Journal of Oil Palm Research Vol. 15 No. 1, June 2003, p. 32-40

DESIGN AND DEVELOPMENT OF A PROTOTYPE TRAILED TYPE OIL PALM SEEDLING TRANSPLANTER

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ABSTRACT

A prototype trailed type transplanter for oil palm seedlings with a configuration consisting of the main chassis, seedling bin, seedling planting assembly, operator compartment, and associated hydraulic system has been designed and developed at the Department of Biological and Agricultural Engineering, Universiti Putra Malaysia (UPM), Malaysia. AutoCAD 2000 software was employed to develop the 3D dimensional model of the prototype machine. The transplanter is to be trailed from a 4-wheel tractor having at least 85 hp (63.4 kW) engine size and equipped with a seedling bin that could accommodate 20 oil palm seedlings per operating trip. Two operators are required in the involved transplanting operation; a driver for the tractor and an operator for transplanter. The driver drives the tractor-transplanter combination in the field, while the operator operates the hydraulic control system of the transplanter to integrate the preparations of planting hole, placement of seedling in the prepared hole, covering of the seedling in the prepared hole, and compacting of the soil around the planted seedling.

Keywords: mechanization, machinery, transplanter, tree seedling, oil palm cultivation.

Date received: 12 August 2002; **Date approved:** 29 March 2003; **Date revised:** 15 July 2003

INTRODUCTION

Planting is one of the most important operations in the plantation that requires great attention. The operation could affect the total area of productivity since it is the starting point in cultivation. Consequently, good planting technique would enhance the production level of the cultivated area. Turner and Gillbanks (1974) mentioned that there are several activities that are involved in the oil palm seedling transplanting operation. These include: lining, holing for planting, transporting the seedling from the nursery to the field, transporting the seedling in a tray or sling from roadside to the planting hole, and finally planting the seedling to a prepared hole.

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Presently, oil palm seedlings are manually transplanted in the field. The planting hole is either prepared manually with a hoe or with the use of a mechanized drill. The drill can be a portable powered posthole digger or a tractor mounted powered digger. Normally, the holes are prepared a few days prior to the planting of palm seedlings. Planting can begin as soon as field preparations have been completed. During planting, the field worker manually places the palm seedling in the prepared hole, covers the seedling, and compacts the soil around the planted seedling using a hoe. As evident, field planting is a slow and laborious operation.

Modern and efficient methods of transplanting seedling need to be introduced in the oil palm plantation. This could be achieved by integrating all activities in the seedling transplanting operation with a mechanized integrated system.

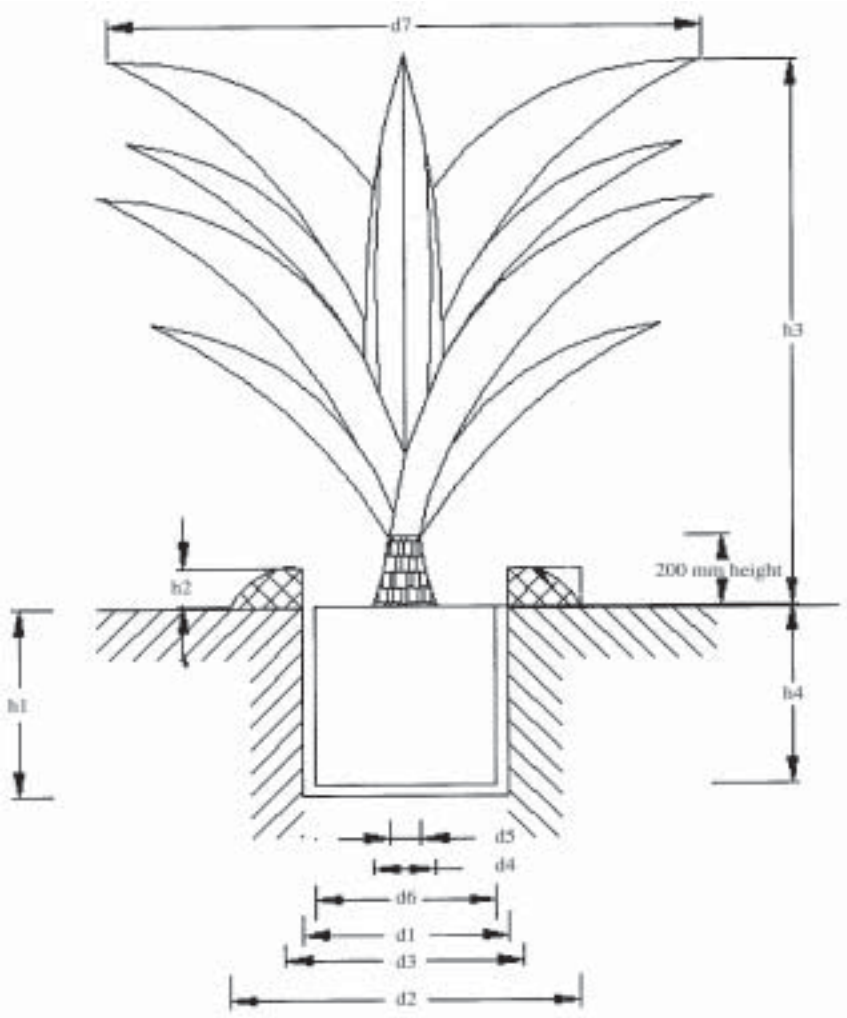
This paper describes the design concept and detail specification of the developed fully integrated prototype machine system for transplanting oil palm seedlings in the plantation.

