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Development of 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 control system equipped with pneumatic circuit 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 control system performance and discharge characteristics were evaluated. 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, (ii) the developed system could be precisely used for granular fertilizer variable rate application, and (iii) the collected observations indicated that the developed system could be significantly used for granular fertilizer variable rate applications with an overall error (from the target rate) in the range of ±6%. This work will be a useful contribution in the area of variable rate technology. Further research work to improve the developed control system and to evaluate its performance under actual field conditions is recommended.

Keywords: *precision farming; Variable-rate technology (VRT); Variable-rate application (VRA); granular fertilizer, pneumatic system; microcontroller*.

1. INTRODUCTION

Traditional farming practices in Sudan relied on massive application of agricultural chemicals to increase yields. Mass application of chemicals in agriculture resulted in contamination of environment and agricultural products. Recent increase of consumer demands for safety of agricultural products requires sustainable approaches to farming practices. The conventional uniform application of fertilizers disregards the productive potential of the various areas within the field. Thus, 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 prescribe and apply 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. With air spreader fertilizer applicators, granular fertilizer material is metered from the on–vehicle holding bin into an air stream by rotating metering wheels. The granules then travel with the air stream through a flexible tube to a location on a boom where they are dispersed by a deflection plate and drop to the ground [1]. Commercially available granular fertilizer air spreaders do not directly measure the flow of material through the pneumatic tubes. Application rates are determined by measuring the rotational speed of the fertilizer metering wheels. From the monitored rotational speed and the delivery capacity of the metering wheels, granular material flow rate through the boom is estimated [2]. Although this method can be calibrated to accurately estimate application rates under ideal conditions, issues such as worn metering wheels, fertilizer application on uneven terrain, and changing fertilizer properties may reduce the accuracy of this delivery.

Granular applicators equipped with VRA have gained popularity in recent years as a result of increased interest in variable-rate application. Swisher et al. [3] 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. Further, that investigation demonstrated the need for a VRT equipment testing standard [4].

Yu et al. [5] reported on a control system for variable-rate application of granular fertilizer in paddy farming. Their system was designed and fabricated with an 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. [6] 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 current systems. Their experiments were carried out to modify the mechanical fertiliser rate adjustment system of pneumatic seedier 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%, (c) the control system response time to step change adjustments is within the range of 0.95-1.90 s, and (d) selecting check distance intervals of more than 3 m will enable the developed system to perform the check and control processes precisely. According to the various research findings in the area of granular fertilizer rate control systems, it is clear that most of the current control systems are based on estimating the fertilizer output rate. Future research in VRA should be concentrated in development of more accurate granular fertilizer applicators and their standards.

The overall objective of this research was to develop ppneumatic system for granular fertilizer flow rate control. Specific objectives were:

1. To develop a granular fertilizer delivery rate control system for adjusting the fertilizer rate automatically rather than manually.
2. To assess and evaluate the overall system performance.

2. MATERIALS AND METHODS

2.1 Test Platform

A mechanical planter (model ATESPAR, GIAD Company) with fertilizer application facility, Fig. 1 (a), was selected as the test platform. In this seedier, the fertilizer output rate was originally mechanically controlled 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.

2.2 Test Fertilizer

The granular compound fertilizer product used throughout the experimental work was Urea; it is the most used fertilizer for crop production in the Sudan. Urea fertilizer is produced by combining anhydrous ammonia and carbon dioxide. 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.

2.3 Discharge rate control system

The control system used for variable-rate application of granular fertilizer was designed to enhance the precision of application. Schematic diagram of the control system is shown in Fig. (2). the proposed control system is composed of three main units and described as follows:

i. **Fertilizer rate control unit:** This unit is used to control the rate of fertilizer using a mechanical lever. To achieve variable rate, a double acting pneumatic cylinder system was used to perform the movement of the lever. The pneumatic control system is composed of air compressor, regulator, and electrically operated directional control valve. Fig. (3) Shows an overview of the double acting cylinder. The electrically operated double acting cylinder is the major component of the above mentioned pneumatic system. Figure (4) illustrates the circuit diagram of a double acting cylinder, operated electrically. In the electrically operated double acting cylinder, compressed air is supplied from a compressor (i) air flows through a cross regulator, (ii) filtered, and regulated, (iii) directed by the solenoid valve, and (iv) the process of expanding and retracting motion is controlled by the speed controller.

