AN RFID-BASED VARIABLE RATE TECHNOLOGY FERTILIZER APPLICATOR FOR TREE CROPS

T. A. Ishola, A. Yahya, A. R. M. Shariff and S. Abd Aziz

Department of Biological and Agricultural Engineering
Faculty of Engineering
Universiti Putra Malaysia
43400 UPM Serdang
Selangor, Malaysia.

ABSTRACT

Currently, in the Malaysian tree crop plantation, fertilizer is applied manually or mechanically at uniform rate without due consideration to nutrient variability. Potential wastage and excessive application of this fertilizer contaminates ground water and raises its mineral contents above the World Health Organization (WHO) limit for safe drinking water. However, Variable Rate Technology (VRT) fertilizer application promotes Green Engineering practice by reducing excessive fertilizer application, land degradation and pollution through leaching and volitization. It could also increase yield and profit.

A VRT fertilizer applicator for band application of granular fertilizer on tree crop was designed, developed and tested. The applicator is 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. The Tag ID is used by the control program of the VRT system in triggering the rotary valves which are the metering units for the system. A database containing the GPS coordinates, the RFID tag ID and the amount of fertilizer to be applied on specified area has to be earlier developed and stored in the memory of computer system of the VRT applicator. When the control program receives the RFID tag ID on the tree, it relates the tag ID to the information in the database and triggers 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 seconds to changes in application rate depending on the magnitude of the change. The VRT applicator has a field capacity of 7.60 ha/h and 8.10 ha/h with field efficiencies of 0.55 and 0.57 at the travelling speed of 4.43 km/h and 4.92 km/h, respectively. The machine performance could be enhanced if the task of filling the fertilizer into the bin is automated. The use of RFID technology has proven to be able to serve as alternative solution for position determinations for the fertilizer applicator in the plantations where the presence of tree canopies hinders the use of available GPS technology.

Keywords: Fertilizer Application, Variable Rate Technology, Radio Frequency Identification, 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 (Goh et al., 2009). The high productivity of oil palm has resulted in expansion to diverse soil and terrain. However, the yield of oil palm is highly dependent on the availability of optimum nutrients in the soil (Tarmizi, 2001). Among the 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. The material and application cost normally ranged from 55% to 65% of the total field production cost for oil palm (MPOB, 2008). Fertilizer price has been described to be unpredictable in nature. The soaring price of fertilizer has tempted some of the oil palm planters to withdraw fertilizer usage as a measure for breaking even. Likewise, potential wastage and haphazard timing of fertilizer application are now given due attention and redress. Hence, its application in the right quantity, right place and right time is highly encouraged (Sabri, 2009).

Due to the nature of the crop root system, broadcasting of fertilizer around the oil palm reduces leaching losses because more roots are in contact with the nutrient. Likewise, pruned fronds from the oil palm are left in alternate rows in between the oil palm trees so as to promote microbial activity, soil moisture conservation and fertilizer uptake efficiency. Therefore, broadcasting of fertilizer on the piles of fronds along palms alternate rows ensures increase in fertilizer absorption since more roots are able to absorb it. 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).

Unfortunately, most of the oil palm plantations in Malaysia still prefer to use manual method of fertilizer application or seldom use the constant rate mechanical fertilizer broadcaster. Probably due to the fact that the commercially available constant rate mechanical fertilizer broadcaster is not appropriate for spot placement fertilizer application that is used for oil palm plantation. Also, it tends to consume more or waste fertilizer during operation. Both the constant rate mechanical fertilizer broadcasters and the manual method of fertilizer application are inefficient and at uniform rate which may not match with the actual nutrient variability and the needs of individual oil palm across the oil palm plantation. This method of fertilizing the whole plantation with a single fertilizer rate obviously leads to over fertilize certain regions and under fertilizing others. Apart from the waste in resources of over fertilizing, the excess fertilizer that gets leached into nearby water bodies constitute environmental hazard. Furthermore, excessive fertilizer application causes Land Degradation and Pollution through leaching and Volatilisation (Wittry and Mallarino, 2004; Wahid et al., 2005; Cugati et al., 2006; Kim et al., 2006 and Ah Tung et al., 2009). A study was conducted to estimate the level of ground water contamination due to fertilizer application in the oil palm plantation in Sabah, Malaysia (Ah 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 oil palm 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 can be described as a way of implementing Green Engineering in fertilizer application. This is because it satisfies the following principles of Green Engineering: Minimizing depletion of the natural resources (soil); striving to prevent wastage (fertilizer) and possessing system components that maximize energy and efficiency. Furthermore, it 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).