PHYSICAL CHARACTERISTICS OF AN OIL PALM SEEDLING

Figure 1 shows the main physical characteristics of an oil palm seedling that were considered in the design of the machine system.

Table 1 presents the results of a field study on the physical characteristics of oil palm seedlings at two nursery locations. The planted seedlings were of *Dura* x *Pisifera* material type and 14 months old. The seedlings from nursery A which were planted in smaller polybags were commonly used by some smallholders since such seedlings were manually easier to carry into the field. The seedlings from nursery B which were planted in bigger polybags were for large scale planting in plantations. Each seedling was measured for its plant height, maximum diameter of trunk, fronds spread at 200 mm height, polybag diameter and soil height.

Diameter of palm seedling trunk and diameter of frond were considered in order to determine the allowable clearance between the clamper jaws of the



Notes:
d1= diameter of planting hole
d2= maximum diameter of the deposited soil
d3= crest diameter of the deposited soil
d4= diameter of palm seedling trunk
d5= diameter of frond spread
d6= bag diameter
d7= diameter of the spreading fronds of palm seedling
h1= maximum height of the planting hole
h2= maximum height of the deposited soil
h3= overall height of palm seedling
h4= soil height inside the bag

Figure 1. Schematic of an oil palm seedling.

TABLE 1. PHYSICAL CHARACTERISTICS OF OIL PALM SEEDLINGS

Physical characteristics	95% CI		Percent.
	Nursery A *1	Nursery B*2	differ.
Diameter of trunk (d_4), mm	61.54 ± 3.50	96.65 ± 5.65	36.32
Frond spread at 200 mm height (d_5), mm	89.37 ± 3.89	148.8 ± 6.03	39.93
Maximum frond spread (d_7), mm	99.14 ± 49.78	1 425.75 ± 3.39	93.00
Maximum plant height (h_4), mm	1 047.9 ± 38.76	1 615.25 ± 3.81	35.12
Total weight (w_1), kg	7.43 ± 0.10	20.795 ± 0.34	64.27
Average percentage different			53.73

Notes:
*1 Seedling bags in nursery A having diameter of 161.74 ± 2.96 mm and height of 195.71 ± 3.72 mm (at 95% CI).
*2 Seedling bags in nursery B having diameter of 254.95 ± 3.55 mm and height of 327.6 ± 5.52 mm (at 95% CI).

seedling-covering machine when they were fully closed. Bag diameter and soil height inside the bag, and total weight of the plastic bag with palm seedling dimensions were used for designing the clamper jaws of the seedling planting assembly. Overall height of palm seedling was used for designing the support frame of seedling planting assembly. Diameter of the spreading fronds of palm seedling was used for sizing the main chassis and support frame of seedling placing unit. The size and age of palm seedling determined the physical dimensions of the seedling. This parameter is crucial as it has a great impact on the overall machine size.

