JURNAL TEKNOLOGI

Full Paper

VRT LIQUID FERTILIZER APPLICATOR FOR SOIL NUTRIENT MANAGEMENT

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Article history
Received
15 July 2015
Received in revised form
2 August 2015
Accepted
26 August 2015

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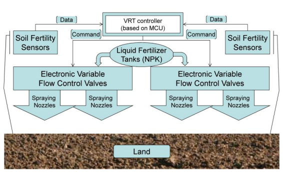
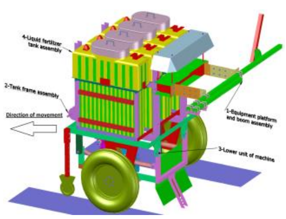
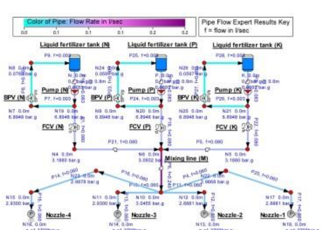
Graphical abstract







Abstract

Sensor based VRT liquid fertilizer application is a suitable way to apply the nutrients for soil management of various crops. Time and resources can be saved using this technology but due to the special characteristics of cereal and tree crops like paddy and oil palm, dedicated designs of VRT liquid fertilizer applicators are needed to fulfill the nutritional requirement of respective crops. The proposed design of VRT liquid fertilizer applicator involves soil fertility sensors, speed sensor, flow control valves, flow sensors and pressure sensor. Design considers the variable fertilizer flow compensation with change in forward speed of machine between 2.5-3.5 km/h. Also this design offers the transfer of data from electronic controller to the external computer for record and performance testing of machine by computing the lag times of flow control valves and application error of machine. Originally, the design is for tree crop; however, with a slight modification in controller's program, this will also be suitable for cereal crops like paddy. To apply the fertilizer, three DC pumps of 6.89 bar pressure and 5 L/min flow rate were used in simulation with the flow lines of 6 mm internal diameter. Flow simulation revealed that the system was able to achieve the 0.06 L/s at 13.73 m/s velocity at nozzles 1 and 2 (full cone nozzles) while nozzles 3 and 4(flat fan nozzles) were delivering the same flow rate but at a little high velocity of 13.94 m/s. A comparatively uniform distribution of fertilizer application may be achieved using flat fan nozzles.

Keywords: VRT (Variable rate technology), liquid fertilizer, flow control valve, flow control system, soil fertility sensor, soil nutrients

1.0 INTRODUCTION

In past decades, a significant rise in the use of agricultural chemicals has been recorded for boosting agricultural production. According to an estimate, more than 2.54 million tons of pesticides per year are being used in the world [1]. While total fertilizer nutrient ($N+P_2O_5+K_2O$) consumption was estimated at 170.7 million tons in 2010 and it is expected to reach 190.4 million tons by the end of 2015 [2]. Both of these chemical types play important role for the protective growth of crops and ultimately in terms of higher yields in the capacity of crop production and soil fertility. Continuously uniform application of these chemicals not only increases the cost of production but also raising a big environmental threat in terms of soil and ground water contamination [3]; [4]; [5]; [6]; [7]. This environmental pollution may not be eliminated completely because of growing food demands day by day at an exceptional high rate but may be reduced by employing variable rate technologies (VRT) for the application of these chemicals leading towards more profit and less environmental pollution [8]. At the time, variable rate technology is the only way which helps to improve the input use efficiency by applying these chemicals at optimum or near optimum rates according to the soil and crop conditions keeping in view the performance of employed VRT system. Because variable application rate of any input mainly depends on the performance of VRT system which has been stayed as a big question for the researchers. With the development and availability of computer, sensor, control valves, actuators, GPS receivers and better data acquisition systems, VRT has paved a path for attaining higher accuracy of input application at variable rates.

Variable rate technology (VRT) can be categorized in three basic groups; map based VRT, real time sensor or vision based VRT and hybrid VRT which is the combination of first two types. Map based VRT is used when historic soil or yield information is already available. Based upon the history, input application rates are determined to develop the prescription maps. In prescription maps, the area is classified in clusters or regions according to the input needs. These digital maps are used to guide the VRT machine to apply input at predetermined variable rates on specific locations identified by GPS receiver. Therefore, the resolution of categorized locations is of significant importance. Specifically for nitrogen application [9] suggested that elemental size of field should not be greater than 1.96 m^2 to get the benefits of variable rate nitrogen application technology. Many studies have indicated a considerable variability of macro nutrients in small areas [10]; [11]; [12]; [13]. Therefore, especially map based variable rate applicator should be able to meet the reasonable resolution of field.