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 spot placement 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. 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. Hence the objective of this research 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.

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. 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 is 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 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 monitors 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 are placed in the bin and left closed to the trunk of the tree. A tractor that carries an RFID reader and a laptop computer comes to collect the bins. The information from the RFID reader is 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).

Likewise, long-range RFID reader plus passive RFID tags placed on trees were used for tree identification in two methods of matching pairs of trees to bins of manually harvested fruits. For method one, passive RFID tags attached to the bins were used while bar code labels attached to the bins were used for method two. There were RFID reader, barcode reader and a digital weighing scale on the orchard tractor used for the bin collection. It was discovered that the RFID bin registration method did not change the normal time for loading the bins but the barcode method resulted in 14 % more time for loading. Furthermore, the use of weighing scale in the field resulted in 33 % time increase in both loading methods (Ampatzidis and Vougioukas, 2009).

MATERIALS AND METHODS

For this research, ultra-high frequency passive tags (Class 1 Gen 2) were used while the RFID reader was Integrated Long Range RFID reader – antenna (ECO – UHF RR102). The frequency range for both was 902 – 928 MHz.

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. Table 1 shows the summary of technical specifications of the developed VRT fertilizer applicator.

Table 1. Technical specifications of the VRT fertilizer applicator

Components	Parameters	Specifications
Rotary Valve		
	Discharge rate	2.13 kg/s
	Speed	100 rpm
Centrifugal turbo blower		
	Total pressure capacity	2.70 kPa
	Volumetric air flow rate	0.36 m^3/s
	Speed	2466 rpm
	Power required	3.27 kW
Screw conveyor		
	Mass discharge rate	11.70 kg/s
	Power required	3.902 kW
Fertilizer bin		
	Angle of repose	40˚
	Capacity	1.20 tons

The whole unit of the VRT fertilizer applicator was mounted on a 4WD prime mover specially designed for oil palm plantation terrain. It has a rated power of 51 kW @ 2600 rpm. Figures 1 and 2 depict VRT fertilizer applicator when it is mounted on the prime mover.

