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Pneumatic System for Granular Fertilizer Flow Rate Control

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Abstract: Variable-rate technology is an essential part of precision farming that can solve the economical and environmental problems associated with traditional farming practices. Utilization of the technology has been limited by the lack of the development of variable-rate applicators. In this study, a control system for mechanical fertilizer rate adjustment was designed and developed. The control system equipped with pneumatic drive was composed of a double acting cylinder, a double solenoid operated valve 5/2, a computer, a microcontroller, a rotary encoder and other operating parts. The developed control system performance and discharge characteristics were evaluated in the laboratory. The main results of this study could be summarized as follows: (i) the automatic setting of the target fertilizer application rate could be performed efficiently and (ii) the developed system could be precisely used for granular fertilizer variable rate application, with an overall error (from the target fertilizer rate) in the range of ±6%. This work will be a useful contribution in the area of variable rate technology as it enhances the application of pneumatic drives for their low cost and design simplicity.

Key words: Precision Agriculture · Variable Rate Technology · Pneumatic Drive · Granular Fertilizer

INTRODUCTION

Traditional farming practices relied on massive application of agricultural chemicals to increase yields. Mass application of chemicals in agriculture resulted in contamination of the environment and agricultural products. Recent increase of consumer demands for safe agricultural products requires sustainable farming practices approaches. The conventional uniform application of fertilizers disregards the productive potential of the various areas within the field. Consequently, some areas are under-fertilized and the others are over fertilized. Increasing the rate of fertilizer generally increases crop yield up to an optimum level, but more fertilizer is less utilized or mobilized.

Precision farming refers to treating within-field variability with spatially variable input application rates using a set of technologies to identify the variability and its causes and prescribes and applys inputs to match spatially variable crop and soil needs. Variable-rate application (VRA) of granular fertilizer material is a common practice in precision agriculture. Granular fertilizers need to be accurately delivered at the prescribed application rates to accomplish the desired outcome of correcting within–field variations in plant nutrients. Granular applicators equipped with VRA have gained popularity in recent years as a result of increased interest in variable-rate application. Swisher *et al*. [1] designed an optical sensor to measure flow rates of granular fertilizer in air streams for feedback control of a variable-rate spreader. Uniform-rate (UR) tests were conducted to assess the accuracy of VRA from four granular applicators: two spinner-disc spreaders and two pneumatic applicators. That experiment showed potential application errors with variable–rate application and the need for proper calibration to maintain acceptable performance. Furthermore, the study demonstrated the need for a VRT equipment testing standard [2]. Yu *et al*. [3] reported on a control system for variable-rate application of granular fertilizer in paddy farming.

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Their system was designed and fabricated with a F/G (Frequency generator) servo system and a discharger. Also, control performance and discharge characteristics of the control system were evaluated. Results of the performance test showed that the uniformity of discharge amount in terms of the CV (Coefficient of Variation) values for given rotational speeds of discharger were in the range of 11.23~2.94% for Super 21 (N:P:K=21:17:17) and 10.80~2.82% for Shinsedae (N:P:K=22:12:12), respectively. They noticed that the CV values increased as the rotational speed of discharger decreased. The uniformity of rotational speeds of the discharger in terms of the CV values were in the ranges of 0.51~3.06%. The uniformity of rotational speed improved as the input level of control signal increased. Tola *et al*. [4] developed a fertiliser rate control system using a real-time fertiliser discharge sensor to enable variable-rate application with a significant reduced error compared to existing current systems. Their experiments were carried out to modify the mechanical fertiliser rate adjustment system of a pneumatic seeder for the automatic control of the fertiliser output rate. The results of their study indicated that: (a) the automatic setting of the target fertiliser rate and periodic checks and control of output rate could be performed efficiently, (b) the system could be significantly used for variable-rate applications with overall system errors in the range of ±5% and (c) the control system response time to step change adjustments was within the range of 0.95-1.90 s. They recommended that, future research in the area of Variable Rate Technology should be concentrated in development of more accurate granular fertilizer applicators.

