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Effects of Operational Variables on Rotary Valve Metering System for a Variable Rate Technology Fertilizer Applicator for Oil Palm

Tajudeen Abiodun Ishola, Azmi Yahya, AbdulRashid Mohammed Shariff,
Samsuzana Abd Aziz and Chow Syh Chuan
Department of Biological and Agricultural Engineering, Faculty of Engineering,
Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia

Abstract: In the Malaysian oil palm plantation, fertilizer application was observed to be done manually or mechanically at uniform rate without due consideration to nutrient variability. The available constant rate mechanical fertilizer spreaders on oil palm plantation were found to be susceptible to excessive fertilizer application. On the other hand, Variable Rate Technology (VRT) could be used to forestall the hazards of excessive fertilizer application. However, full knowledge of the operational variables of the metering system of a VRT applicator has become inevitable for proper utilization of this technology. A rotary valve metering system test rig was designed and constructed for the purpose of studying the characteristics of the system. A linear regression equation was developed to relate the discharge rate of the metering system to the screw conveyor speed, rotary valve speed, fertilizer bulk density and repose angle. The coefficient of determination (R^2) of the regression equation was 98.65%. The screw conveyor speed, the rotary valve speed and type of fertilizer were found to have statistically significant effect on the discharge rate of the system. It was observed that the discharge rate of the system decreased with increase in rotary valve speed. The outcome of this study will enhance the use of rotary valve in the VRT fertilizer applicator for oil palm.

Key words: Variable rate technology, rotary valve, fertilizer, oil palm

INTRODUCTION

Oil palm is the number one oil producing crop globally. It is a valuable tree crop in Malaysia. In 2008, RM 65.2 billion was realized from the export oil palm products in the country (Alkabbashi *et al*., 2009; Goh *et al*., 2009; Mohammed *et al*., 2011). Its high yield potential has caused expansion in its cultivation to various soils and terrains (Teoh and Mashitah, 2010; Feng *et al*., 2011). In a way to maintain the high yield of oil palm, fertilizer has to be used to supplement the nutrient in the soil. Fertilizer application is an essential operation for a successful oil palm production. It is a crucial operation that takes a large share of the production budget. However, the price of fertilizer in Malaysia is very inconsistent. As such, serious measures are taken to forestall its wastage (Sabri, 2009).

The two methods of fertilizer application in the Malaysian oil palm plantations are the manual and the constant rate mechanical fertilizer spreader. Most oil palm plantations opt for the manual method despite its low field capacity. There are claims that the constant rate mechanical fertilizer spreader wastes a lot of fertilizer. However, both methods of fertilizer application are at constant rate which does not consider the variability of soil nutrient across the plantation. As such, there is the tendency of applying excess fertilizer in some areas and less in others. Besides the wastage in fertilizer, excessive fertilizer application leads to pollution of stream and rivers that are close by Fadzilah and Mashitah (2010). Likewise, excess fertilizer on the soil causes soil erosion and air pollution through volatilisation (Wittry and Mallarino, 2004; Wahid *et al*., 2005; Cugati *et al*., 2006; Kim *et al*., 2006; Tung *et al*., 2009). Recently, a new technology known as Variable Rate Technology (VRT) emerged. The VRT concept offers solution to this problem by treating with actual fertilizer rates for site-specific oil palm needs. 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; Kim *et al*., 2006; Ahmad and Chan, 2009).

It was 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

Corresponding Author: Tajudeen Abiodun Ishola, Department of Biological and Agricultural Engineering, Faculty of Engineering, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia Tel: +60146369210

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). 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 in the oil palm plantation. However, to successfully have a VRT fertilizer applicator, full knowledge of the operational variables of its metering system is of utmost priority. This will allow predictability of its output at different configuration (Alfatni *et al*., 2008; Sharifian and Derafshi, 2008; Svensson, 1994).

A study was carried out to investigate the operational characteristics of four fertilizer metering systems: wire auger, star-shaped feed wheel, feed screw and ridged traction wheel (Camacho-Tamayo *et al*., 2009). It was asserted that the mass flow rate of these metering systems is directly proportional to the rotating speed of the system. Likewise, the particle size, repose angle, bulk density and moisture content of the fertilizer also affected the discharge rate of the metering systems. Nevertheless, rotary valve metering system was not considered in their study. Hence, the objective of this study was to examine the operational characteristics of rotary valve metering system for a Variable Rate Technology (VRT) fertilizer applicator for oil palm.