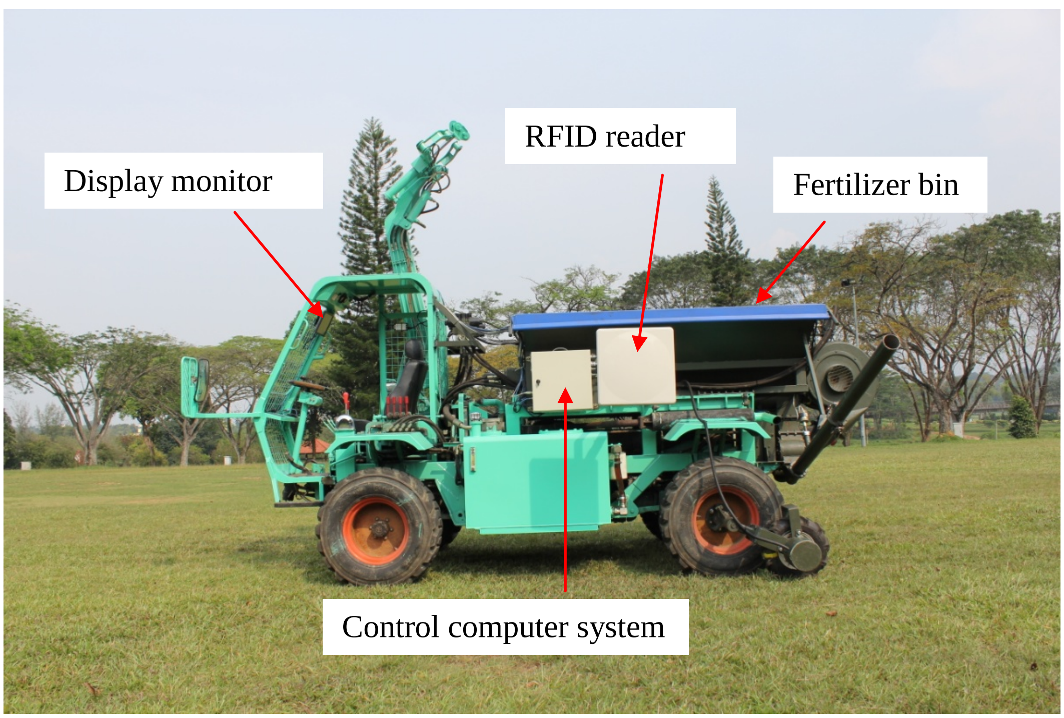

Figure 1. Side View of the VRT fertilizer applicator on the prime mover

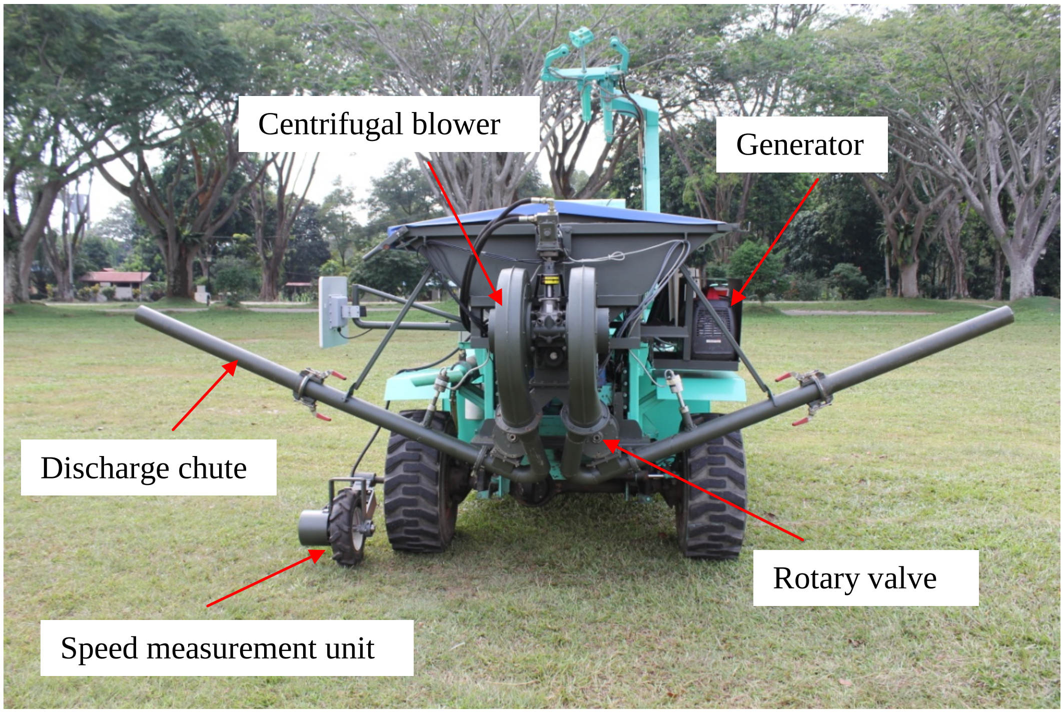

Figure 2. Rear View of the VRT fertilizer applicator on the prime mover

Operation of the Variable Rate Technology fertilizer applicator

The Variable Rate Technology (VRT) fertilizer applicator (Figures 1&2) is operated by one operator. On board the VRT fertilizer applicator is NI 3110 embedded computer system (Host PC) (Figure 3) and a dedicated 2 KVA generator (Honda EU 20i). Prior to 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 (Figure 4) 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 is stored in the hard disc memory of the host PC.

