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# An RFID-based Variable Rate Technology Fertilizer Applicator for Tree Crops

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**Abstract:** Variable Rate Technology (VRT) fertilizer application could reduce pollution through leaching and volatilisation. A VRT fertilizer applicator for band application of granular fertilizer on tree crop was designed, developed and tested. The applicator was equipped with a long-range Radio Frequency Identification (RFID) reader to detect the stored tag ID on the available passive RFID tags attached on the trees. When the control program received the RFID tag ID on the tree, it related the tag ID to the information in a database and triggered the VRT fertilizer applicator system to apply precise amount of fertilizer to that particular area. Based on the experimental evaluation of the response time of the VRT applicator, it was found to take 2-3 sec to changes in application rate depending on the magnitude of the change. The VRT applicator has a field capacity of 7.22 and 7.71 ha $h^{-1}$ with field efficiencies of 0.54 and 0.52 at the travelling speed of 4.43 and 4.92 km $h^{-1}$, respectively. The use of RFID technology has proven to be able to serve as alternative solution for geo-location determinations for the fertilizer applicator in the plantations where the presence of tree canopies has hindered the use of GPS technology.

**Key words:** Fertilizer application, variable rate technology, RFID, precision farming

## INTRODUCTION

Oil palm, rubber, cocoa and coconuts are the major tree crops cultivated in Malaysia. About 66.1% of the total cultivated area under these crops is presently under oil palm. Hence, palm oil is the major commodity in the country and it is the number one source of vegetable oil globally (Alkabbashi *et al*., 2009; Goh *et al*., 2009; Mohammed *et al*., 2011). Varying soil and terrain are now used to cultivate oil palm due to its high yielding capacity. However, the yield of oil palm is highly dependent on the availability of optimum nutrients in the soil (Tarmizi, 2001). Among these four major crops, oil palm is known to be the highest fertilizer consumer. Fertilizer constitutes a major factor for the crop productivity and the highest field production cost in well managed oil palm plantations (Orewa, 2008). The material and application cost normally ranged from 55-65% of the total field production cost for oil palm (Goh *et al*., 2009). The cost of fertilizer in Malaysia is always fluctuating. Its high rising cost has caused oil palm plantations to seek ways of checking waste and proper application timing. Hence, its application in the right quantity, right place and right time is highly encouraged (Sabri, 2009).

Dried oil palm fronds are cut and laid in every other row in between oil palm trees. This practice helps to maintain soil moisture, activities of soil microbes and effective use of fertilizer (Atnaw *et al*., 2011). Thus, spreading of fertilizer on top of these stacks of dried oil palm fronds allows for greater absorption of the fertilizer. Hence, an ideal fertilizer applicator should be such that it applies the fertilizer right on the stack of palm fronds on the alternate rows of the machine path (Tarmizi, 2001).

Presently, fertilizer is either applied manually or by the use of constant rate mechanical fertilizer spreader in the oil palm plantation in Malaysia. Although, the mechanical spreader has higher field capacity, most plantations still choose to use the manual method. It has been observed that more fertilizer is wasted when the mechanical spreader is used. However, these two methods of fertilizer application are uniform mode of application. The varying status of soil nutrients across the field is not taken into cognizance. Hence, there is high possibility of applying overdose of fertilizer in certain areas and inadequate dose in others. Apart from the cost of the excess fertilizer that is applied, it could easily be washed into streams, ponds and rivers around the plantation. In addition, excess fertilizer in the soil exposes the soil to erosion and the volatile part of the fertilizer contaminates the air (Wittry and Mallarino, 2004; Wahid *et al*., 2005; Cugati *et al*., 2006; Kim *et al*., 2006; Tung *et al*., 2009; Sadeghipour *et al*., 2010). A study was conducted to estimate the level of ground water contamination due to fertilizer application in the oil palm plantation in Sabah,

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Malaysia (Tung *et al*., 2009). The leaching of nitrogen and potassium nutrients from ammonium chloride and muriate of potash fertilizers and their consequent effects on the quality of ground water during the monsoon season was investigated. It was observed that when application rates of nitrogen and potassium exceeded the optimum, there was a resultant negative effect on the ground water quality. The nitrogen in the form of ammonium was more than the World Health Organization (WHO) limit of 0.5 mg $L^{-1}$ concentration while the potassium went above the 12 mg $L^{-1}$ WHO concentration limit for safe potable ground water.