MATERIALS AND METHODS

Metering system test rig for the VRT fertilizer applicator: To investigate the operational variables of the rotary valve metering system, a test rig was designed and constructed. The test rig consists of a hopper, screw conveyor, a fertilizer distribution channel, two rotary valves and a support frame. The hopper was trapezoidal in shape with 2070 mm length, 1570 mm width, 700 mm depth and 1200 kg capacity.

There was a trough of 200 mm diameter welded to the base of the hopper. The screw conveyor which has a pitch of 190 mm and length of 2000 mm ran inside the trough. The screw conveyor was covered on top with a 260 mm diameter upper concave plate. The upper concave plate had six slots of 50 mm by 450 mm at the sides to allow easy flow of fertilizer to the screw conveyor. The screw conveyor was run by an Elektrim Slinik 7.5 hp at 1500 rpm, 3 phase electric motor. The trough below the screw conveyor has a rectangular opening of 150 mm by 200 mm at one end which opened into a distribution channel. The channel had two rectangular openings, each measuring 150 by 100 mm. One rotary valve was fitted to each of the distribution channels outlets. The inlet and outlet of the rotary valve were also 150 by 100 mm. The rotary valve had eight blades which were made from Ultra-High-Molecular-Weight polyethylene (UHMWPE or UPE) plastic. The diameter of the rotary valve was 138 mm. The inner wall of the rotary valve was also lined with UPE plastic. Each rotary valve was run by a Morelli Montroli 0.5 hp at 1350 rpm, 3 phase electric motor model MI040-AD71. The frame upon which the whole machine was attached is 1600 mm long, 900 mm wide and 1500 mm high.

Operational variables of the metering system: The test rig used for the investigation of the operational variables is shown in Fig. 1. The operational variables were divided into machine variables and fertilizer variables. The machine variables include screw conveyor speed and rotary valve speed while fertilizer variables consist of fertilizer bulk density and repose angle. The fertilizers used in the study were Nitrophoska Blue TE with 12-12-17-2+TE (NPK) fertilizer, Muriate of Potash (MOP) fertilizer and Ammonium Chloride (AC) fertilizer. These are the commonly used fertilizer in the oil palm plantation. Their properties were determined experimentally in the laboratory. The results are presented in Table 1.

Control and data acquisition system for metering system: One Autonic E100H35-10000-6-L-5 rotary encoder (screw

Fig. 1: Metering system test rig for the VRT fertilizer applicator

Table 1: Properties of the NPK, MOP and AC fertilizers

Properties	NPK	MOP	AC
Bulk density	1100 (kg m^{-3})	1200 (kg m^{-3})	790 (kg m^{-3})
Shape	Spherical	Irregular	Spherical
Angle repose	38°	32°	41°

NPK: Nitrophoska blue TE with 12-12-17-2+TE fertilizer, MOP: Muriate of potash fertilizer, AC: Ammonium chloride fertilizer conveyor encoder) and Two Autonic E5058-100-3-T-24 rotary encoders (rotary valve encoder) were used in this study. The control and data acquisition system consisted of these sensors, NI Crio 9073 CompactRIO embedded controller (compactRIO), C-series modules: Two units of NI 9411 and one NI 9265, NI 3110 embedded computer system and other computer accessories such as keyboard, monitor and mouse. The sensors were connected directly to the C-series modules which are fixed in the slots of the compactRIO. The C-Series Modules are data acquisition and control hardware that has in-built signal conditioner. The screw conveyor encoder was connected to one NI 9411 module while the two rotary valve encoders were connected to the other NI 9411 module. The NI 9265 module was used to control the electrical motors via their respective frequency inverters. The compactRIO was connected to the computer system via ethernet cable. The LabVIEW 2011(Laboratory Virtual Instrumentation Engineering Workbench) software running on the computer system was used for electric motor control as well as to read and process the signal coming from the sensors via the compactRIO. The data was stored in real time in the hard drive of the computer system for subsequent retrieval and analysis. Prior to the investigation of the characteristic of the metering unit, all the sensors used were adequately calibrated. All the connection of the sensors, electric motor, frequency inverter, controllers and computer system are shown in Fig. 2.