At the start of the operation on each block, the RFID tags is attached to the oil palm trees according to the prescription maps for each block. The bin is filled with the type of fertilizer to be applied. The valve of the hydraulic motor of the centrifugal blowers is actuated to put them on. The valve of the hydraulic motor of the screw conveyor is also switched on when the applicator is about to get to the first tree so as not to compress the fertilizer before the rotary valves start to work.

The generator and the RFID reader are switched on. The control program in LabVIEW software platform is also run to get the rotary valve ready for work. The rotary valve speed is triggered by the tag ID of the RFID tags on the trees. Only one tag ID is used to control the two rotary valves. The control of each of the rotary valve comes from RFID reader and the host PC. This is accomplished by the control program on the host PC and NI Crio 9073 CompactRIO embedded controller (CompactRIO) (Figure 3). The RFID reader reads the tag ID of the RFID tags on the tree and sends it the control program. The control program receives the tag ID, compares it with the prescription map. When there is a match, it sends control to the rotary valve via the compactRIO. The speed of the rotary valve is set according to the required discharge rate and dosage for each point on the oil palm plantation. Once the operator clicks the run command on the control program, it takes over the control of the VRT fertilizer application. The operator only needs to concentrate on driving the prime mover. As the fertilizer exits the rotary valve and enters the air duct of the centrifugal blower, it is 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 (Figure 5). This operation continues until the fertilizer bin is almost empty. Then, the operator clicks the pause button of the control program and switches off both the blowers and the screw conveyor in order to refill the fertilizer bin. When he is ready to continue again, he clicks the run button on the control program, switches on the blowers and the screw conveyor again and then the operation goes on.

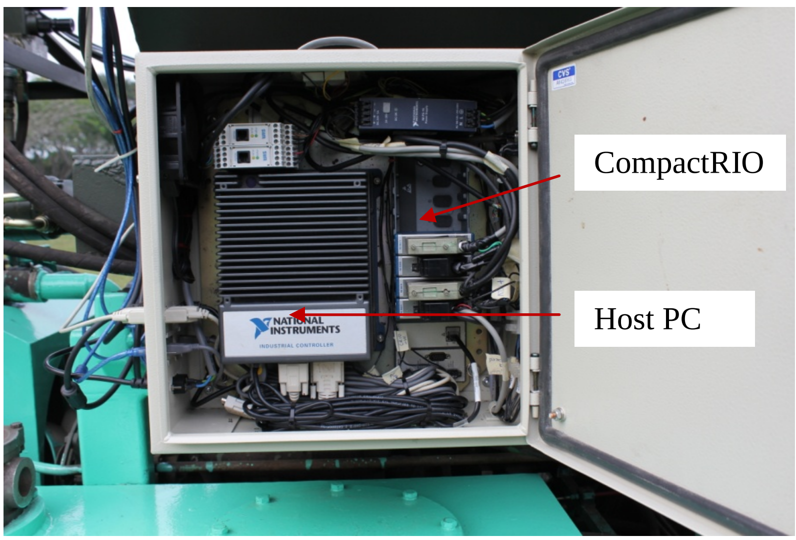

Figure 3. Control computer system

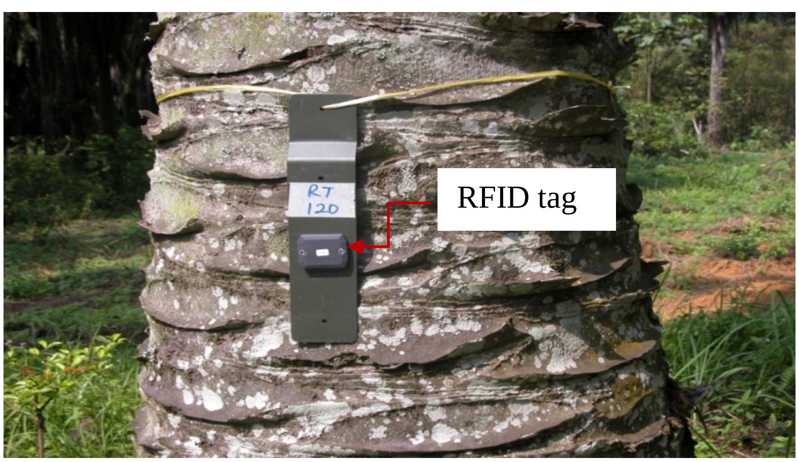

Figure 4. RFID tag attached to oil palm tree.

