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Pneumatic Control of a Variable Orifice Nozzle

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Abstract. *A variable-orifice nozzle with droplet optimization was recently developed and introduced for use on agricultural sprayers. The VariTarget (VT) nozzle reacts to changes in the system flow rate via a metering assembly that is controlled by a diaphragm and spring. As the liquid pressure changes, the VT metering assembly attempts to control the flow rate and spray pattern exiting the nozzle. The goal of this study was to replace the spring controlled "reactive" system with a pneumatically controlled metering assembly. The proposed system would allow for the metering assembly to adjust the flow rate and spray pattern exiting the nozzle by increasing or decreasing air pressure on the diaphragm. Controlled with an electronic regulating valve, the diaphragm air pressure was tested to determine if desired flow rate variation could be achieved. Initial results indicated that increasing air pressure on the diaphragm results in a decreased flow rate through the nozzle as the input carrier pressure remained constant. The VT nozzle discharge rates for the four set carrier pressures (10, 20, 30, and 40 psi) ranged from as low as 0.2 gpm (maximum air pressure at 10 psi carrier pressure) up to 1.8 gpm (minimum air pressure at 40 psi carrier pressure). Based on these data the proposed pneumatic control system has the potential to provide a new method for* *variable-rate pesticide application where nozzle flow rates and spray patterns can be controlled pneumatically using sprayer system operating values and electronic regulating valves.*

Keywords. *precision agriculture, pesticide application, variable-rate technology, precision spraying, spray nozzles.*

Introduction

Pesticide application errors result in a costly and time consuming problem for agricultural producers. A consequence of off-rate errors is spatial rate variations across the field. Off-rate errors can result from pressure changes across the width of the spray boom which in turn affects nozzle distribution pattern and droplet size. Velocity changes across the spray boom also occur while the sprayer is turning, which can have a significant effect on resulting application rates This problem is exacerbated with larger equipment as increased boom width results in greater velocity variations.

Although the effects of increased glyphosate application on crop yields have not been quantified, studies have shown that over-application of glyphosate to GR soybeans can result in reduced plant growth (Reddy et al., 2000; and Reddy and Zablotowicz, 2003). Conversely, under-application of pesticides can result in lower yields due to weed competition in corn (Cox et al., 2006) and soybeans (Shafagh-Kolvanagh et al., 2008). A recent analysis of sprayer paths found that a sprayer fitted with a 25 m boom produced a wide variation of effective application rates across substantial portions of a field while turning (Luck et al., 2009). This study revealed that in one 35 ha field, 10% of the field received >110% of the target rate while 13% of the field received <90% of the target rate, as a result of boom velocity variation arising in turns. A later study by Luck et al. (2010) incorporated flow rates based on nozzle pressure measurements (Fig. 1). The results of this study indicated that only 23% to 34% of the area received application rates at the target rate ±10% across three study fields.