Table 2 presents the result of a field study on the physical characteristics of planting hole and deposited soil that was prepared by a tractor with a posthole digger. Diameter and height of planting holes dimensions were used for sizing the auger bit of the machine system for the purpose of preparing the planting hole. Maximum diameter and maximum height of the deposited soil were used for sizing the clamper jaws of the seedling covering mechanism. The maximum height was also used to determine the allowable ground clearance height for clamping-covering mechanism when set to release the palm seedling into the prepared hole. Crest diameter of the deposited soil was used to determine the minimum opening size of the clamper jaws to accommodate sufficient amount of deposited and accumulated soil on the ground for covering the planted palm seedling. Degree of compacted soil around the planted palm seedling was used for sizing the base plate attachments for the clamping jaws and estimating their repetitive number of blows for compacting the soil around the planted palm seedling. Volume of soil for covering the palm seedling in the prepared hole was used for sizing the clamper jaws and the jaws' opening for the covering operation of the planted seedling.

The maximum diameter of deposited soil around the planting hole decreased with the time of the day. However, the maximum height of the deposited soil around the planting hole increased with the time of the day. Such changes could be attributed to the change in both the shape and size of the deposited soil clogs with time. The deposited soil clogs were observed to be rounder and regular in the morning than they were in the late afternoon because of evaporation process. Consequently, the deposited soil around the planting holes prepared in the afternoon was generally composed of particle clogs with varying shapes and sizes. The particle clogs on the surface of the deposited soil appeared to be larger than the inside portion. According to McKyes (1985), soils with irregular shape clog particles have larger angle of repose and better flow ability. Thus, this explains why the deposited soil around the prepared hole has higher crest and smaller maximum diameter when the hole preparation operation were conducted in the afternoon. The average volume of soil required to cover the planted seedling in the prepared planting hole was estimated to be 108.79×10^6 mm^3. This required volume of soil is about 85.8% of the total available deposited soil around the prepared hole. In the design of the machine system, the opening of clamper jaws prior to the beginning of the covering operation should be set wide enough to accommodate such volume of soil to cover the planted seedling.

MACHINE SYSTEM CONFIGURATION

The following criteria were considered in establishing the basic design of the proposed transplanter for oil palm seedlings:

- simple in design, construction and operation;
- trailed type equipment meant for a 4-wheel tractor with at least 85 hp (63.4 kW) engine size;
- two men operation machine system; one for driving tractor-transplanter and one sitting at

TABLE 2. PHYSICAL CHARACTERISTICS OF PLANTING HOLE AND DEPOSITED SOIL

Dimensions	Time	95% CI
Diameter of planting hole (d_1), mm	7:00 am-8:00 am	484.4 ± 6.5
	11:30 am-12:30 pm	490.8 ± 8.28
	3:30 pm-4:30 pm	483 ± 3.84
Maximum diameter of deposited soil (d_2), mm	7:00 am-8:00 am	$1\,378 \pm 159.83$
	11:30 am-12:30 pm	$1\,327 \pm 52.02$
	3:30 pm-4:30 pm	$1\,262 \pm 13.93$
Crest diameter of deposited soil (d_3), mm	7:00 am-8:00 am	812 ± 51.72
	11:30 am-12:30 pm	829 ± 31.99
	3:30 pm-4:30 pm	792 ± 35.46
Maximum height of deposited soil (h_2), mm	7:00 am-8:00 am	190 ± 10.38
	11:30 am-12:30 pm	214 ± 12.04
	3:30 pm-4:30 pm	231.6 ± 9.63
Estimated total volume of deposited soil, (mm^3)	7:00 am-8:00 am	$129.11\times10^6 \pm 31.97\times10^6$
	11:30 am-12:30 pm	$127.88\times10^6 \pm 14.44\times10^6$
	3:30 pm-4:30 pm	$122.72\times10^6 \pm 5.05\times10^6$
Estimated total volume of filled soil, (mm^3)	7:00 am-8:00 am	$111.33\times10^6 \pm 31.97\times10^6$
	11:30 am-12:30pm	$110.11\times10^6 \pm 14.44\times10^6$
	3:30 pm-4:30 pm	$104.94\times10^6 \pm 5.05\times10^6$

the back to operate the hydraulic controls of the functional machine parts;
- completely integrated system capable of preparing the planting hole, placing of seedling in the prepared hole, covering of the seedling in the prepared hole, and compacting the soil around the planted seedling;
- able to reduce the time and labour requirements for the palm seedling transplanting operation; and
- robust construction for higher durability under rough terrain conditions.