Figure 5. The VRT fertilizer applicator during fertilizer application

Response time of the VRT system to RFID triggered application rate

An experiment 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 is read every second by the host PC via the compactRIO and saved with use of control program. A row of palm trees in an oil palm plantation was selected for the experiment. RFID tags were attached to the oil palm trees as shown in Figure 4. 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 moves 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 experiment, 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 experiment was conducted on the oil palm plantation of Taman Pertanian Universiti unit 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 9.8 m. The machine was operated at 4.43 km/h and 4.92 km/h. The width of operation was 30 m. 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:

1) TL = Time to manually open fertilizer bags and fill the bin with the fertilizer.
2) T1 = Time to travel to first palm tree from loading point.
3) TR1 = Time to travel & Apply fertilizer from first palm to last palm tree in the first row.
4) TU = Time to turn at the headland after the last palm in first row to the first palm in palm in second row.
5) TR2 = Time to travel & Apply fertilizer from first palm to last palm tree in the second row.

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

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 Figures 6 to 8 and table 2. The range of speed of the rotary valves was 60 rpm to 180 rpm. Figure 6 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 takes 2 seconds to change from one speed to the next. Figure 7 shows the changes in speed of the rotary valve in descending order. The speed was varied at interval of 30 rpm. Also, it was observed that it took 2 seconds to change from one speed to the next. Figure 8 represents the change in the rotary valve speed in a random manner. It was noticed that when there is a difference of more than 30 rpm between one speed and the next, it took 3 seconds for the rotary valve to stabilize at the new speed. This range of the response time obtained here is similar to the range of 1.5 to 3.03 seconds obtained by Kim et al., 2008.

