Variable Rate Manure Spreader:
Technology to Validate a Nutrient Management Plan

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INTRODUCTION

Better accounting of manure nutrients helps save commercial fertilizer costs and helps establish the value of manure assigned to neighboring crop farmers. Federal and state regulations require reporting of manure applications to cropland, and imply that calibration of equipment must be carried out to some (unspecified) level of accuracy. Furthermore, there are areas within many fields where application of manure is not allowed at all; automatic shutoff of equipment when entering those setback areas is needed. Most liquid slurry tank spreaders have a simple gate valve on the discharge pipe to the applicator, and the gate valve is opened fully while spreading manure in the field. Those spreaders do not have any method for varying the flow rate of manure coming out of the tank; therefore the only way to change the application rate per acre is to vary the ground speed of the vehicle. Historically a nitrogen based application rate could usually be accommodated with the ground speed variation method. But since the ratio of nitrogen to phosphorus in manure is usually out of balance with respect to crop needs, the phosphorus content in the manure often being two to four times the crop uptake when manure is applied based on nitrogen needs, producers are forced by regulation to reduce application rates to keep from over-supplying phosphorus. Unregulated applicators often cannot be pulled at high enough ground speeds to accomplish the low phosphorus based rates required by manure nutrient management plans. Factors that make it undesirable or impossible to increase the field travel speed enough to reduce the application rate include: the draft requirement is too high for the tractor; the soil injection toolbar causes undesirable tillage pattern (too much soil thrown for the intended operation); the vehicle dynamic characteristics and condition of the field make it impossible to maintain control or are hazardous to equipment and the operator. The only suitable way to get acceptable application rates in these cases is to reduce the flow leaving the tanker through a controlling mechanism. Being able to set any constant rate of slurry flow, over a fairly wide range from full flow to perhaps one-fourth of the maximum, is the first level of automation.

A further advantage to having variable rate flow control is allowing for ground speed changes as the vehicle travels through the field. Many fields have varying implement draft requirements caused by changing slopes, different soil types, wet spots, etc. The vehicle must be slowed approaching turns and to go around obstacles. Having a mechanism to sense ground speed and
reduce manure flow rate accordingly, thus keeping a constant per-acre application rate, is the second level of automation.

Fields which vary in their productivity, soil types, and other characteristics that determine the crop nutrient needs should have the manure application rate matched to those needs as the slurry delivery vehicle traverses the field. To accomplish that level of field nutrient management, a GPS/GIS (global positioning system/geographic information system) interface system such as that used by other precision agriculture technologies (grid based soil testing, automated yield mapping and variable rate fertilizer application) can be adapted to the slurry spreader (Morris et al. 1999). This constitutes the third level of automation.

Finally, since manure slurry is not a consistent product in its nutrient content or its fluid properties, on-board sensing of the product as it leaves the slurry tank discharge – the fourth level of automation – is needed to provide the “fine adjustment” on manure application rates throughout the field.

The advantages of a fully developed variable rate slurry spreader technology cannot be overemphasized. Such systems will reduce time spent in field calibration, will give much more accurate results with as-applied verification, will reduce commercial fertilizer inputs, and will provide a higher level of accountability in implementing state- and federally-mandated nutrient management plans. Having the ability to incorporate field-specific mapping through GPS/GIS will enable valuable integration of the manure nutrient management plan into the rest of the farm’s agronomic operations. Integrated GPS coupled mapping will also provide automatic shutting off of application equipment within setback areas (near streams, wells, tile inlets, and other sensitive areas.)

**SYSTEMS CURRENTLY AVAILABLE**

At least three North American manufacturers of slurry tankers offer options for variable rate manure spreading. Two use on-board centrifugal pumps to discharge the manure from the tanks to the toolbar applicators. The third uses a positive displacement pump. In all cases the liquid flow rate sensing and feedback systems incorporate magnetic flow meters, and the systems change pump or valve settings in response to

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Figure 1. Slurry tanker with PTO pump and variable rate application mechanism. Not shown: tank fill port. Tank headspace is not sealed.
the flow rate requested by on-board computers and ground speed sensors. The applicators include GPS/GIS rate control systems (Figure 1.)