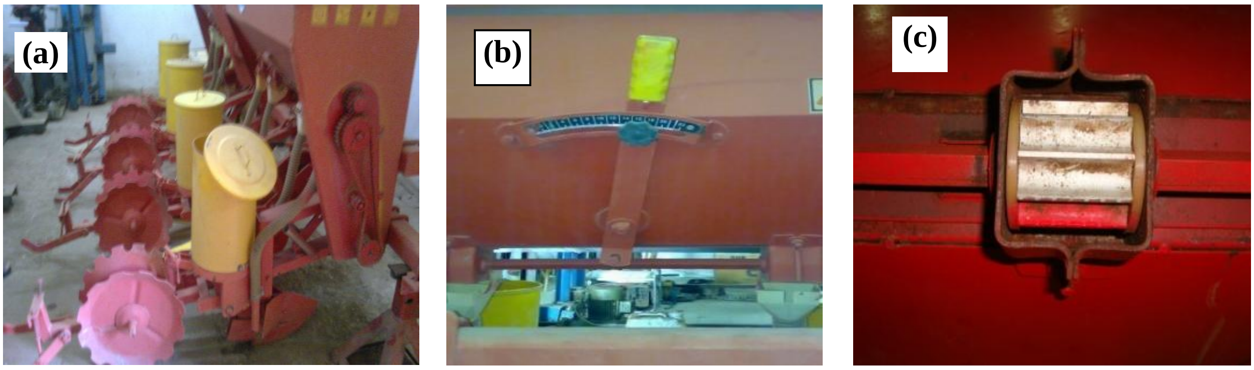

Fig (1). (a) Tested planter (Model ATESPAR, GIAD Company), (b) fertilizer rate adjusting lever, and (c) fertilizer metering mechanism

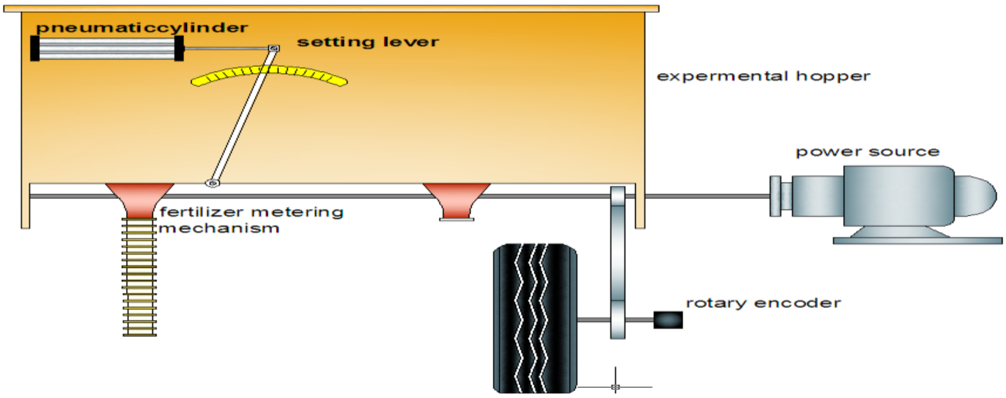

Fig (2). Schematic diagram of the proposed control system

ii. **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) used to perform this work. It has a wide operating voltage range of 5 to 24 VDC and resolution of 200 PPR (pulses/rotation).

iii. **Main Control Unit:** To integrate the functions of the system components an Atmel ATMega16L microcontroller used. It has a digital supply voltage, and four Ports (A, B, C, and D). A port serves as the analog inputs to the A/D Converter and also serves as an 8-bit bi-directional I/O port. Figure 6 shows the microcontroller.

2.4 Fertilizer Rate Setting

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.

To perform the automatic adjustment of the fertilizer setting lever, the double acting cylinder was attached to the lever-handle 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 distance travelled by the piston (the stroke).

2.5 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 with variations in ground speed using an electrical motor (220 V, 0.4 kW), connected to a variable speed gear box to give two speeds as showing in Fig. 2.

i. **Control system performance:** Experiments to evaluate the performance of the developed system were conducted under various target fertilizer rates of 100, 150, 200, 250, 325, and 400 kg/ha and operating speeds of 1.9, 1.3 m/s. 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.