Recently, the introduction of fertilizer applicator having a Variable Rate Technology (VRT) system offers solution to earlier mentioned problems by treating with actual fertilizer rates for site-specific crop needs. It advances the benefits of applying different rate of a fertilizer in different grids of the same plantation in order to obtain optimum pH and/or fertility values over the entire plantation. With this new VRT, grid or zone sampling is employed to determine the soil fertility variability of the plantation and fertilizers at variable-rates are applied onto each of these grids or zones. VRT fertilizer application is economical because it has the potential to reduce cost of production while increasing yields. It is environmental-friendly and sustainable due to the fact that the hazards of soil degradation as a result of excessive fertilizer application is eliminated (Norton *et al*., 2005; Ghazali *et al*., 2008).

It has been pointed out that the commercially available variable rate fertilizer spreaders are for field crops and vegetable production. In order to use them for tree crops like citrus, these variable rate fertilizer spreaders were modified by placing baffle plates in front of the spinner disc so as to deflect the fertilizer particles under the tree in a banded pattern (Cugati *et al*., 2006). Furthermore, the available VRT systems are only suitable for broadcast fertilizer application. For example, a field planted with rice, soybeans etc. In a situation where band application of fertilizer is desired like oil palm plantation, it is not appropriate because of the design of the discharging mechanism. In addition, the problems of GPS signal loss under the tree canopy is militating against the use of GPS system for VRT systems (Wahid *et al*., 2004). From the foregoing, it is obvious that there is no appropriate VRT fertilizer applicator for the oil palm yet, especially for the band application of fertilizer.

RFID tag or transponder consists of an electronic microchip and an antenna. The microchip is used to store data like serial number while the antenna facilitates the transmission of data from the RFID tag to an RFID reader through radio waves. The information obtained by the RFID reader is converted to digital information and transmitted to a computer system where the information is stored and used (Sampe and Masuri, 2008; Al-Safadi and Al-Sulaiman, 2011). The RFID tags are known to be able to withstand harsh environmental conditions. The two types of RFID tags are the active and the passive RFID tags. RFID technology has been used for several applications like livestock identification, asset tracking, toxic waste management, agricultural machinery identification etc., (Roberts, 2006). Generally, it was claimed that RFID applications in precision agriculture has led to increment in profit, productivity and efficiencies with minimal negative effects on wildlife and the environment. It also provides real time information from the field that is useful in making informed decision for agricultural management (Ruiz-Garcia and Lunadei, 2011).

An automated RFID based yield mapping system for manually harvested fruits which monitored the yield per each tree was developed. Passive RFID tags were attached to each tree and their corresponding collection bin. The fruits harvested from a tree were placed in the bin and left closed to the trunk of the tree. A tractor that carried an RFID reader and a laptop computer came to collect the bins. The information from the RFID reader was transmitted to the laptop computer via serial port communication and stored in the database on the computer. The relative geo-location of each tree and their yield were estimated from the tag IDs of the trees and the bins. An initially prepared table containing the tag IDs and the absolute positions of each tree was employed in order to develop the yield map (Ampatzidis *et al*., 2009). Hence the objective of this study was to develop Variable Rate Technology (VRT) fertilizer applicator for the oil palm and other tree crops with the incorporation of Radio Frequency Identification (RFID) technology.