Three major types of drives used for Variable Rate applicators are basically used: electric, pneumatic and hydraulic. Each type has its own advantages and disadvantages. The main advantages of pneumatic drives are their low initial cost and design simplicity. Therefore, the major objective of this research was to develop a pneumatic system for granular fertilizer flow rate control to replace the manual adjustment system existed in the planter. Specific objectives were:

- To develop a pneumatic control system for adjusting granular fertilizer rate automatically rather than manually.
- To assess and evaluate the overall system performance in the laboratory.

MATERIALS AND METHODS

Test Platform: A mechanical planter (Model ATESPAR, GIAD Company) with fertilizer application facility, was selected as the test platform (Fig. 1-a). In this planter, the fertilizer output rate was originally controlled mechanically by an adjustment lever as shown in Fig. 1-b. The fertilizer metering mechanism was equipped with a fluted feed roller for conveying fertilizer from the hopper and directing it to the fertilizer tube (Fig. 1-c). The transmission system (consists of a series of chains and gears) is used to apply variable speeds to the output shaft driving the fluted feed rollers.

Test Fertilizer: The granular compound fertilizer product used throughout the experimental work was Urea. Urea fertilizer is produced by combining anhydrous ammonia and carbon dioxide and the chemical formula for Urea is $CO(NH_2)_2$. Its composition is: 20% C, 6.6% H_2, 26.7% O_2 and 46.7% N_2. The used fertilizer had a bulk density of 1.405 g/cm^3.

Discharge Rate Control System:

A control system was designed to enhance the preciseness of variable-rate application of granular fertilizer. Schematic diagram of the control system is shown in Fig. 2.

The developed control system was composed of three main units:

- Pneumatic fertilizer rate control unit: This unit was used to automatically control the mechanical lever through which the fertilizer application rate is adjusted. To achieve this, a double acting pneumatic cylinder system was used to perform the movement of the lever. The pneumatic control system is composed of an air compressor, a double acting pneumatic cylinder, a regulator and electrically operated directional control valve.
- Working Condition Monitoring Unit: This unit was used to monitor the working speed, the distance travelled and hence the area covered at any moment. A rotary encoder (Model E6B2-CWZ6C OMRON Company, Malaysia) was used to perform this work.

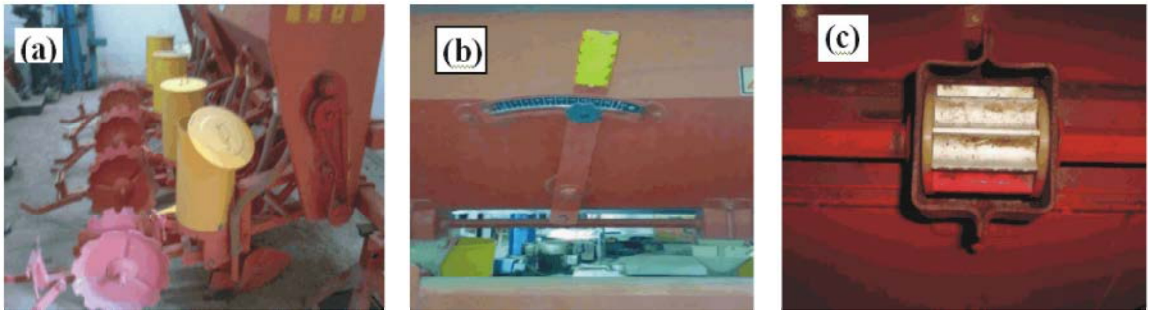

Fig. 1: (a) Tested planter, (b) fertilizer rate adjusting lever and (c) fertilizer metering mechanism