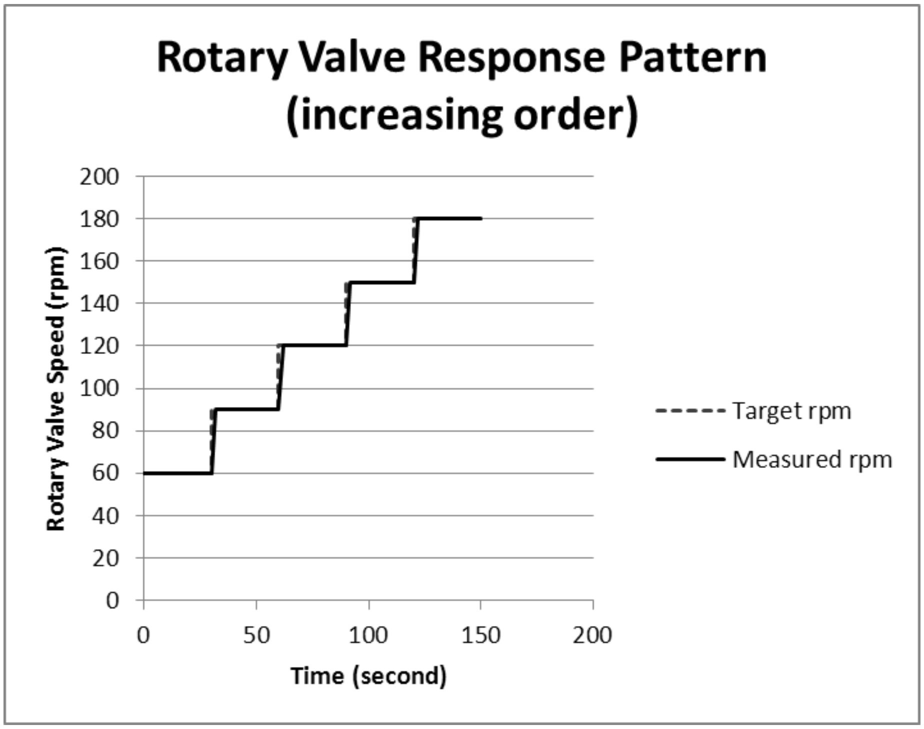

Figure 6. Speed change of the rotary valve in ascending order

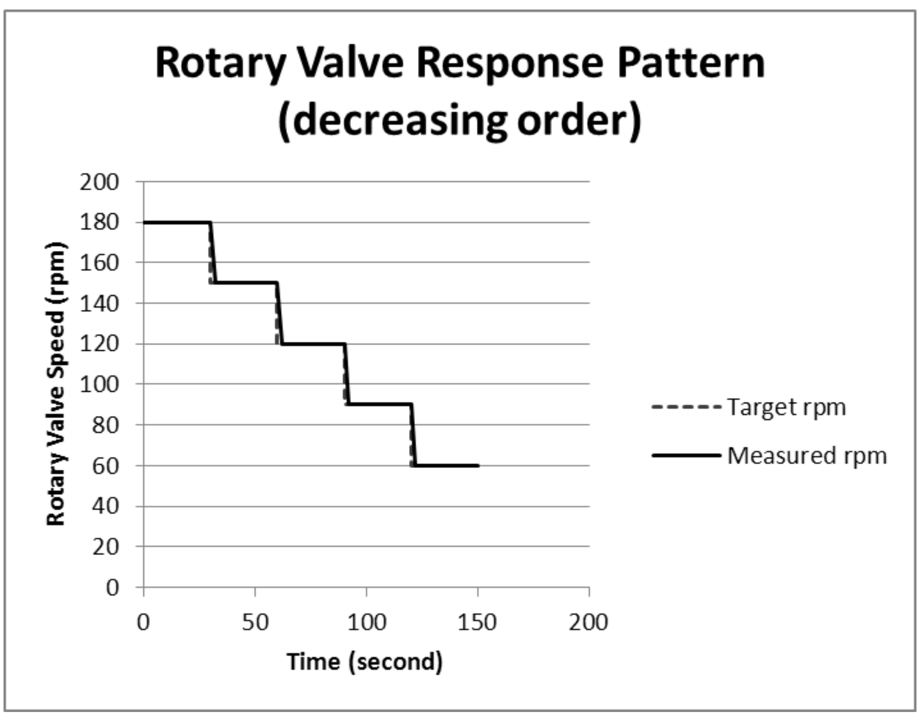

Figure 7. Speed change of the rotary valve in descending order

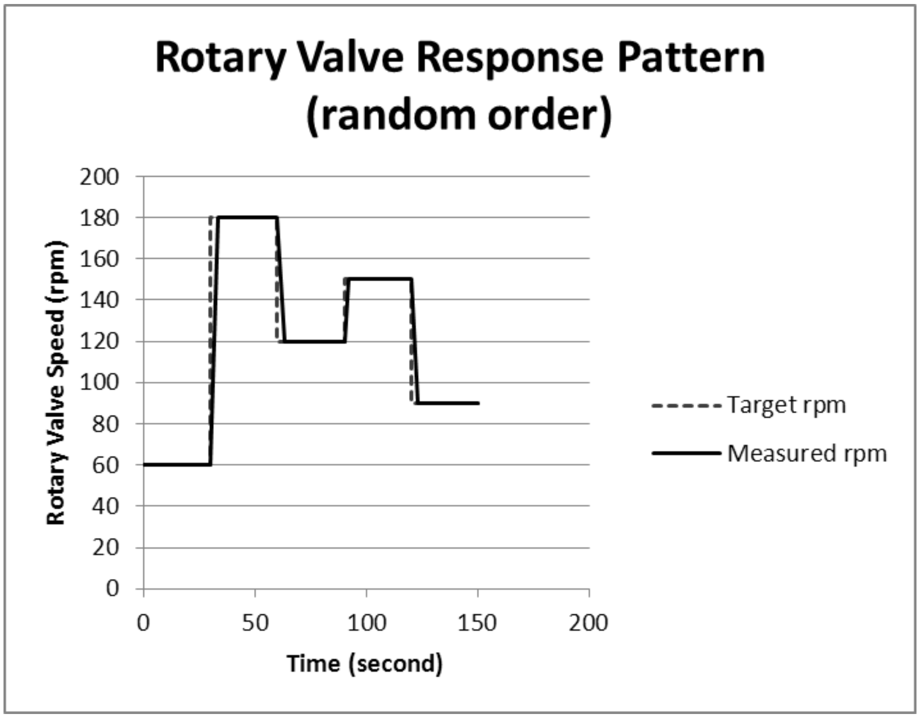

Figure 8. Speed change of the rotary valve in random order

Table 2. Response time of rotary valve speed transition

Mode of change	Rotary valve speed changes from one rpm to another	Mean time taken
Increasing	60 to 90; 90 to 120; 120 to 150; 150 to 180	2 seconds each
Decreasing	180 to 150; 150 to 120; 120 to 90; 90 to 60	2 seconds each
Random	60 to 180	3 seconds
	180 to 120	3 seconds
	120 to 150	2 seconds
	150 to 90	3 seconds

Field capacity and Efficiency of the VRT fertilizer applicator

The following performance indices were derived from the measurement of time

$$Field\ Capacity\ \left({}^{ha}/_{h}\right) = \frac{Area\ of\ Plot\ (ha)}{(TL + T1 + TR1 + TU + TR2)h} \quad 1$$

$$Field\ Efficiency\ (decimal) = \frac{(TR1 + TR2)h}{(TL + T1 + TR1 + TU + TR2)h} \quad 2$$

All the parameters in equations 1 and 2 are as earlier defined. The results obtained are shown in Tables 3 and 4.

Table 3. Proportion of time for each task in the fertilizer application

Task	Time proportion (%)	
	at 4.43km/h	at 4.92 km/h
Time to manually open fertilizer bags and fill the bin with the fertilizer. (TL)	36.55	38.94
Time to travel to first palm tree from loading point. (T1)	1.96	1.74
Time to travel & Apply fertilizer from first palm to last palm tree in the first row.(TR1)	26.47	25.03
Time to turn at the headland after the last palm in first row to first palm in palm in second row.(TU)	4.25	4.39
Time to travel & Apply fertilizer from first palm to last palm tree in the second row.(TR2)	30.77	29.9

Table 4. Performance of VRT fertilizer applicator