Figure 2 shows the 3-D conceptual design of the proposed machine system having an overall dimension of the machine is 5250 mm length, 2170 mm width and 3250 mm height. The machine is to be trailed behind a 4-wheel tractor having at least 85 PTO hp (63.4 kW) engine size and hydraulic flow 66.2 litres min^{-1} with maximum operating pressure of 172.36 bar. The tractor also serves as a power source to the hydraulic system of available functional units within the transplanter. The overall construction of the machine consist of the main chassis, seedling bin, conveying unit and seedling planting assembly.

Main Chassis

The main beam of chassis was designed to carry the total machine weight and consists of chassis frame, axle and tyres, and drawbar. The main chassis is equipped with an axle having single 7.50-16-14 PR, 410 kPa tyres. The selection of tyre size is made on the estimated loading of 1500 kg with reference to ASAE Standard S430.1FEB96; Agricultural Equipment Tyre Loading and Inflation pressures (ASAE Standard, 1996). The main chassis beam was designed to have a goose neck type drawbar to give good cornering ability to the tractor-transplanter when cornering at field headlands. A ladder was located at main chassis of the transplanter to enable the operator to climb up and down from the machine.

Seedling Bin

The seedling bin was designed to accommodate 20 seedlings with a total weight of 450 kg per planting trip. The seedling bin consists of the seedling bin body and the conveying unit. Conveying units are positioned at both sides of the main chassis. The conveyor unit was designed to move the seedlings to the position closed to the operator. The conveyor chain has a 38.1 mm pitch with slatted bars at every 300 mm interval. The space between adjacent slatted bars would be able to accommodate a pair of seedlings. Each conveyor line

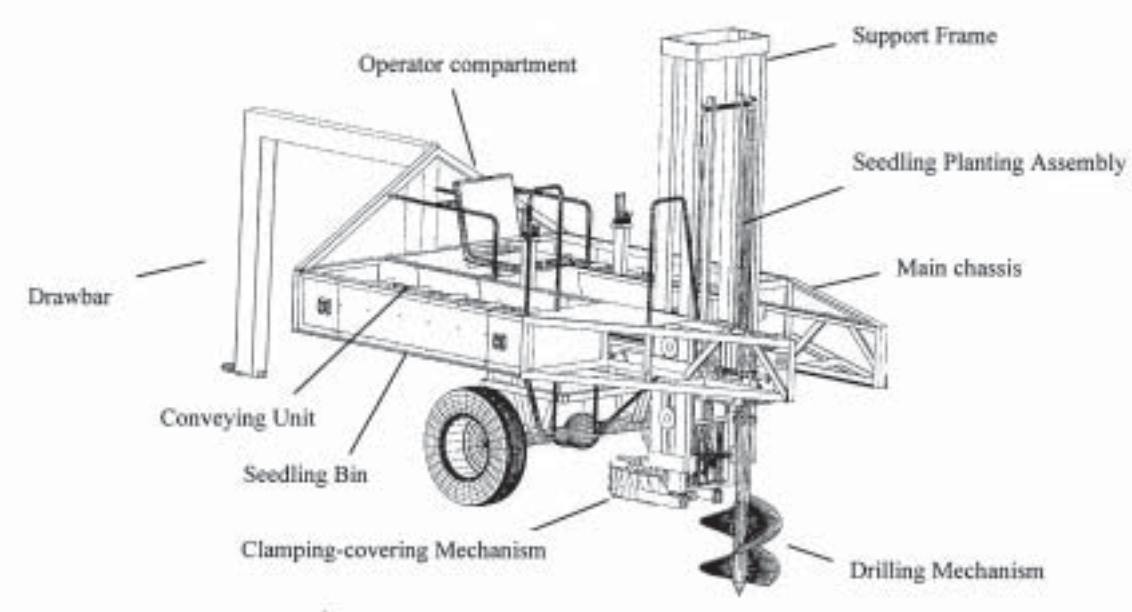


Figure 2. The proposed trailed type transplanter for oil palm seedling.

was designed to carry a total of five pairs seedlings. The side panels to each conveyor unit help to ease the movements of the seedlings and prevent them from falling off the conveyor unit.