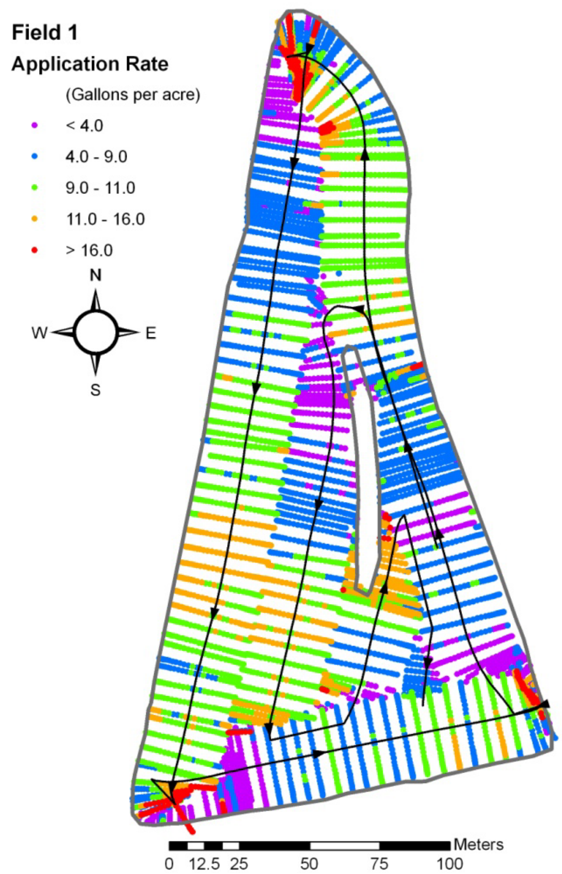

Figure 1. Estimated field coverage application rates (target rate 10 gal/ac).

At this time, there are no commercially available systems capable of compensating for spray boom velocity variations while spraying in turns. Possible systems that could provide a solution to this problem include pressure/flow control, pulse-width modulation, and direction injection of chemical concentrate. Another solution that holds some promise is the variable-orifice nozzle. The VariTarget (VT) nozzle reacts to changes in the system flow rate via a metering assembly actuated by a diaphragm and spring. As the liquid pressures change, the VT metering assembly reacts to control the flow rate and spray pattern exiting the nozzle.

Previous testing of the VT nozzles indicated the potential for varying flow rates while maintaining droplet size uniformity and spray pattern (Bui, 2005; Daggupati, 2007). Drawbacks include limited control of flow rates and no opportunity for feedback control for individual nozzle flow rates. The goal of this study was to replace the spring biased diaphragm with controlled pressurized air. The proposed system would allow for the metering stem to change nozzle orifice size thereby changing the flow rate and pattern of the nozzle by adjusting the air pressure at the diaphragm. The objectives of this study were to 1) replace the existing spring biased diaphragm with pneumatic control and 2) evaluate pneumatically controlled nozzle to determine the range of flow rates possible while maintaining constant carrier pressure.

Materials and Methods

The coarse droplet (green tip) VT nozzle (Delavan AgSpray Products, Mendota heights, MN) was used for testing. Figure 2 shows the original configuration of a VT nozzle along with the modified configuration used during testing. The spring/diaphragm housing assembly cap was removed from the original VT nozzle and replaced with a new assembly which was machined to fit a ¼" NPT quick-disconnect hose coupling from the air supply (Fig. 2).

Figure 2. Original VT nozzle configuration (right) with the VT nozzle modified for testing (left).

It was necessary to seal the diaphragm located inside the VT nozzle so that the carrier (water) would not cross the diaphragm to the air supply side. To accomplish this, the metering stem (Fig. 3) was tapped and threaded so that the diaphragm could be tightly sealed on top of the metering stem with a machine screw. This process ensured a barrier between the carrier and air sides of the diaphragm. As the air pressure was increased on the diaphragm, the metering stem was forced into the orifice, thereby reducing the orifice opening. A reduction in air pressure allowed the carrier pressure to force the metering stem to withdraw and open the orifice.

Figure 3. The VT nozzle with metering stem and diaphragm in place (left) and metering stem with diaphragm attached and sealed with a machine screw (right).

The modified VT nozzle was placed fixed to a spray table and provided carrier and air supplies (Fig. 4). Air pressure was controlled by an electro-pneumatic (EP) air pressure regulating valve (T3521, Marsh Bellofram, Newell, WV). The EP valve allowed for quick adjustment and control of the air pressure on the diaphragm via a laptop computer that utilized the control program provided by the manufacturer. Carrier was supplied by the pump (6-5110 Roller Pump, Delavan Pumps, Inc., Minneapolis, MN) and the carrier pressure was controlled with a pressure regulating (PR) valve (Model 23120, TeeJet Technologies, Wheaton, IL). The carrier pressure was set with the PR valve with the pump operating at maximum output