Discharge rate of the Rotary valve metering system: The metering system test rig was tested in order to determine the effects of the operational variables: screw conveyor speed, rotary valve speed, fertilizer bulk density and repose angle on the discharge rate of fertilizer from the metering system. The screw conveyor was driven by a 5.5 kW electric motor through a chain drive. The speed of the 5.5 kW electric motor was controlled with a Panasonic BFV80754Z frequency inverter-7.5 kW. The screw conveyor encoder was connected to the screw conveyor shaft in order to monitor the speed. They rotary valves were each driven by 0.37 kW electric motors which were equipped with rotary valve encoders. The speed of the electric motor was controlled with a Hitachi SJ200-007NFE

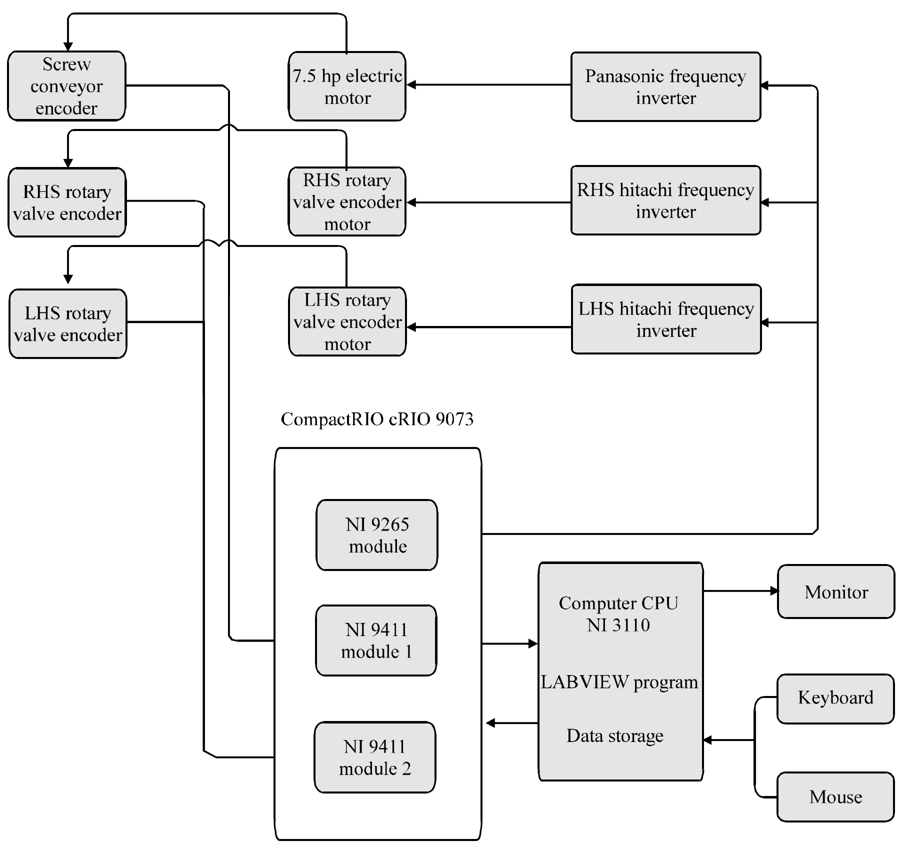

Fig. 2: Schematic of the control and data acquisition system for the metering unit test rig

frequency inverter-0.75 kW. A weighing container was used to collect the fertilizer from the rotary valves. The container was hung through a DACELL load cell model UU-T010 with 10 tons capacity. The load cell was used to determine the weight of fertilizer inside the container. All the control and data acquisition were accomplished by the use of LabVIEW 2011 software running on the computer system. The fertilizer hopper was filled up with each of the ertilizers in turn to determine the effect of all the variables on the discharge rate of fertilizer. Three different replicates were conducted for each fertilizer in the test. The discharge rate was measured by reading the weight of fertilizer inside the weighing container through the digital indicator and the time of discharging was measured with a stop watch. The discharge rate of the fertilizer was calculated and recorded.