On the other hand real time sensor based VRT don't need extra systems and time to prepare the prescription maps. This technology uses real time sensors to detect the required soil, plant or yield information and applies the input at desired rates. In most cases, this application rate change is triggered every second. For the application of fertilizer, there is a good development in optical sensors to determine the level of nitrogen fertilizer. At the time, some other sensors called Ion Selective Electrodes (ISE) are also commercially available but only for the detection of nitrogen and potash concentration among the macro nutrients.

All types of VRT use some of the common components such as electronic controllers, variable rate control valves/actuators, flow rate sensors, pressure sensors, speed sensors and/or object detectors. Sometimes controller can be easily added with other necessary components to the conventional agricultural machines which are used for applying inputs at uniform rate [14]. Electronic controller accepts the inputs from sensors, the data from prescription maps and user commands through hardware and/or software interfaces to determine the desired rate of application with the help of formula or an algorithm. Usually this operation is performed in the range of few micro seconds to few milliseconds.

The performance of VRT applicators is severely affected by the individual performance of each component of the system especially the flow control vales having the time delay of 1-4.5 s affecting overall nutrient management [15]. While evaluating the performance of pressure based VRT systems, [15] found that the time delay in the GPS positioning influences the accuracy of the application for map based variable rate application. This finding is in line with the conclusion of [16] who studied the VRT granular fertilizer applicator and revealed that overall performance of the variable rate technology (VRT) equipment triggered by real time sensors was much better in comparison with the equipment triggered by GPS. The same aspect was raised by [17] when they were studying the pressure based VRT systems. They revealed that total transport lag in the pressure based variable rate technology was approximately 2 s due to GPS signal lag time of 0.5 s and control valve response time of about 1.5 s.

All of the above mentioned types of VRT can be used for tree and cereal crops like oil palm plantation and paddy but with a little modified design. Unfortunately, precise application of fertilizer is still a big problem for the farmers especially in the case of large fields Another constraint for the adoption of current technology is high equipment cost and requirement of skills and good knowledge to operate the sophisticated equipment especially in the case of map based VRT.

This paper proposes the concept of low cost VRT liquid fertilizer applicator to solve the mentioned problem.

2.0 DESCRIPTION OF DESIGN

The proposed design is based on sensor technology for on-the-spot soil fertility analysis and it eliminates the requirement of GIS and time consuming costly analysis of soil for Nitrogen, Phosphorus and Potassium (NPK) in laboratory. Figure 1 shows the basic operational concept of machine. This design offers two different electronic systems (system 1 and system 2) to deal with the soil for routine deficiency of NPK in specific ratio and abnormal deficiency of NPK respectively. Since every crop consumes NPK in specific ratio in normal routine, therefore, this consumption is considered as routine soil nutrient deficiency. This condition can be found in those fields which have been treated with very good soil nutrient management techniques for the past few years.

While abnormal deficiency means that N or P or K or any combination is severely deficient creating unbalanced ratio of NPK in the soil. This is caused if the nutrients have been applied in unbalanced quantities for the past few years. Manual application of fertilizer may create this type of nutrients deficiency in the field. In this condition, field needs an effective soil management to overcome the deficiency of nutrients.

