	Harvesting	Motorized cutter	4 500	18.5	0.93	7.2
4.	FFB in-field evacuation & collection	*Wakfoot*	27 000	1.1	1.1	17.5
5.	Loose fruit collection	Air-assisted loose fruit separator	10 000	NA	NA	NA
	Total		142 700	19.6	2.03	24.7

Note: * NA = not available.

TABLE 4. RECTANGULAR PLANTING PATTERN MECHANIZATION COMBINATION

No.	Operation	Machine	Machine cost (RM)	Operation cost (RM ha^{-1})	Productivity (t ha^{-1})	Coverage (ha day^{-1})
1.	Fertilizer application	Spreader + mini tractor (40 hp)	50 600	NA	NA	NA
2.	Weed control	Tractor-drawn tanker sprayer (300 litres) + mini tractor (40 hp)	50 600	NA	NA	NA
3.	Harvesting	Motorized cutter	4 500	16.9	0.84	6.5
4.	FFB in-field evacation & collection	*Wakfoot*	27 000	1.04	1.04	15.9
5.	Loose fruit collection	Air-assisted loose fruit separator	10 000	NA	NA	NA
	Total		124 700	17.3	1.88	21.9

Note: * NA = not available.

TABLE 5. HEXAGONAL PLANTING PATTERN MECHANIZATION COMBINATION

No.	Operation	Machine	Machine cost (RM)	Operation cost (RM ha^{-1})	Productivity (t ha^{-1})	Coverage (ha day^{-1})
1.	Fertilizer application	Spreader + mini tractor (40 hp)	50 600	NA*	NA	NA
2.	Weed control	Tractor-drawn tanker sprayer (300 litres) + mini tractor (40 hp)	50 600	NA	NA	NA
3.	Harvesting	Motorized cutter	4 500	19.5	0.98	7.5
4.	FFB in-field evacuation & collection	*Wakfoot*	9 000	1.1	1.1	18.5
5.	Loose fruit collection	Air-assisted loose fruit separator	10 000	NA	NA	NA
	Total		142 700	20.6	2.08	26

Note: * NA = not available.

CONCLUSION

Based on the simulations above, the most efficient mechanization package recommended was still for the triangular planting pattern with coverage of 313.4 ha per day and a productivity of 2.21 t ha^{-1}. Following this was the hexagonal planting pattern with 26 ha coverage per day at a productivity of 2.08 t ha^{-1}. Implementation of the most efficient mechanization with alternative planting patterns management system would provide a new system that can increase the functionality of the current manual plantation practices. Moreover, development of this system also indirectly helps the end-users in acquiring a better and faster assessment of information regarding suitable mechanization packages.

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REFERENCES

CORLEY, R H V; HEW, C K; TAM, T K and LO, K K (1973). Optimal spacing for oil palm. *Advances in Oil Palm Cultivation* (Wastie, R L and Earp, D A eds.). Incorporated Society of Planters, Kuala Lumpur. 16-18 November 1972. p. 52-71.

HARTLEY, C W S (1967). *The Oil Palm.* Longman, New York.

HELENA, A J J; DESA, A and LEE, T S (2009). Development of an integrated environmental friendly mechanization package for oil palm plantation. *Proc. of a Postgraduate Seminar on Engineering towards Safety, Health and Environmental Excellence, Vol. 16*. p. 163-178.

TEO, L; TIONG, S K K; ABDUL RASHID, S and EE, K W (1993). EPA's experiences on the use of mechanical buffalo for in-field FFB collection and assisted manuring. *Proc. of the 1991 PORIM International Palm Oil Conference – Agriculture* (*Module 1*). p. 179-187.

TURNER, P D and GILLBANKS, R (1974). *The Palm Cultivation and Management*. Incorporated Society of Planters, Kuala Lumpur.

Appendix 1

1) Square planting pattern
Total number of palms per acre = 55 palms
Movement of machine:

1-row distance = 21 × 8.23 m = 172.82 m
2-row distance = 2 × 172.82 m = 345.64 m
Additional row = 10 × 8.23 m = 82.3 m
Inter-row distance = 2 × 8.23 m = 16.46 m
Total distance a machine can move per acre
= 444.4 m

To obtain the coverage per hectare from the available information of the triangular planting pattern was used to extrapolate the conversions of the following:

Coverage = y ha per day
1 ha = 1/y day

But,

1 ha = 2.471 ac

Then,
1 ha = 1/2.471y ac per day

For 1 ac of the triangular planting pattern, the machine moves 534.9 m,
Thus,

534.9 m = 1/2.471y ac per day
1 m = 1/(2.471y)(534.9) ac per day
Coverage for the square
planting pattern = 444.4/(2.471y)(534.9) ac per day
= y × (444.4/534.9) ha per day
Productivity = coverage × (triangular productivity/66 palms) × 55 palms

2) Rectangular planting pattern
Total number of palms per acre = 50 palms
Movement of machine:

1-row distance = (10 × 8.23 m) + (9 × 9.14 m)
= 164.56 m
2-row distance = 2 × 164.56 m = 329.12 m
Additional row = 9 × 9.14 m = 82.26 m
Inter-row distance = 2 × 8.23 m = 16.46 m

Total distance a machine can move per acre
= 428 m

The following conversion was based on triangle planting pattern:

For 1 ac of the triangular planting pattern, the machine moves 534.9 m,
Thus,

534.9 m = 1/2.471y ac per day
1 m = 1/(2.471y)(534.9) ac per day

Coverage for the rectangular
planting pattern = 428/(2.471y)(534.9) ac per day
= y × (444.4/534.9) ha per day
Productivity = coverage × (triangular productivity/66 palms) × 50 palms

3) Hexagonal planting pattern
Total number of palms per acre = 58 palms
Movement of machine:

1-row distance = 15 × 8.23 m = 123.45 m
3-row distance = 3 × 123.45 m = 370.35 m
Additional row = 9 × 8.23 m = 74.07 m
Inter-row distance = 3 × 7.13 m = 21.4 m

Total distance a machine can move per acre
= 465.8 m

The following was based on triangle planting pattern:

Since 1 ac of triangle moves 534.9 m, thus
534.9 m = 1/ 2.471y ac per day
1 m = 1/ (2.471y)(534.9) ac per day

Coverage of square
planting pattern = 465.8/(2.471y)(534.9) ac per day
= y × (444.4 / 534.9) ha per day
Productivity = coverage × (triangle productivity/ 66 trees) × 55 trees