## MATERIALS AND METHODS

**Overview of the VRT fertilizer applicator:** All the components of the VRT fertilizer applicator were properly designed. Due consideration was paid to the type, characteristics and method of fertilizer application in the oil palm plantation. The whole unit of the VRT fertilizer applicator was mounted on a 4WD, 4WS prime mover specially designed for oil palm plantation terrain. It has a rated power of 51 kW at 2600 rpm. Figure 1 depicts the VRT fertilizer applicator when it is mounted on the prime mover.

**Operation of the variable rate technology fertilizer applicator:** The Variable Rate Technology (VRT) fertilizer applicator (Fig. 1) was operated by one operator. Prior to

Fig. 1: Variable rate technology fertilizer applicator on the prime mover

the fertilizer application, a prescription map should have been prepared. This map contains the plane coordinates, the tag identification number (tag ID) of the RFID tags (Fig. 3) used to mark the trees which tallies with the respective fertilizer dosage required for each point on the oil palm plantation. The prescription map data was stored in the hard disc memory of the NI 3110 embedded computer system (host PC). On board the VRT fertilizer applicator was a dedicated 2 kVA generator. At the start of the operation on each block, the RFID tags were attached to the oil palm trees according to the prescription map for each block. The bin was filled with the type of fertilizer to be applied. The valve of the hydraulic motor of the centrifugal blowers was actuated to put them on. The valve of the hydraulic motor of the screw conveyor was also switched on when the applicator was about to get to the first tree so as not to compress the fertilizer before the rotary valves start to work.

The 2 kVA generator and the RFID reader were switched on. The control program in LabVIEW 2011 software platform was also run to get the rotary valve ready for work. The rotary valve speed was triggered by the tag ID of the RFID tags on the trees. Only one tag ID was used to control the two rotary valves on the machine. The control of each of the rotary valve came from the control program on the host PC and NI Crio 9073 CompactRIO embedded controller (CompactRIO). The RFID reader read the tag ID of the RFID tags on the tree and sent it to the control program. The control program received the tag ID, compared it with the prescription map. When there was a match, it sent control signal to the rotary valve via the compactRIO. The speed of the rotary valve was set according to the required discharge rate and dosage for each point on the oil palm plantation. Once the operator clicked the run command on the control program, the control of the VRT fertilizer application was done solely by the system. The operator only needed to concentrate on driving the prime mover. As the fertilizer exited the rotary valve and entered the air duct of the centrifugal blower, it was thrown by the blast of air from the blower to the top of the pile of cut oil palm fronds on either side of the machine path in the plantation. However, the operator switched off the screw conveyor when the VRT applicator had gone beyond the last oil palm tree in each row and switched it on again when it was approaching the first oil palm tree of the next row. By this, wastage of fertilizer was prevented when the VRT applicator was being turned at the headland. The operation continued until the fertilizer bin was almost empty. Then, the operator switched off both the blowers and the screw conveyor and clicked the pause button of the control program in order to refill the fertilizer bin. When the operator was ready to continue again, the blowers and the screw conveyor were switched on and the run button on the control program was clicked and then the operation went on. In case, there was change in travel speed, there was a speed feedback to the compactRIO which in turn changed the discharge rate to match the newly attained travel speed.

**Response time of the VRT system to RFID triggered application rate:** A study was conducted in order to determine the time lag between the detection of an RFID tag ID and adjustment of the VRT system to the new fertilizer application rate corresponding to the application map. The rotary valves were equipped with rotary encoders in order to measure their respective speed during the operation of the machine. The signal output from these rotary encoders was read every second by the host PC via the compactRIO and saved by the use of the control program. A row of palm trees in an oil palm plantation was selected for the study. RFID tags were attached to the oil palm trees. The arrangement of the RFID tags was such as to change the speed of the rotary valves in three different ways. First was in ascending order. Second was in descending order and the last was in random order. Each arrangement was replicated three times. The VRT applicator was set up and operated as described earlier.