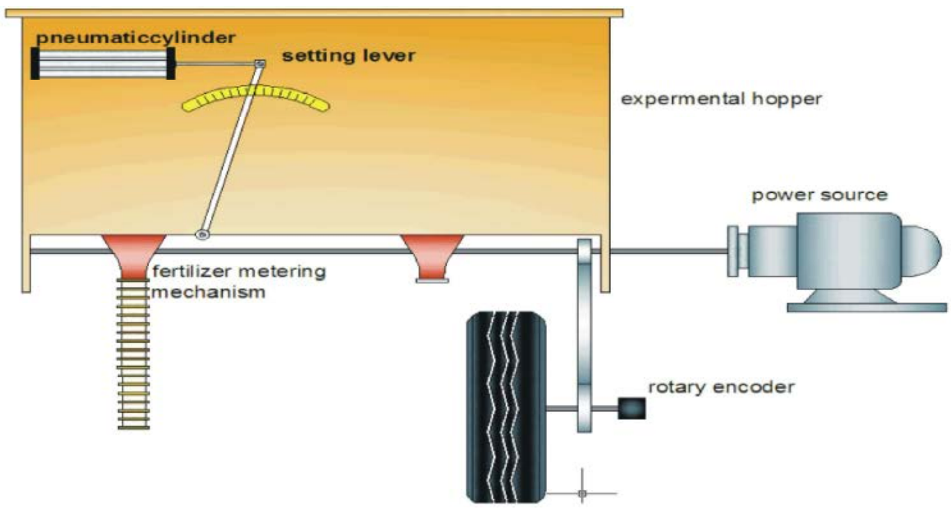

Fig. 2:Schematic diagram of the developed control system.

- Main Control Unit: To integrate the functions of the system components, an Atmel ATMega16L microcontroller was used. It has a digital supply voltage and four Ports (A, B, C and D). Port number A is for the analog inputs to the A/D Converter and also serves as an 8-bit bi-directional I/O port.

Fertilizer Rate Setting: To perform the automatic adjustment of the fertilizer rate setting lever, the double acting cylinder was attached to the lever-handle in order to move it forward or backward according to the desired fertilizer application rate. To control the position of the lever that will match the target fertilizer rate, the flow rate was calibrated and adjusted in terms of the distance travelled by the piston (the stroke). The system components were setup, calibrated and the system performance of each component was evaluated separately. These experiments were carried out under various speeds and target fertilizer application rates.

Execution of the Experimental Work: A C++ software program, to integrate the functions of the system components, has been successfully developed. Tests were conducted under stationary conditions, at constant application rates and two ground speeds (1.3 and 1.9 ms^{-1}) using an electric motor (220 V, 0.4 kW) equipped with a variable speed gear box. Experiments were conducted in three stages:

- Control system performance: Experiments to evaluate the performance of the developed system were conducted under various target fertilizer rates (100, 150, 200, 250, 325 and 400 kg/ha) and two operatingspeeds (1.3 and 1.9 ms^{-1}). The control system feedback is based on the travel distance rather than on time in order to overcome the fluctuations in the operating speed, therefore, four change distances of 30, 60, 90 and 120 m were selected to represent the travelled distance for the system control feedback.

- Control system response to variable rate application**:** Step changes in the target fertilizer rates at pre-determined travelled distances were simulated within the software and tested for the two operating speeds (1.3 and 1.9 ms^{-1}).
- The developed system was finally tested against its response to on-the-go fertilizer adjustment efficiency, the measured output error and the system response time.

RESULTS AND DISCUSSIONS

Adjustment of the Fertilizer Setting Lever: The flow rate was calibrated and adjusted by means of the distance travelled by the piston (the stroke) or Setting Lever position. The fertilizer output rate was determined in kg/ha for the given lever position. Experiments, to assess the fertilizer rate adjustment accuracy, were conducted at two operating speeds (1.3 and 1.9 ms^{-1}) and at 19 different lever positions. Observations were taken for 3 replicates at each lever position and operating speed. The average results of the fertilizer output rates for the tested lever positions are presented in Fig. 3. The results indicated a strong linear relationship (R^2 = 0.996) between the lever position and the fertilizer output rate, as given in Equation 1.

$$y = 3.0606x + 5.0296 \quad (1)$$

Where; x is a piston travelled distance (or setting lever position) in mm and y is the fertilizer output rate in kg/ha.