NOT AVAILABLE: VARIABLE RATE VACUUM LOADED TANKERS AND ON-BOARD NUTRIENT SENSING

In many ways the vacuum loaded and pressure discharge tanker is the most flexible vehicle for loading and delivering manure from the farm to the field. However, there is currently no manufacturer of hardware that supplies a variable rate application system for vacuum loaded tankers.

Compared to manure, commercial fertilizer has the advantage of being a homogeneous material, i.e. its nutrient concentration doesn’t change over time or throughout the load. Manure can of course vary in nutrients and in solids content from load to load and even within an individual load. The need for an on-the-go nutrients sensor, at least for nitrogen and phosphorus, is immense. However, responses of simple transducers – e.g. electrical conductivity, pH, and near-infrared reflectance – have not shown good correlation with manure nutrient concentrations. Some new on-board test is needed (Figure 2.)

PROJECT OBJECTIVES

The objectives of this project were to (1) develop a reliable, low-cost prototype variable rate slurry application rate control system for a vacuum loaded tanker, and (2) develop a rational strategy for determining the expected accuracy of a variable rate manure delivery system. The results of the second objective were reported in Funk et al. (2003).

METHOD

The method included building the prototype, and laboratory- and field-testing it. The earlier prototype work was reported in detail in Funk et al. (2000, 2002). A commercially available vacuum slurry tank was fitted with a pinch valve and pneumatic pressure sensing array, and two different slurry delivery devices: a broadcast device with orifice and splash plate, and a soil injection toolbar. The slurry tank used was a twin-axle unit (Better-Bilt™ Model 2600VT, Top
Air Incorporated, Cedar Falls, IA) with rear discharge and a PTO-operated vacuum/pressure air pump capable of maintaining approximately one atmosphere of pressure on the tank during discharge of the tank’s contents. A pressure relief valve on the tank prevented over-pressurizing the vessel. The rear mounted six-inch discharge was fitted with a hydraulically operated gate valve, which was fully open during testing.

The pneumatic pinch valve has become a common element in wastewater treatment systems because of the valve’s inherent non-clogging construction (Fig. 3) and its ease of connection to automatic controls. In this project a pneumatic pinch valve was interposed between the slurry tank discharge and the slurry application device (the broadcast device for one set of tests, and the soil injection toolbar for another set.) The pinch valve served both as a flow metering and flow measuring device, the valve serving as a variable-area obstruction flow meter.

Three different pinch valves were tested: a four-inch Red Valve™ (Red Valve Company, Inc. Pittsburgh, PA) Type A, a four-inch Elasto-Valve™ type AJ-AL (Elasto-Valve Rubber Products Inc., Sudbury, ON), and a six-inch Red Valve™ Type A. The smaller diameter valves were useful in early tests because of their smaller bulk, and were evaluated to see how their flow characteristics compared. Only the six-inch valve was field tested.

The tank was supplied with a quick-coupled broadcast device consisting of a 90-degree sweep elbow and detachable orifice with a splash plate. The 4-inch sweep elbow was reduced from the nominal discharge diameter by a series of two pipe reducers in a welded assembly. Orifice diameter was 2 inches. Flow tests were conducted both with the orifice in place and removed. A five-shank soil injection toolbar (Top Air™) was supplied that was attached to the slurry tank for the field tests (Fig. 4 and 5).

Flow rates in the first prototype development stage were obtained by time-based weight changes of the total slurry tank system, as measured by an interconnected set of five portable electronic

Figure 3. Pneumatic pinch valve cross section.

Figure 4. Field tests of the slurry tank showing pinch valve (left center), air tank (over toolbar) and controller box (on tank).
wheel scales (Model PT300™, Intercomp, Minneapolis, MN). The slurry tank and scales served as a portable "hydraulics table." Later a set of datalogger-compatible axle and tongue load scales was installed on the tanker to improve the high-flow-range stationary calibration tests.

Using clear water as the fluid, flow rates out of the tank and pressures were measured to characterize the pinch valve and produce a prediction function. Following field tests with lagoon liquid (less than 1% solids) and dairy slurry (about 2% solids), further calibration tests were run, also using the lagoon liquid and dairy slurry.