As the VRT applicator moved in the row of the oil palm trees, the RFID tag ID was detected and stored in the host PC. Also, the speed setting of the rotary valve was continuously saved in the host PC. Separate data file was used for each run. After the whole study, each data file was examined to extract the time lag between the change in tag ID and stabilization of the rotary valve speed to the new speed setting. This was used as the response time of the VRT system.

**Field capacity and Efficiency of the VRT fertilizer applicator:** In an attempt to measure the field performance of the VRT fertilizer applicator, a time motion study of the process of fertilizer application was carried out. The purpose was to derive some field performance indices and compare them to those of the conventional Uniform Rate (UR) fertilizer applicator for oil palm. The study was conducted on the oil palm plantation of the Agricultural Park of Universiti Putra Malaysia. The total area used was 1.508 hectares. The oil palm trees were seven years old. The spacing of the trees was 8.8 m and the row spacing was 8 m. The machine was operated at 4.43 km $h^{-1}$ and 4.92 km $h^{-1}$. The fertilizer used was NPK (12-12-17-2+TE).

The RFID tags were attached to the trees according to the application rate desired for each portion of the experimental plot. The VRT applicator was set up and operated as described earlier. The following parameters were measured with stop watch and recorded:

TL = Time to manually open fertilizer bags and fill the bin with the fertilizer (h)
T1 = Time to travel to first palm tree from loading point (h)
TR = Time to travel and Apply fertilizer from first palm to last palm tree in the rows (h)
TU = Time to turn at the headland after the last palm in one row to the first palm in the next row (h)
TRF = Time to return to the loading point for refilling the bin with fertilizer (h)

The whole experiment for each machine speed was repeated three times.

The following performance indices were derived from the measurement of time:

$$FC = \frac{AP}{TL + T1 + TR + TU + TRF} \quad (1)$$

$$FE = \frac{TR}{TL + T1 + TR + TU + TRF} \quad (2)$$

Where:
FC = Field capacity (ha $h^{-1}$)
FE = Field efficiency (decimal)
AP = Area of plot (ha)

All other parameters in Eq. 1 and 2 are as earlier defined.

## RESULTS AND DISCUSSION

**Response time of the VRT system to RFID triggered application rate:** The results obtained from the investigation of the response of the VRT system to changes in application rates are shown in Fig. 2-4. The range of speed of the rotary valves was 60-180 rpm. Figure 2 shows the changes in speed of the rotary valve in ascending order. The speed was varied at interval of 30 rpm. It could be seen that it took 2 sec to change from one speed to the next. Figure 3 shows the changes in speed of the rotary valve in descending order. The speed