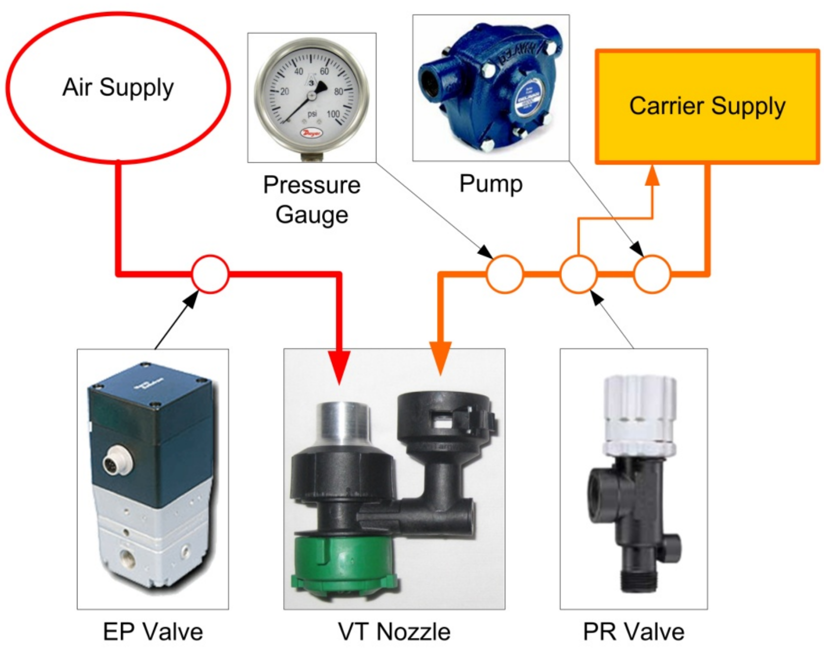

Figure 4. Test system diagram for control of carrier delivery and diaphragm air pressure to the VT nozzle during testing.

The carrier pressures selected for testing were: 10, 20, 30, and 40 psi. At each carrier pressure setting, the air pressure was increased to maximum (approx. 80 psi) via the EP valve and then reduced by 2 to 3 psi until there was no additional effect on the nozzle discharge rate. During testing, the carrier was collected from the VT nozzle and weighed (to provide a minimum of 0.25 gal) and the collection time was recorded. This procedure was repeated three times.

The observed effect of air pressure on nozzle discharge was plotted versus diaphragm air pressure. The nozzle discharge versus carrier pressure was plotted to observe the range of discharge rates in relations to the diaphragm air pressure and constant carrier pressures.

Results and Discussion

VT nozzle discharge rates (gpm) versus air pressure are shown in Fig. 5 for the four selected carrier pressures. For constant carrier pressures, a wide range of flow rates from the VT nozzle were possible. For instance, at a carrier pressure of 10 psi, the VT nozzle discharge ranged from 0.2 to 1.1 gpm for diaphragm air pressures ranging from 22 to 13 psi. The same tendency can be seen for the other carrier pressure settings of up 40 psi where the VT nozzle discharge was controlled from 0.3 to 1.7 gpm by adjusting the diaphragm air pressure from 40 to 25 psi. The data plotted in Fig. 5 demonstrates that VT nozzle discharge increases with carrier pressure, which is typical for standard nozzles. While the effects of the pneumatic control on pattern uniformity and droplet size distribution from the VT nozzle are still unknown, the results in Fig. 5 show the potential for this nozzle to achieve wide range of application rates.