Since the pinch valve required regulated air pressure for its flow-control activation, a low-cost, reliable pressure sensing circuit connected to the same air supply was developed. A 12 VDC air compressor (Thomas model # 405ADC38/12) was used for field tests and later calibrations. To measure liquid differential pressure across the pinch valve being tested, a pneumatic air bleed arrangement was built which incorporated inexpensive differential pressure transducers (Omega Engineering™ model PX 137-030, 0-90 mV at 0-30 psi, 12 VDC excitation) on the pneumatic supply lines (Fig. 6).

Liquid pressures on either side of the pinch valve were measured as the air pressure in the supply lines between the 0.020 inch stainless steel restrictor orifices and the liquid main conduit from the slurry tank. Bourdon-tube pressure gauges were used for data validation. A second sensor measured the pressure difference between the tank headspace and the liquid inlet to the pinch valve; and a third sensor measured the pressure difference between the pinch valve outlet and the atmosphere, which represented the final pressure drop across the injection toolbar. To obtain the ground speed related flow control in field tests, a radar gun (Dickey-john™) was installed on the tanker and the output connected to the data logger, a linear approximation being programmed in. The tanker was field tested and various hardware refinements were made to improve reliability. A top view of the control system is shown in Figure 7.

![Figure 5. Slurry tanker with vacuum loading/pressure discharge and variable rate application mechanism, with no flow rate feedback. Not shown: tank fill port. Headspace is sealed, and pressurized in the field by the PTO pump.](image-url)
Tests with the broadcast equipment showed that the low to medium flow rates were stable and predictable (Fig. 8). High flow rates where the pinch valve was open or almost completely open were harder to predict by the pinch valve case pressure only, but the “total pressure” was a good indicator of that range of operation (Fig. 9). Stationary calibration tests with the soil injection equipment (Fig. 10) also showed moderately good flow control in the low- to mid-range flow rates. Observations in the field indicated that the radar ground speed sensor provided continuous input to the datalogger/controller and varied the slurry application rate according to ground speed.

Figure 6. Vacuum loaded slurry tank with air pressure sensing feedback control. Sensors predict slurry flow by measuring air line bleed pressure into the slurry stream, and tank headspace pressure. Not shown: high pressure air bleed supply line and step-down orifices.

Figure 7. Top rear-facing view of variable rate control system installed on injection toolbar of vacuum loaded slurry tank. Center, pneumatic pinch valve. Top center, slurry distribution manifold. Right, 12 VDC pump and pressure sensors. Bottom left, I/P transducer housing. Left, air tank.
Figure 8. Slurry tank flow v. 6" valve case pressure for broadcast device.

Figure 9. Slurry tank flow v. liquid pressure measured at inlet to pinch valve, broadcast applicator device.
DISCUSSION

The prototype variable rate system could be used for existing tankers, or for towed-hose applicators as an add-on lower cost control system linking ground speed sensing with magnetic flow meter installations. The pneumatic pinch valve might also be used as a “soft-closing” end-of-row shutoff mechanism to reduce manure surface run-on during turns. Manure spillage at end rows is a common problem with pump-supplied towed hose systems and shutoff valves for toolbars are an expensive option that requires a pressure-rise cutoff at the supply pump.

Temporal response of the system, i.e. the ability to quickly follow changes in controller demand with increased or decreased slurry flow, must be addressed but is not simple to implement, due partly to the size of the valves being actuated. An example of laboratory tests of a 4-inch pinch valve’s temporal response with the Marsh-Bellofram I/P transducer is shown in Figure 12. Field test response of the 6” valve on the slurry tanker was similar. The lab and field test series were done without closed-loop feedback; a feedback loop could greatly increase (i.e. degrade) response time depending on the control hardware and software. Response is dependent on air supply pressure; typical response at 60 psi supply pressure to a step input (settling within 10% of the new setpoint) was about four to six seconds (similar to results produced by experimental equipment reported in Morris et al. 1999), and performance degraded quickly as supply pressures fell below 60 psi. Inspection of the pressure v. time plots of the laboratory tests indicates that the system is underdamped, and could perhaps be optimized for field installations with little effort.
With a vehicle traveling at only 5 miles per hour, it would take about 40-50 feet for the application rate to respond to a step input and stabilize at the new rate.

![Test1: Valve Pressure vs. Time for Varying Flow Rate](image)

Figure 11. Typical time response of Marsh-Bellofram current-pressure transducer and 4" pinch valve to step inputs. Open loop control. Tests show a typical response time of about four to six seconds.