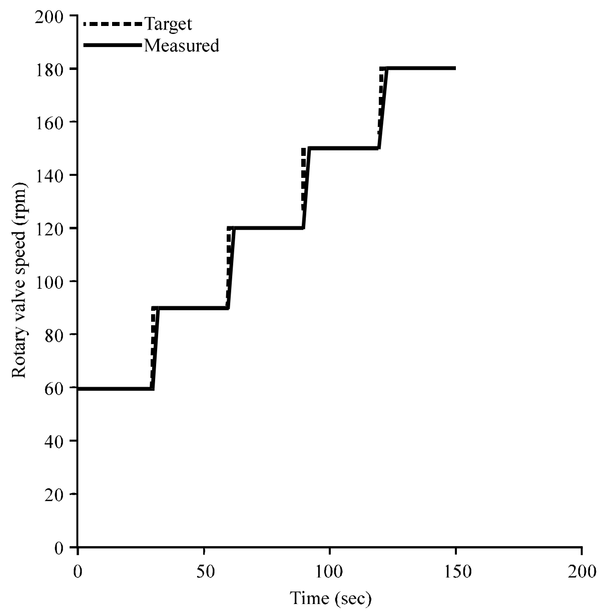


Fig. 2: Speed change of the rotary valve in ascending order

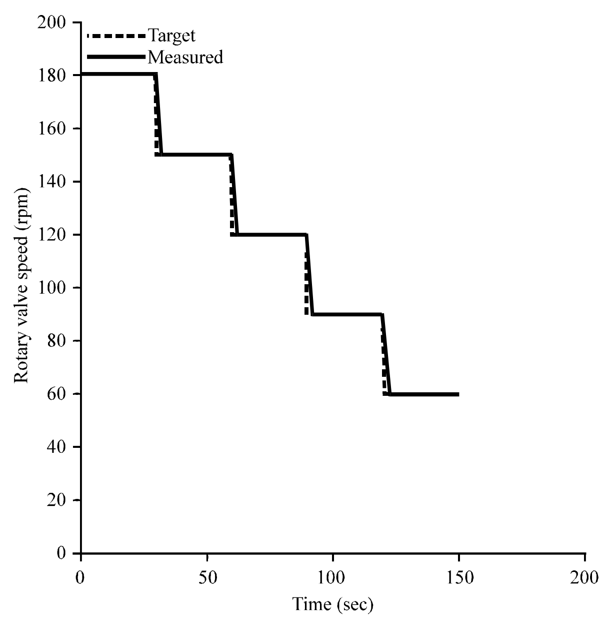


Fig. 3: Speed change of the rotary valve in descending order

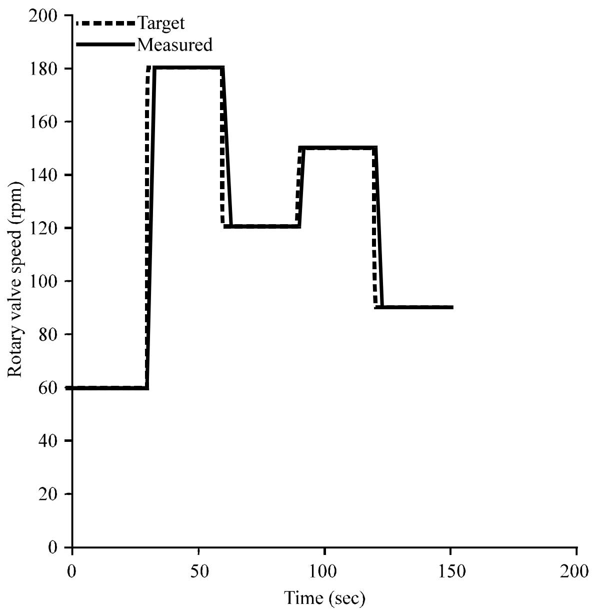


Fig. 4: Speed change of the rotary valve in random order

was varied at interval of 30 rpm. Also, it was observed that it took 2 sec to change from one speed to the next. Figure 4 represents the change in the rotary valve speed in a random manner. It was noticed that when there was a difference of more than 30 rpm between one speed and the next, it took 3 sec for the rotary valve to stabilize at the new speed. This implies that the VRT system took a period of 2-3 sec to change from one application rate to the other depending on the magnitude of the change. This range of the response time obtained here is similar to the range of 1.5-3.03 sec obtained by Kim *et al.* (2008). Likewise Schumann *et al.* (2006) pointed out that the response time for this type of VRT system was 2-5 sec. In addition, similar trend of results were obtained by Cugati *et al.* (2006, 2007) and Fulton *et al.* (2001, 2003). The behaviour exhibited by the RFID system used in this study was also reported by Ampatzidis *et al.* (2009), Sampe and Masuri (2008) and Wei and Chetty (2012).