Seedling Planting Assembly

The seedling planting assembly is used to plant the seedling into planting hole. There are three functions of the seedling planting assembly; preparing planting hole operation, placing the seedling inside the prepared hole and covering the planted seedling, and compacting the soil around the planted seedlings. The seedling planting assembly consists of the following parts:

Support frame. The support frame is used to provide support for both the complete drilling mechanism and clamping-covering mechanism. The two side vertical cylinders provide the vertical movements for the drilling and clamping-covering mechanisms while the two side horizontal cylinders provide the horizontal movements for the seedling planting assembly.

Drilling mechanism. The drilling mechanism is used to prepare the planting hole for the palm seedling. The drilling auger is powered directly by a hydraulic motor. The auger is pivotly attached to the support frame and could be tilted by operating the tilting hydraulic cylinder. The present auger size could be able to prepare a 304.8 mm (12 inch) diameter-planting hole. Such a hole size would be big enough to accommodate the 28 cm width × 36 cm length polybag seedlings.

Clamping-covering mechanism. The clamping-covering mechanism is used to push the available soil that is deposited and accumulated on the ground to cover the planted seedling. The mechanism is made up of two clamping jaws and a gear-driving unit. There are four inline spur gears that rotate in opposite direction in the gear-driving unit. Opening and closing movements of the clamping jaws are made possible by this inline spur gear set that is operated by a bi-directional hydraulic motor. Each clamping jaw is equipped with an incline base plate attachment for covering the planted seedling. A base plate attachment is mounted below each clamping jaw for compacting the soil around the planted seedling.

Operator Compartment

Operator compartment was designed to provide enough space for the transplanter operator to perform all functional operations that are involved in the transplanting of seedlings in the field. A seat is provided for the operator to seat when the tractor-transplanter is moving to the next planting location. Rigid floor base with sufficient space is provided at the seat frontal for the operator to carry out the necessary planting operations. Two plastic fertilizer buckets are provided behind the transplanter operator to keep the excess fertilizer during the seedling planting operation. There is another smaller plastic fertilizer bucket placed on the floor at the operator leg for his immediate use.

Hydraulic System

The hydraulic system in *Figure 3* was designed to actuate all operational systems of the transplanter.

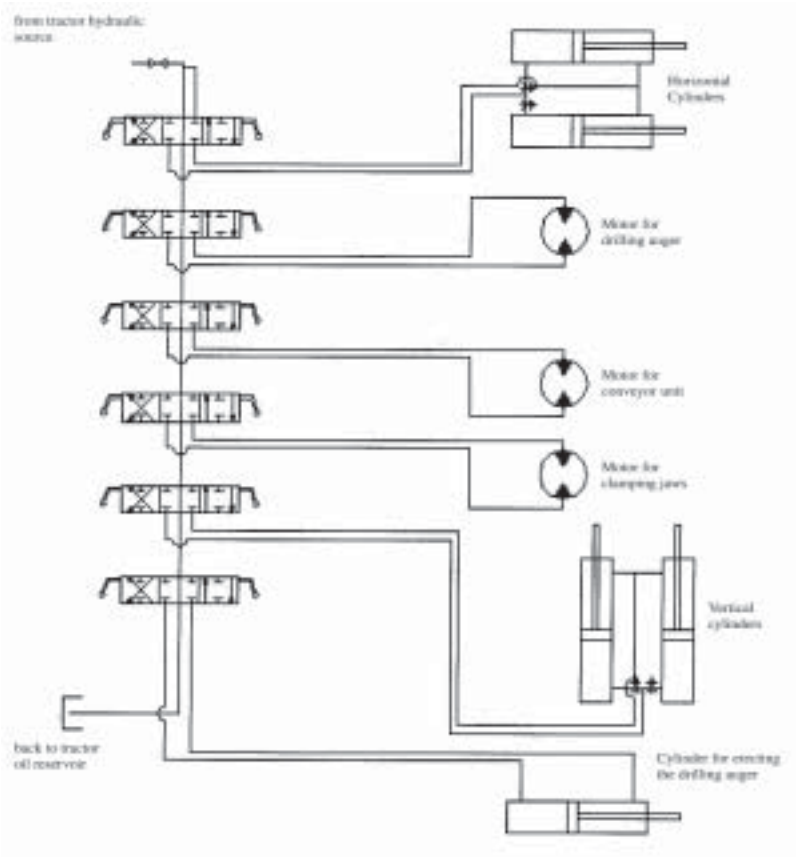


Figure 3. Schematic diagram of the hydraulic system for the transplanter.