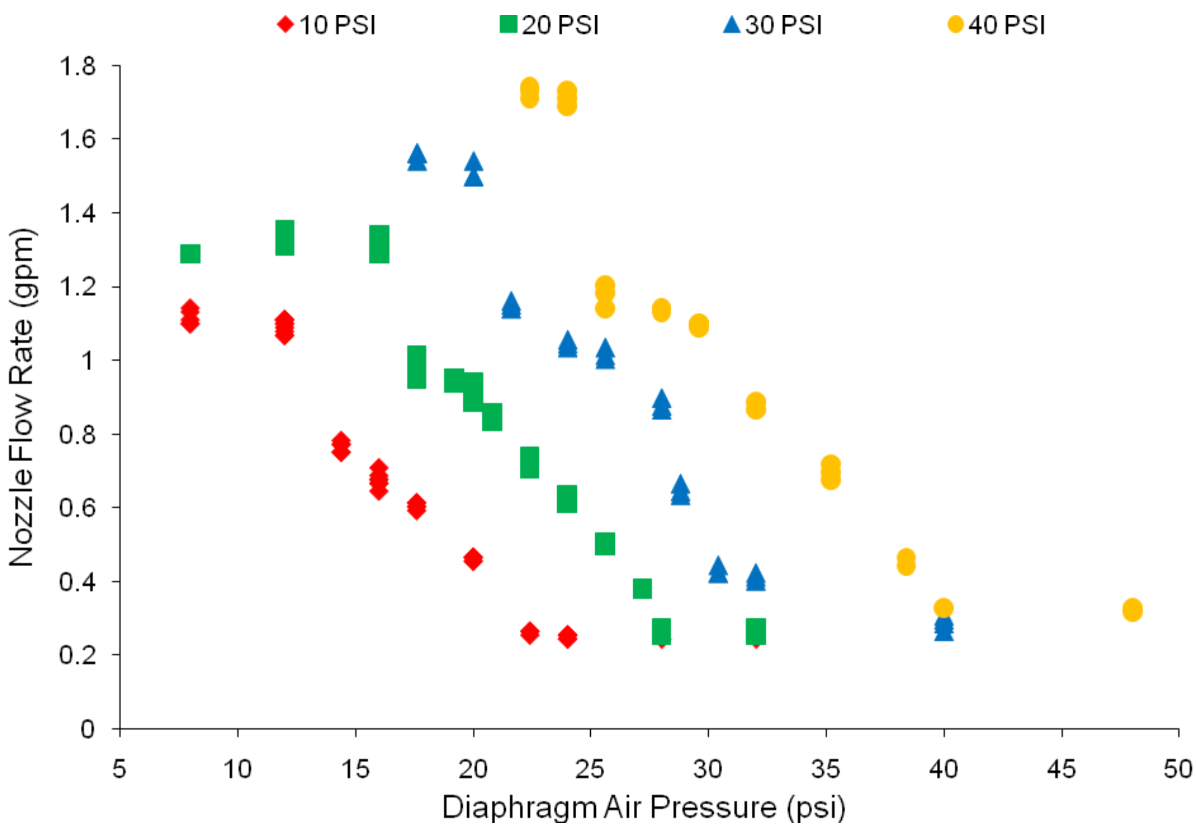

Figure 5. Nozzle flow rate versus diaphragm air pressure for 10, 20, 30, and 40 psi carrier pressures.

The VT nozzle discharge rate versus diaphragm air pressure at the four carrier pressures is shown in Fig. 6. These data show the potential range of VT nozzle discharge at specified carrier pressure as diaphragm air pressure is varied. For a carrier pressure setting of 10 psi, the effective nozzle discharge varies from 1.1 to nearly 0.2 gpm inversely with diaphragm air pressure. The reason for showing the VT nozzle discharge data in Fig. 6 is to demonstrate the range of discharge rates that are possible when compared with the original VT nozzle configuration. Calibration data, obtained from the nozzle manufacturer, are plotted in Fig. 6.

From these data the potential for varying the discharge rate of the VT nozzle is obvious; however, this range of variation is only possible by adjusting carrier pressure. By actively controlling the VT nozzle stem position by applying air pressure to the diaphragm, it is possible to achieve a wider range of flow rates for constant carrier pressures.