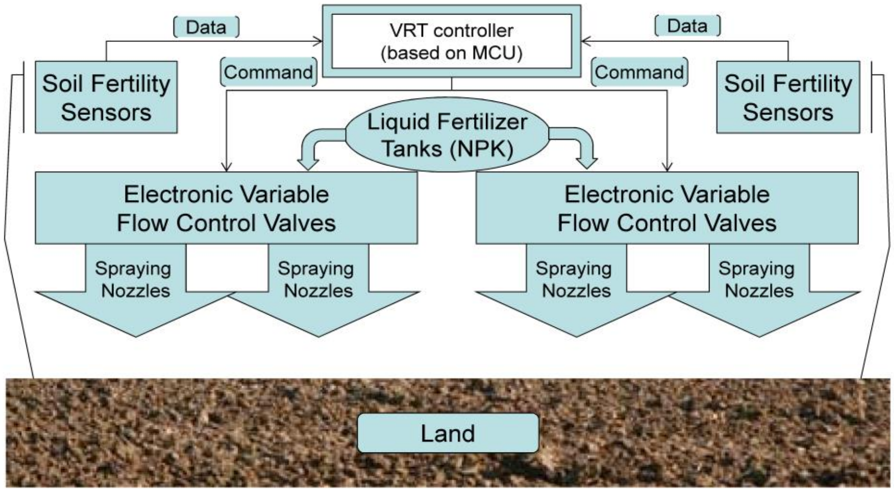


Figure 1 Operational overview of VRT liquid fertilizer applicator

Figure 1 shows the schematic design of VRT liquid fertilizer applicator. System 1 will use the 'redox potential' based soil fertility sensor and system 2 will adopt digital soil test kit which works on colorimetric method. The fertility data will be sent to VRT controller which will determine the deficiency of NPK in the soil based on provided soil nutrients standards. The computed NPK will be applied using three flow control valves, one each for N, P and K fertilizer tanks. It is important to mention that N, P and K fertilizers will be dissolved in the water in calculated concentrations. These three nutrients will be stored in separate independent tanks having separate battery operated dc pumps. Fertilizer will be applied according to the need of crop. This will not only minimize the wastage of fertilizer but also help to reduce the ground water contamination. It is also important to mention that machine will also be able to apply the fertilizer in tree plantations. In case of tree plantations, it will apply the fertilizer on both sides of tree while moving at one side of tree. This means, a part of spraying boom of machine must be set at a certain angle to cover the area across the tree. The angle will be computed using the derived equation of projectile motion. This one side movement of machine will reduce the field operation of machine by half while saving the fuel and power. This will also help to improve the field capacity of machine to 28 min/ha with 16 min system operation time in one hectare.

Since machine is tractor driven therefore, for a tree crop, an ultrasonic sensor will be installed on tractor body 2.6 m far from the fertilizer applicator so that tree can be detected before the machine entrance in application area. Before operation, the operator will have to set the machine either on system 1 or system 2 based on field condition. System 1 is only able to deal with soil having routine deficiency of NPK in specific ratio while system 2 is able to determine abnormal deficiency of NPK using quick colorimetric soil test kit. The controller will get speed information from speed sensor because electronic controller must have the automatic facility for 'variable application compensation' according to the change in forward speed of machine with in a range of 2.5-3.5 km/h. This characteristic will help to improve the precise application of fertilizer.

Based on the system selection, controller will collect information from respective sensor to calculate the NPK deficiency and will turn on the electric DC pumps. Then controller will adjust the proportional flow control valves to get variable flow for NPK which will be applied on mentioned area using spray nozzles.

Flow and pressure sensors will continuously monitor the respective information and send to controller during the operation to assess the flow rate from the flow control vales precisely for one tree. Speed, calculated fertility, flow rates of all three fertilizers and pressure in flow line will be transferred to external computer wirelessly with time information for record using the 'Data Logger Suite v2.6'. Data Logger Suite v2.6 is a software having plugins to transmit the data to Microsoft Excel. Another important factor to consider is the cost analysis of proposed VRT machine which will be performed in comparison with conventional (manual) method of fertilizer application.

2.1 Determination of Soil Fertility

Although sensor based VRT fertilizer applicator is a good choice for a variety of crops but unfortunately, only remote optical sensor is available to detect the nitrogen in plants. Ion selective electrodes (ISE) for nitrogen and potassium detection are also available but they detect both nutrients from the plant and/or soil extracts and require frequent calibration. Currently ISE technology is suitable in laboratory analysis and does not offer the detection of phosphorus. While standard laboratory methods are costly and take days or weeks for NPK analysis depending upon the number of soil samples. So long waiting time changes the nutrient scenario of field. For quick detection of macro nutrients, there are two possible ways. One is determination of oxidation reduction (Redox) potential of soil in mV which can be calibrated with different concentrations of standard calibration solutions for N, P and K mixed in specific ratio. This method is only successful for routine deficiency of NPK in the soil. This technique can be used as a 'real time sensing' of soil fertility and can help to monitor the soil condition for every tree. System 1 of VRT liquid fertilizer applicator is based on this method (Figure 2).

Second method involves the use of quick soil test kit to analyze NPK in the soil. It takes approximately 20-30 min for four soil samples to analyze. This is a close approximation of NPK compared to standard laboratory results. This method is basically colorimetric analysis. Digital soil test kit (Rapitest Kit 1605) can be installed in machine in combination with the specifically designed soil test kit reader.