The system consists of two units of double acting cylinder 2000 mm stroke with 36 mm cylinder bore for vertical movement of the seedling planting assembly, two units of double acting cylinder 750 mm stroke with 36 mm cylinder bore for horizontal movement seedling planting assembly, one unit of double acting cylinder 300 mm stroke with 36 mm cylinder bore for tilting the auger bit, a unit of bi-directional low speed high torque hydraulic motor TRW Parker MB 08 Series Roller Vane motor for operating the conveying unit, a unit bi-directional low speed high torque hydraulic motor TRW Parker MB 08 Series Roller Vane motor for operating clamping-covering mechanism, a unit bi-directional hydraulic motor TRW Parker MB 18 Series Roller Vane for operating the auger bit, two sets of Salami VD06A 6-port-3 position directional control valves, and a set of hydraulic hoses for flowing the hydraulic liquid. A pair of quick release coupler is used to connect the hydraulic flow from tractor hydraulic liquid reservoir to the hydraulic system of the machine. Two sets of flow dividers are utilized to distribute the flow for operating the vertical and horizontal movement of the hydraulic cylinders.

The involved hydraulic system operational could be categorized into positioning the drilling mechanism, preparing the planting hole, conveying the seedling, placing the seedling inside the planting hole, covering and compacting the planted seedling. These five categories of operations are not run simultaneously during the field transplanting of seedlings. The second and fifth categories of operations are crucial for determining the total required operating hydraulic pressure for the transplanter. *Table 3* presents the required total hydraulic pressure within the individual operations for the available hydraulic system. As observed, the use of a 63.4 kW John Deere 6405 tractor with a rated outlet hydraulic pressure of 172.36 bar as the source of hydraulic power to the transplanter is acceptable since all the five operational categories are not run simultaneously during field transplanting of seedlings.

TOTAL MACHINE MASS AND COST

The total machine mass was estimated by adding together the mass of all individual components of the machine while total machine cost was estimated by adding together both components and fabrication costs of all the individual components of the machine. Based on the conducted analysis, the total estimation machine mass and cost are 1644 kg and RM 29 030, respectively. Among the listed machine components, the seedling planting assembly has the

TABLE 3. REQUIRED TOTAL HYDRAULIC PRESSURE WITHIN INDIVIDUAL OPERATIONS

Operational types	Required total hydraulic pressure, bar
Positioning the drilling mechanism	0.39
Preparing the planting hole	162.15
Conveying the seedling	0.54
Placing the seedling inside the planting hole	0.58
Covering and compacting the planted seedling	120.72

highest mass, followed by main chassis, hydraulic system, seedling bin, and operator compartment. About 32.73% of the total estimated machine mass was taken for the seedling planting assembly and only about 3.58% was taken for the operator compartment. Among the listed components, the hydraulic system has the highest cost, followed by seedling planting assembly, seedling bin, main chassis, and operator compartment. About 63.30% of the total estimated cost was spent for the hydraulics system and only about 0.85% of the total estimated was spent for the operator compartment.