**Field capacity and efficiency of the VRT fertilizer applicator:** The proportion of time spent on each task in the fertilizer application operation is shown in Table 1. The abbreviations in the Table 1 are as earlier defined. This Table 1 reveals that the largest proportion of the time was spent on manually opening of the fertilizer bags and loading the fertilizer into the bin. At field speed of 4.43 km $h^{-1}$, 47.66% of the total time was spent on opening the fertilizer bags and filling the bin with the fertilizer. Likewise, at travel speed of 4.92 km $h^{-1}$, 50.17% of the total time was used for opening the fertilizer bags

Table 1: Relative time taken for each task in the fertilizer application

| Task | Time proportion (%) at (4.43 km $h^{-1}$) | Time proportion (%) at 4.92 (km $h^{-1}$) |
|---|---|---|
| TL | 47.66 | 50.17 |
| T1 | 2.56 | 2.24 |
| TR | 37.31 | 35.39 |
| TU | 5.54 | 5.66 |
| TRF | 6.94 | 6.54 |

TL: Time to manually open fertilizer bags and fill the bin with the fertilizer (h), T1: Time to travel to first palm tree from loading point (h), TR: Time to travel and apply fertilizer from first palm to last palm tree in the rows (h), TU: Time to turn at the headland after the last palm in one row to the first palm in the next row (h) and TRF: Time to return to the loading point for refilling the bin with fertilizer (h)

Table 2: Performance of variable rate technology fertilizer applicator

| | Type of fertilizer applicator | | |
|---|---|---|---|
| Performance index | VRT at (4.43 km $h^{-1}$) | VRT at (4.92 km $h^{-1}$) | UR at (6.00 km $h^{-1}$) |
| Field Capacity (ha $h^{-1}$) | 7.22 ± 0.05 | 7.71 ± 0.07 | 4.63 ± 0.03 |
| Field Efficiency (decimal) | 0.54 ± 0.06 | 0.52 ± 0.03 | 0.36 ± 0.03 |

VRT: Variable rate technology, UR: Uniform rate

and filling the fertilizer into the bin. Furthermore, going by Eq. 1 and 2, the field capacity and field efficiency of the VRT applicator could be increased if the time for this task is reduced. This could be achieved if the task is fully or partially automated. It will be observed that at both travel speeds, the proportion of time taken to return to the loading point for refilling the bin with fertilizer was greater than the time taken to travel to the first palm tree from the loading point. The difference was more than 4% in each case. This difference could be further reduced if the fertilizer bags are positioned at strategic points on the plantation for quicker refilling of the bin during fertilizer application. Hence, the field capacity and field efficiency of the VRT applicator could be further improved.

The conventional Uniform Rate (UR) fertilizer applicator used during an earlier study comprised of an 850 kg spinner disc fertilizer spreader mounted on a tractor. The tractor was a 4WD New Holland TD80D with rated power of 53.7 kW at 2500 rpm. It could be deduced from Table 2 that at 4.43 km $h^{-1}$, the field capacity and field efficiency of the VRT applicator were 1.56 times and 1.54 times, respectively higher than those of the UR applicator at 6 km $h^{-1}$. Likewise, at 4.92 km $h^{-1}$ the field capacity and field efficiency of the VRT applicator were 1.67 times and 1.49 times, respectively higher than those of the UR applicator at 6 km $h^{-1}$.

## CONCLUSION

A Variable Rate Technology (VRT) fertilizer applicator for band application of granular fertilizer on tree crop was designed, developed and tested. It uses RFID technology for the triggering of the VRT system. A long-range UHF RFID reader together with other VRT capability systems was mounted on the VRT applicator. Also, UHF Passive RFID tags were attached to the trees according the desired application rate for each point on the field.

A study was carried out to evaluate the response time of the VRT applicator. It took 2-3 sec to respond to changes in application rate depending on the magnitude of the change. At a travelling speed of 4.43 km $h^{-1}$, the VRT applicator had field capacity and field efficiency that were 1.56 times and 1.54 times, respectively higher than those of the UR applicator at 6 km $h^{-1}$. Likewise, at 4.92 km $h^{-1}$ the field capacity and field efficiency of the VRT applicator were 1.67 times and 1.49 times, respectively higher than those of the UR applicator at 6 km $h^{-1}$. The performance VRT applicator could be improved further if the task of filling the fertilizer into the fertilizer bin is automated. This RFID-based VRT fertilizer applicator seems quite promising for use under the tree canopy where signal loss has militated against the success of the GPS-based systems.

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