The obtained results indicated that setting of the fertilizer application rate could be precisely accomplished. Hence, the first stage of this study has been successfully performed.

Effect of Speed on the Performance of the Developed System: The performance of the developed system was tested against the operating speed. The average results of the system output rate versus the target fertilizer rate at the two selected operating speeds (1.3 ms^{-1} and 1.9 ms^{-1}) are presented in Fig. 4.

As illustrated in Fig. 4, the amount of the output fertilizer rate was observed to be relatively the same as the target fertilizer rate with slight differences. Also from Fig. 4, it is clear that the output rate decreased as the operating speed increased and that the output fertilizer rate at the low speed is higher than the target fertilizer rate. While at high operating speed, the output fertilizer rate was observed to be lower than the target fertilizer rate.

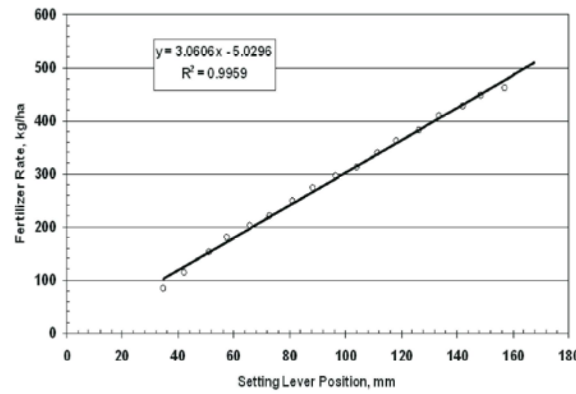

Fig. 3: Setting lever position versus the fertilizer output rate.

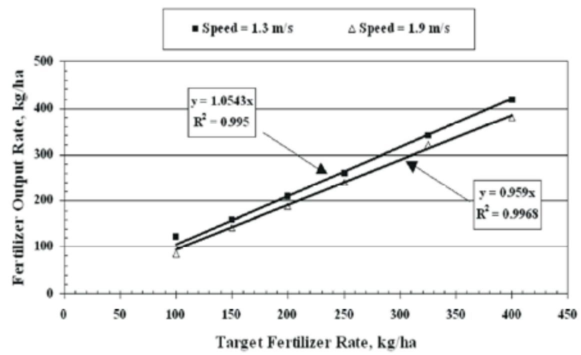

Fig. 4: System output rate vs. target fertilizer rate as affected by the forward speed.

For further interpretation of the results, ANOVA statistical analysis was applied to the collected observations for the two operating speeds. Statistical results showed that, significant differences between the values of the output rate based on the operating speed were observed. That could be attributed to the assumption that at high speeds the amount of the fertilizer delivered by the fluted wheel is relatively low compared to that at low operating speeds. Some fertilizer could be projected back from the fluted wheel cells as a result of high speeds.

Control System Response to Variable Rate Application: Further experiments were conducted to evaluate the developed system response to step changes in the target fertilizer rate at a pre-determined travelled distance intervals at two operating speeds (1.3 ms^{-1} and 1.9 ms^{-1}). Variable fertilizer application rates were simulated in the developed computer program (namely: 400, 200, 325, 100, 250 and 150 kg/ha). Table 1 represents the combinations of various target fertilizer rates and the pre-determined travelled and change distances.