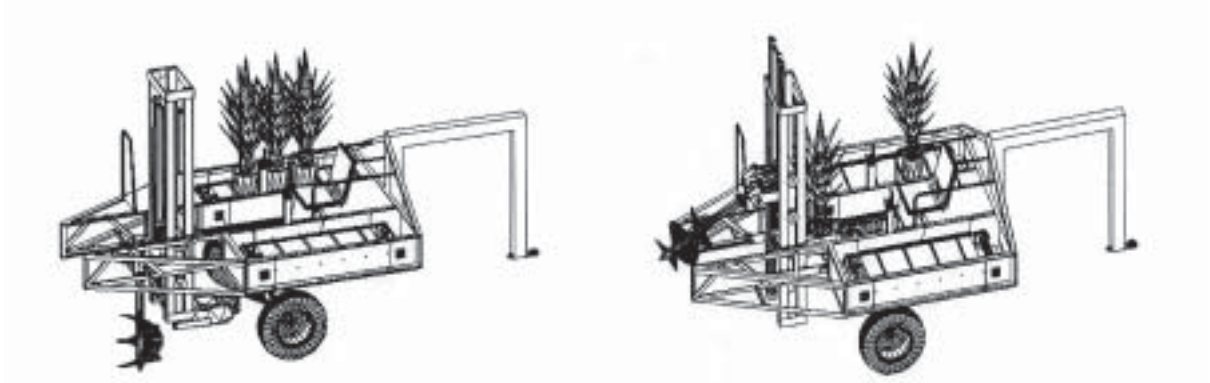
MACHINE OPERATION

The field needs to be prepared prior to the transplanting operation with the machine. This involves lining and marking the planting holes in the field plot. Such works could be conducted immediately after the completion of the land clearing operations. Once the field is ready for planting, the tractor operator drives the tractor-transplanter combination to follow the already marked planting line in the field plot. The tractor operator stops the tractor for the transplanting operation at the marked planting position. The transplanter operator then operates the hydraulic control system of the transplanting machine to integrate all operational activities. Upon completion, the driver drives the tractor to the next planting hole within the same planting line.

Figure 4 summarizes the operational sequences of tractor-transplanter. Firstly, the operator extends the two side horizontal cylinder to move the complete drilling-clamping-covering assembly forward closest to his position. Following that, the operator sets the miniature centre cylinder to extend to erect the drilling auger to vertical position. The operator sets the two side vertical cylinder to extend to lower the complete drilling-clamping-covering assembly. Concurrently, the operator sets the auger motor to rotate to penetrate into the ground for preparing the hole. When the drilling auger has reached the required depth, the operator sets the two side vertical cylinder to retract to lift up the complete drilling-clamping-covering assembly to rest position. While lifting, the auger motor is set to rotate in reverse rotation to bring up all available loose soil to the ground surface. Next, the operator sets the miniature centre cylinder to retract to tilt the drilling auger rearwards to rest position. Finally, the operator sets the two side horizontal cylinder to retract to move the complete drilling-clamping-covering assembly rearwards to complete the hole preparation operation.

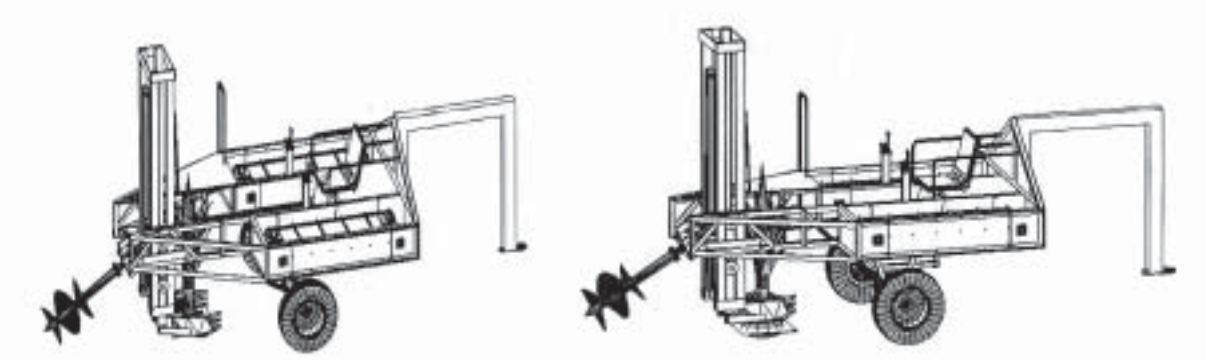
Planting operation starts with manual picking of the nearby palm seedling from the seedling bin and removal of plastic polybag from the seedling by the operator. If there is no more palm seedling available in seedling bin could be picked by operator hand, the conveying unit in seedling bin was run to deliver the seedling close to the operator hands for picking. Before picking the seedling, the operator takes a scoop full of fertilizer CIRP from the nearby fertilizer container and spread the fertilizer uniformly in the prepared planting hole. Once the plastic polybag from the seedling is removed, the operator places the seedling inside the clamping-covering mechanism of the seedling placement unit. Next, the operator sets the two side vertical cylinder to extend to lower the complete drilling-clamping-covering assembly with the seedling. The complete assembly is lowered to the position where the clamping jaws' lowest points are at 5 mm above crest of deposited soil. Upon reaching the position, the operator sets the clamping jaws to wide-open to release and place the seedling into the hole below. While the clamping jaws are at wide-open, the operator sets the main cylinder to extend until the complete drilling-clamping-covering assembly reaches the ground surface. The clamping jaws are set to close back when the complete assembly touches the ground. As clamping jaws collapse to close, the jaws push the accumulated soil on the ground to cover the planted seedling.