An Analysis of Variance (ANOVA) was conducted using Statistical Analysis System, SAS 9.2 software (SAS Institute Inc., USA) to identify the statistical significance of the operational variables and their interactions at 0.01 and 0.05 probability levels. Factorial experiment in completely randomized design comprising of three fertilizer types (NPK, MOP, AC); two screw conveyor speeds (30, 35 rpm) and five rotary valve speeds (60, 90, 120, 150, 180 rpm) were used for the statistical test. Furthermore, a linear regression equation was developed for the discharge rate of metering system with respect to the screw conveyor speed, rotary valve speed, fertilizer bulk density and repose angle by using SAS program. The equation could be referred to the characteristic equation for the metering system. This is in line with earlier studies by Svensson (1994), Yu and Arnold (1996), Reumers *et al.* (2003), Allaire and Parents (2004), Gundogdu (2004) and Camacho-Tamayo *et al.* (2009).

RESULTS AND DISCUSSION

Effect of fertilizer and machine variables on the metering system discharge rate: The results of the analysis of variance of the effects of screw conveyor speed, rotary valve speed, fertilizer bulk density and repose angle on the discharge rate of the metering system showed that the fertilizer type and the rotary valve speed are highly significant at probability level of 0.01 while the screw conveyor speed was significant at probability level of 0.05. This could be understood from the fact that the screw conveyor and the rotary valves were the parts that actually conveyed the fertilizer out of the machine. These results concur with the results obtained in other studies (Svensson, 1994; Camacho-Tamayo *et al.*, 2009). Furthermore, it was observed practically that the changes in speed of the rotary valve and the screw conveyor affected the discharge rate of the system. However, the interaction of the screw conveyor speed, rotary valve speed and the fertilizer type was not significant at probability level of 0.05.

Behaviour of the fertilizer-metering system: The mean plots of the discharge rate at screw conveyor speed of 30 and 35 rpm are shown in Fig. 3 and 4, respectively. For each of the fertilizer used, the discharge rates of the two rotary valves were found to be equal for the same speed setting of the screw conveyor and the rotary valves. With reference to Fig. 3 and 4, it could be observed that the AC