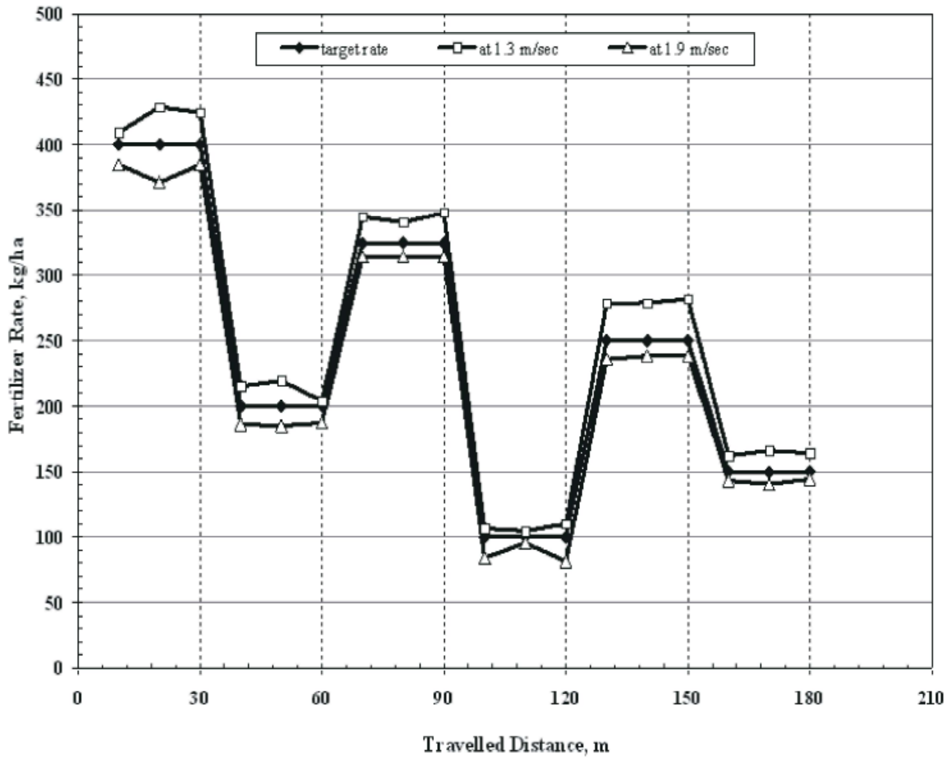

Fig. 5: The system response to variable rate application for 30 m change distance.

Table 1: Combinations of variable rate experiments parameters

	Change Distance = 30					
Travel Distance, m	0-30	30-60	60-90	90-120	120-150	150-180
Target Fertilizer Rate, kg/ha	400	200	325	100	250	150
	Change Distance = 60					
Travel Distance, m	0-60	60-120	120-180	180-240	240-300	300-360
Target Fertilizer Rate, kg/ha	400	200	325	100	250	150
	Change Distance = 90					
Travel Distance, m	0-90	90-180	180-270	270-360	360-450	450-540
Target Fertilizer Rate, kg/ha	400	200	325	100	250	150
	Change Distance = 120					
Travel Distance, m	0-120	120-240	240-360	360-480	480-600	600-720
Target Fertilizer Rate, kg/ha	400	200	325	100	250	150

Variable rate experiments indicated that the developed control system could be efficiently used for the application of granular fertilizer at variable rates. Example of variable rate results is given in Fig. 5 for the change distance of 30 m.

For further interpretation of the collected observations for the variable rate application, the system measured output error based on the target fertilizer rate under two operating speeds (1.3 and 1.9 ms^{-1}) was calculated and evaluated. The amounts of the measured output errors for both the under and over fertilization are within the range of ±6%. The developed control system response time to the transition from one step change to the other during the variable rate application experiments was found to be in the range of 0.08 – 1.00 seconds.

CONCLUSIONS AND RECOMMENDATIONS

This study was carried out to modify the mechanical fertilizer rate adjustment system in order to adjust and control the fertilizer application rate using a pneumatic drive system. The following conclusions and recommendations could be drawn from the obtained results:

- Automatic setting of the target fertilizer application rate was achieved efficiently.
- The developed system could be efficiently used for variable application of granular fertilizer with overall system errors (from the target rate) in the range of ±6%.
- The collected observations indicated that the control system response time to step change adjustments (the transition period from one fertilizer rate to the other) is within the range of 0.08 – 1 second.
- Upgrade the control system by adding real time sensor to measure the output fertilizer rate for the control feedback and on-the-go adjustment of the application rate.
- Validation experiments under field conditions should be carried out to check the performance of the developed system and to perform any essential modifications based on the results of the field experiments.

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