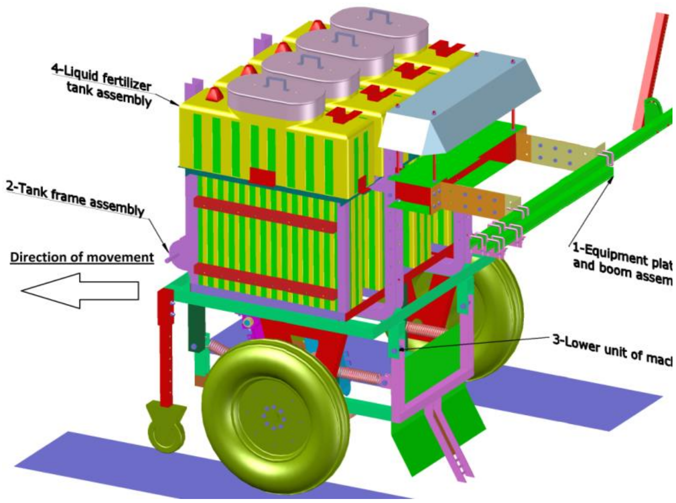


Figure 2 VRT liquid fertilizer applicator (Back side)

In a soil study, 48 soil samples collected from oil palm plantation, Malacca, Malaysia were sent for NPK analysis to the soil research lab of United Plantations, Malaysia. Same samples were tested using mentioned soil test kit. For N (NO_3^-), P (P_2O_5) and K (K_2O), results matching percentage was 91.38, 89.66 and 94.83 respectively. System 2 of machine will adopt this method. In such a case, field can be divided in 3-4 regions (better in small grids) to test their soils in 20-30 min before running the machine. Results can be saved in the controller of machine for four NPK tests. Then machine can be operated in every region based on respective results.

3.0 SIMULATION OF LIQUID FERTILIZER FLOW SYSTEM

To determine the pressure drops, flow rates and velocities of liquid fertilizer at different points of the liquid fertilizer flow system is very important. Definitely, the diameter, length and roughness of the pipe lines will affect all the factors mentioned above.

For flow simulation in 'Pipe Flow Expert v6.39', high strength rubber pipes were selected with internal diameter of 6 mm and roughness of 0.005 mm which can handle the maximum pressure of 13 bar. Figure 3 shows the detailed simulation results of liquid fertilizer flow system. In current design, BPV (N), BPV (P) and BPV (K) are the back pressure valves for respective fertilizers. Since the software uses ordinary diaphragm pump without pressure switch therefore, to simulate the system correctly, these valves have been added. In real machine, there is no need of installing BPVs because automatic DC pumps (maximum pressure: 6.89 bar) will be used with adjustable pressure switches. It is important to note that from node 10 (N10, end of mixing line) the lengths of pipe lines to the nozzle 1 and 2 are 1.4 m each while the pipe lengths for nozzle 3 and 4 are 1m each. In case of tree plantation, nozzle 1 and nozzle 2 both will be full cone nozzles (2.35 mm dia.) installed on angled boom at calculated angles. While Nozzle 3 and 4 will be flat fan nozzles (2.35 mm dia.) installed on horizontal boom facing the ground at mutual distance of 0.6 m (2 ft) and at the height of 1.45 m from ground. For full flow capacity of pumps (5 L/min = 0.833 L/s each), nozzle 1 and 2 delivered 0.06 L/s at 13.73 m/s velocity. Full cone nozzles 1 and 2 installed at certain angles will disperse and expand the liquid to broader circular areas for full coverage of 2.5 m across the tree like oil palm. Fan nozzles 3 and 4 are delivering the same flow rate but at a little high velocities of 13.94 m/s. It is a definite fact that fan type nozzles will perform better for the fertilizer distribution at machine side as compared to the nozzles 1 and 2 which are following liquid trajectory. But small distribution error is acceptable because the main objective is to deliver the right amount of nutrients to tree crop. For cereal crops, all of the installed nozzles will be flat fan type only on the horizontal boom for a better distribution pattern of liquid fertilizer to the crop plant.

4.0 CONCLUSION

Sensor based VRT liquid fertilizer application is a suitable way to apply the nutrients for soil management of various crops. Time and resources can be saved using this technology but due to the special characteristics of cereal and tree crops like paddy and oil palm, dedicated designs of VRT liquid fertilizer applicators are needed to fulfill the nutritional requirement of respective crops. The proposed design of VRT liquid fertilizer applicator involves soil fertility sensors, speed sensor, flow control valves, flow sensors and pressure sensor. Design considers the variable fertilizer flow compensation with change in forward speed of machine between 2.5-3.5 km/h. Also this design offers the transfer of data from electronic controller to the external computer for record and performance testing of machine by computing the lag times of flow control valves and application error of machine.