**RETFIT VARIABLE RATE SYSTEM**

Major capital expense items for building the system on an existing tanker are the pneumatic pinch valve, the air compressor system, the radar ground speed sensor, on-board rate controller, and the I/P transducer (electronic air pressure regulator) (Table 1).

Fabricating the system, while it is not complicated, will require standard mechanical and electrical skills, with special attention required for dust and water proofing the pneumatic supply and control systems. Machine-specific calibration will be required, with a series of steady-flow test runs on either a full tank of slurry (valve case pressure and tank headspace pressures held constant) or with a partial tank and truck scales to determine net change in tank weights over time. A chart of case pressures v. flow rate must be constructed, from which the automatic controller can be programmed. If the pressure-sensing system is installed, it can be used to fine-tune and track system performance over time. However, our tests have shown that an open-loop system, i.e. with no pressure feedback to the controller, is simpler and probably adequately accurate.

Longevity of the pneumatic pinch valve liner is not known. Replacement of the liner is a straightforward shop disassembly/reassembly procedure. Our experience with the oil-less 12 VDC air compressor is limited but indicates that the piston/cylinder wears out rather quickly and air supply diminishes to an unacceptable level. Therefore we recommend consideration of a continuous-duty vehicle air compressor (necessarily more expensive than the 12 VDC model) where possible.
Table 1. Components list for retrofitted variable rate system incorporating pneumatic pinch valve, radar ground speed sensing, and air bleed pressure sensing.

<table>
<thead>
<tr>
<th>Qty.</th>
<th>Item</th>
<th>Specifications</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6&quot; Type A Red Valve pneumatic pinch valve or equivalent</td>
<td></td>
<td>size depends on tank discharge pipe diameter; 6&quot; most common)</td>
</tr>
<tr>
<td>1</td>
<td>Air compressor</td>
<td>100 psi continuous, ___ SCF minimum at 60 psi</td>
<td>12 VDC powered, or tractor mounted belt-driven (preferred).</td>
</tr>
<tr>
<td>1</td>
<td>Air tank</td>
<td>10-15 gallon minimum, 200 psi rated.</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Line filter and condensate drain</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Current-to-pressure (I/P) transducer (electronic air pressure regulator);</td>
<td>0-5 VDC input 0-30 psi output.</td>
<td>Marsh-Bellofram Model 2000 S or equivalent. Match input to rate controller output specification.</td>
</tr>
<tr>
<td>1</td>
<td>Dust tight and water tight enclosure</td>
<td></td>
<td>Some enclosure functions can be combined into larger boxes if needed.</td>
</tr>
<tr>
<td>1</td>
<td>Rate controller</td>
<td>Match I/O specifications to ground speed sensor, I/P transducer, etc.</td>
<td>Raven, etc.</td>
</tr>
<tr>
<td>1</td>
<td>Radar ground speed sensor</td>
<td>Standard 0-5 VDC output, speed range appropriate to tractor/implement combination</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Air bleed orifice assembly in copper tubing</td>
<td>.020” orifice spray nozzle disc, stainless steel</td>
<td>For optional air bleed pressure sensing circuit</td>
</tr>
<tr>
<td>3</td>
<td>Differential air pressure sensors; tank headspace to pinch valve inlet, valve inlet to outlet, and valve outlet to atmosphere</td>
<td>0-30 psi, 12 VDC excitation voltage, 0-5 VDC output. Omega Engineering model # PX 137-030 DV or equivalent</td>
<td>For optional air bleed pressure sensing circuit.</td>
</tr>
<tr>
<td></td>
<td>Tubing, fittings</td>
<td>Air lines suitable for 100 psi (high pressure side) or 30 psi (low pressure sensing circuit)</td>
<td>High pressure lines connect compressor, air tank, and I/P transducer. Also supply optional air bleed pressure sensing circuit, high side.</td>
</tr>
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CONCLUSIONS

Laboratory and field tests indicate that a pneumatic control system using off-the-shelf components can be used as the major mechanical component at any of the levels of control needed for nutrient management plan implementation – constant flow rate, constant per-acre application rate, GPS/GIS interfaced for precision application, and on-board nutrient sensing. The system fills a need for vacuum-loaded tankers, since a liquid slurry pump and magnetic flow meter are not needed.
ACKNOWLEDGEMENT

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REFERENCES