The compacting operation proceeds immediately upon the completion of the planting-covering operation. While the clamping jaws are closed, the operator sets the two side vertical cylinder to retract to lift up the complete drilling-clamping-covering assembly to a height about 100 mm above ground



a. Lowering the complete drilling mechanism and clamping-covering mechanism and operating the auger to prepare the planting hole.

b. Lifting-tilting the auger bit rearwards and placing the seedling into the clamping-covering mechanism.



c. Lowering the complete drilling mechanism and clamping-covering mechanism with the seedling and releasing the seedling into the prepared hole.

d. Covering the palm seedling and compacting the soil around the planted seedling.

Figure 4. Machine operational sequences.

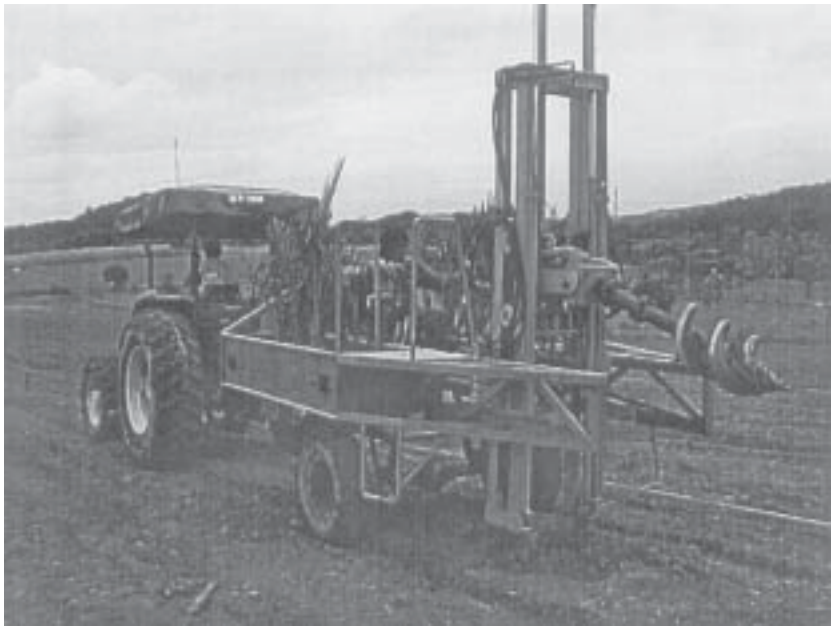


Figure 5. Fully developed prototype oil palm seedling transplanter.

level. The operator then sets the two side vertical cylinder to extend for the complete assembly to press and compact the ground surface around the planted seedling. The operator repeats this sequence of operation for several times to the required compaction degree for the surface soil covering the planted seedling. Upon the completion of this compacting operation, while the clamping jaws are at wide opening, the operator sets the two-side vertical centre cylinder to retract to lift up the complete drilling-clamping-covering assembly to rest position. Finally, the operator sets the two side horizontal cylinder to retract to move the complete assembly rearwards to rest position that give enough height clearance for the machine not to damage the seedling when it moves. This last sequence of operation completes the whole transplanting actives with the machine. The driver moves the tractor to the adjacent hole location within the planting line to proceed with the next transplanting operation.

CONCLUSION

The established design concept and development of a trailed type transplanter for oil palm seedling has been presented and described. The developed prototype transplanter is as shown in *Figure 5*. The total estimation machine mass and cost of the developed prototype transplanter is 1644 kg and RM 29 030, respectively. The machine system could be able to integrate the operational activities of preparing the planting hole, placing of seedling in the prepared hole, covering of the seedling in the prepared hole, and compacting of the soil around the planted seedling in plantation field. The physical characteristics of oil palm seedling have been studied to provide the required design inputs for proposed machine system. The activities involved in manual field transplanting of oil palm seedlings had been closely observed to obtain the design requirements for the proposed machine system.

ACKNOWLEDGEMENT

This research project is classified under RM7 IRPA Project No. 01-02-04-0138. The authors are very grateful to the Ministry of Science, Technology and the Environment of Malaysia for granting the fund for this research project.

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