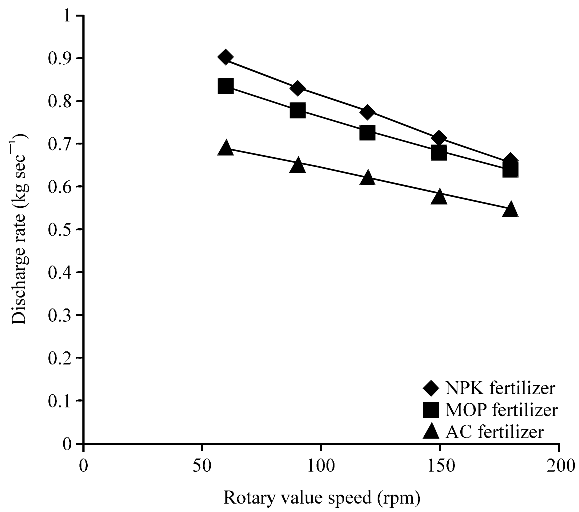

Fig. 3: Mean discharge rate at 30 rpm screw conveyor speed

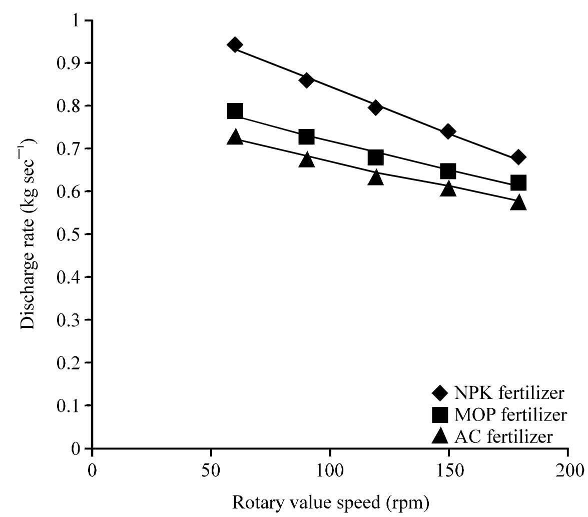

Fig. 4: Mean discharge rate at 35 rpm screw conveyor speed

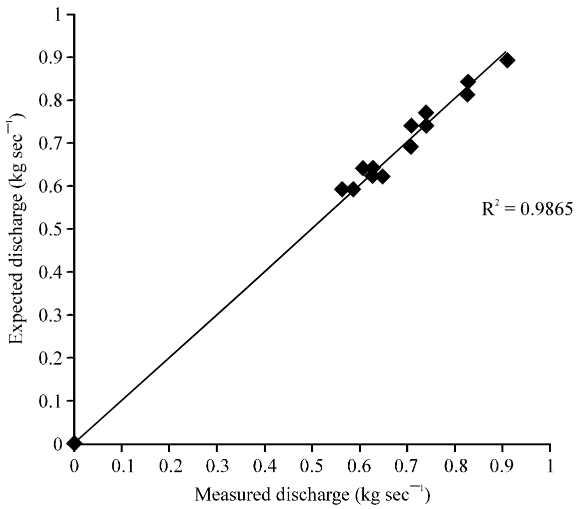

Fig. 5: Measured discharge rate plotted against predicted discharge rate

Table 2: Comparison of the discharge rate of the NPK, MOP and AC fertilizers

Fertilizer	Discharge rate (kg sec^{-1})	Min or max	Rotary valve speed (rpm)	Screw conveyor speed (rpm)
NPK	0.66	Min.	180	30
	0.95	Max.	60	35
MOP	0.62	Min.	180	35
	0.84	Max.	60	30
AC	0.55	Min.	180	30
	0.73	Max.	60	35

NPK: Nitrophoska blue TE with 12-12-17-2+TE fertilizer, MOP: Muriate of potash fertilizer, AC: Ammonium chloride fertilizer

fertilizer had the lowest discharge rate at both screw conveyor speeds. This could be due to its low bulk density and high repose angle. The highest discharge rate was obtained with NPK fertilizer owing to its higher bulk density and spherical shape. The discharge rate values of the MOP fertilizer was in-between the values obtained for NPK and AC fertilizers.

These results are in the same trend as those obtained by Reumers *et al*. (2003) and Camacho-Tamayo *et al*. (2009). However, the discharge rate of the metering system decreased with increase in the speed of the rotary valves. This was due to the fact that the faster the speeds of the rotary valve the lesser the time it has to collect fertilizer particle for conveyance. This behavior was also observed by Yu and Arnold (1996) and Camacho-Tamayo *et al*. (2009). The effect was described as "fullness effect" by Yu and Arnold (1996). A comparison of the discharge rate of the fertilizers from the metering system in term of minimum (min) and maximum (max) values is shown in Table 2.

Characteristic equation for the metering system: The Linear regression equation obtained for the discharge rate of the metering system is presented in Eq. 1:

$$Qr = 0.00070091\beta+0.02351\gamma+0.000607\varepsilon-0.00161\sigma-0.70262 \quad (1)$$

Where:
Q_r = Discharge rate (kg sec^{-1})
β = Fertilizer bulk density (kg m^{-3})
γ = Fertilizer repose angle (degree)
ε = Screw conveyor speed (rpm)
σ = Rotary valve speed (rpm)

It could be seen from the equation that the discharge rate was directly proportion to the fertilizer bulk density, screw conveyor speed and repose angle of the fertilizer. However, it was inversely proportional to the rotary valve speed. This was due to the "fullness effect" earlier mentioned. An experiment was conducted to evaluate the characteristic equation developed for the metering system. Some configurations of the metering system were selected and tested for each fertilizer type. The correlation between the discharge rate values predicted by Eq. 1 and the measured discharge rate is shown in Fig. 5. A determination coefficient of 98.65% was obtained. This implies that the characteristic equation properly represents the behaviour of the metering system.

CONCLUSION

An experimental test rig was designed and constructed for the investigation of the operational characteristics of the rotary valve metering system of a VRT fertilizer applicator for oil palm. The screw conveyor speed, rotary valve speed and fertilizer type had significant impact on the discharge rate of the metering system. The highest discharge rate of 0.95 kg sec^{-1} was obtained for NPK fertilizer at rotary valve speed of 60 rpm and screw conveyor speed of 35 rpm. However, the lowest discharge rate value of 0.55 kg sec^{-1} was observed for AC fertilizer at rotary valve speed of 180 rpm and screw conveyor speed of 30 rpm. Generally, the discharge rate of the metering system decreased as the rotary valve speed increased from 60 to 180 rpm. A characteristic equation of the discharge rate of metering system as a function the screw conveyor speed, rotary valve speed, fertilizer bulk density and repose angle was also developed.

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