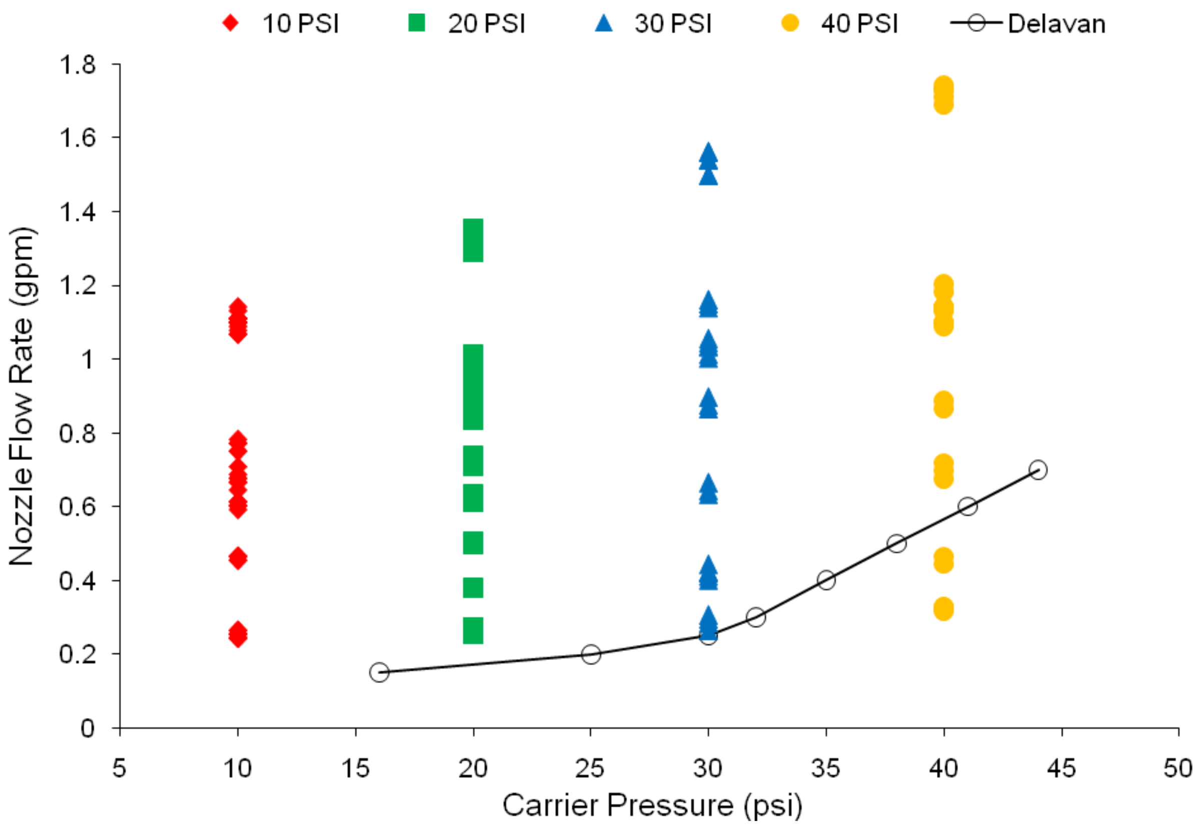

Figure 6. Nozzle flow rate versus carrier pressure as air diaphragm air pressure was adjusted (calibration curve for VT nozzle also included).

Conclusions

The results from this study indicate there is potential for the VT nozzle to achieve a wide range of flow rates at constant carrier pressures when the nozzle is controlled by applying air pressure to the diaphragm to actuate the metering stem. The VT nozzle discharge rates for the four carrier pressures tested (10, 20, 30, and 40 psi) ranged from as low as 0.2 gpm (maximum air pressure at 10 psi carrier pressure) up to 1.8 gpm (minimum air pressure at 40 psi carrier pressure). While future work is necessary to determine the effects of pneumatic control of the VT nozzle on pattern uniformity and droplet size distribution, the results of this initial study indicate that varying application rates using this method may be a promising option for variable rate pesticide application.

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