Performance index	VRT applicator @ 4.43 km/h	VRT applicator @ 4.92 km/h	Conventional UR applicator @ 6.00 km/h[1]
Field Capacity (ha/h)	7.60 ± 0.05	8.10 ± 0.06	4.63 ± 0.03
Field Efficiency (ha/h)	0.57 ± 0.04	0.55 ± 0.03	0.36 ± 0.03

[1]Source from Su (2011)

The conventional uniform rate (UR) fertilizer applicator used during the work of Su (2011) 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 @ 2500 rpm. It could be deduced from Table 4 that at 4.43 km/h, the field capacity and field efficiency of the VRT applicator were 1.64 times and 1.63 times respectively higher than those of the UR applicator at 6 km/h. Likewise, at 4.92 km/h the field capacity and field efficiency of the VRT applicator were 1.75 times and 1.57 times respectively higher than those of the UR applicator at 6 km/h.

Looking at Table 3 reveals that largest proportion of the time was spent on manually opening of the fertilizer bags and loading the fertilizer into the bin. Again, going by equations 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.

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.

An experiment was carried out to evaluate the response time of the VRT applicator. It took 2 – 3 seconds to respond to changes in application rate depending on the magnitude of the change. At a travelling speed of 4.43 km/h, the VRT applicator had field capacity and field efficiency that were 1.64 times and 1.63 times respectively higher than those of the UR applicator at 6 km/h. Likewise, at 4.92 km/h the field capacity and field efficiency of the VRT applicator were 1.75 times and 1.57 times respectively higher than those of the UR applicator at 6 km/h. 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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