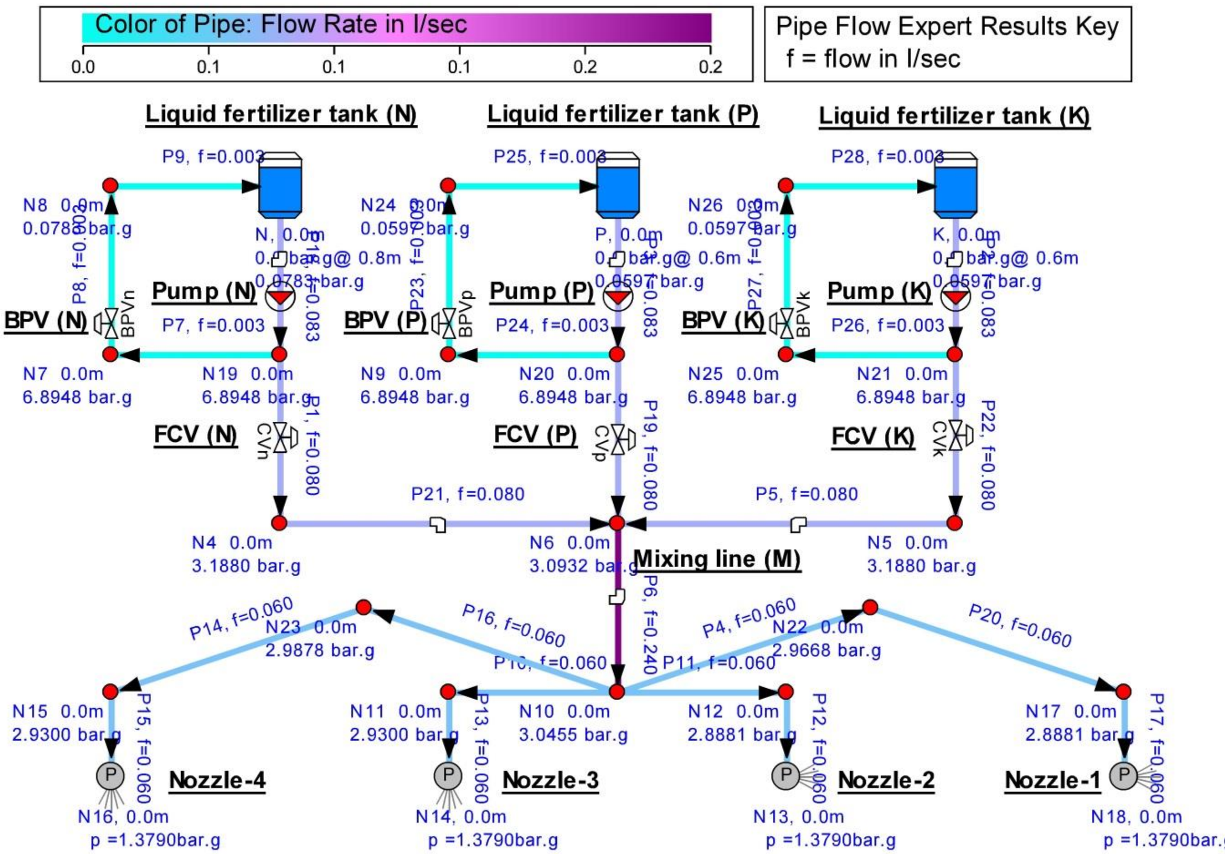


Figure 3 Simulation results of liquid fertilizer flow system

Originally, the design is for tree crop; however, with a slight modification in controller's program, this will also be suitable for cereal crops like paddy. Two different methods have been proposed in this design for the determination of soil fertility. One is based on real time measurement of redox potential of soil which will be only applicable for routine deficiency of nutrients in the soil. Second method uses the digital soil test kit based on colorimetric analysis of soil for measurement of nitrogen, phosphorus and potassium. On-spot testing of soil can be performed before running the machine in 20-30 min. This VRT liquid fertilizer applicator can apply fertilizer in 5 x 5 m^2 area around the tree by involving liquid fertilizer trajectory. To apply the fertilizer across the tree, dc pump of 6.89 bar pressure and 5 L/min flow rate was used in simulation with the flow lines of 6 mm internal diameter. Flow simulation revealed that the system was able to achieve the 0.06 L/s at 13.73 m/s velocity at nozzles 1 and 2 (full cone nozzles) while nozzles 3 and 4 (Flat fan nozzles) were delivering the same flow rate but at a little high velocity of 13.94 m/s. A comparatively uniform distribution of fertilizer application may be achieved using flat fan type nozzles.

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