Figure (3). Double acting cylinder

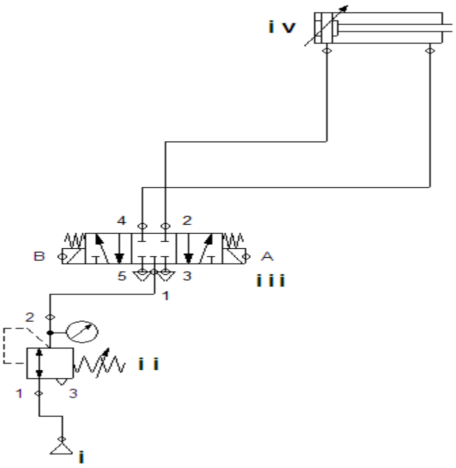

Figure (4). Circuit diagram of a double acting cylinder

i. **Control system response to variable rate application:** Step changes in the target fertilizer rates at a pre-determined travelled distances were simulated within the software and tested under two operating speeds (1.9 and 1.3 m/s). Experiments were conducted to analyze the control system against its response in terms of on-the-go fertilizer adjustment efficiency, the measured output error, and the system response time, Table 1 illustrates the setup of the variable rate application experiments.

3. RESULTS AND DISCUSSION

3.1 Calibration of Fertilizer Setting Lever

The flow rate was calibrated and adjusted in terms of the distance traveled by the piston (the stroke) or Setting Lever position. Therefore, the first stage work was to conduct comprehensive experimental work aiming at relating the lever position and the fertilizer output rate. The lever position is indicated by the distance traveled by the cylinder piston. The fertilizer output rate was determined in kg/ha for the given lever position.
Experiments 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 were presented in Fig. 5. It was found that automatic control of the fertilizer application rate could be achieved precisely as indicated by the linear relationship between the lever position and the fertilizer output rate, as follows in Equation (1):

$$d_p = 0.001R_f + 0.002 \qquad (1)$$

Where: d_p is piston traveled distance or setting lever position, in meter and R_f is fertilizer output rate, in kg/ha.

3.2 Control System

The control system for variable-rate application of granular fertilizer was designed to integrate the functions of the system components. The control system is composed of a computer (PC), microcontroller (ATMega16L**)**, rotary encoder. C++ program was developed to integrate the system components in order to perform the proposed task. Fig. 6 shows the fertilizer control system block diagram.

3.3 Target Fertilizer Rate and Actual Output Rate

Fig. 7 shows the average results of the target fertilizer and the system output rates for the tested operating speed 1.3 m/s and the tested travel distances 30m. Figure seen that the fertilizer output was linearly related to target rates. The linear relationship was very strong as indicated by the regression equation:

$$y = 1.015x \qquad (2)$$

Where, Y is the system output rate, in kg/ha and X is the target fertilizer rate, in kg/ha. The coefficient of correlation (R2) was found to be 0.998.

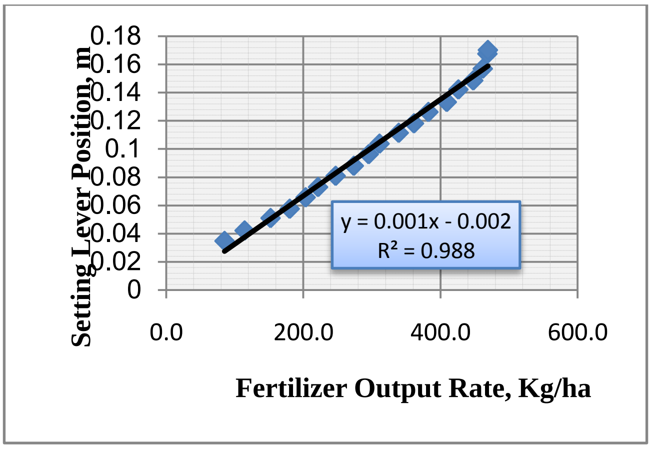

Figure (5). Fertilizer setting lever position versus fertilizer output rate

3.4 Effect of Speed on the Performance of the Developed System

The performance of the developed system was tested against the operating speed. Fig. 8 shows the average results of the target fertilizer and the system output rates at the tested operating speeds (speed1 = 1.9 m/s, and speed 2 = 1.3 m/s) and for the tested travel distances (30, 60, 90, and 120 m). From this figure it is clear that output rate increased as the operating speed decreased. For further interpretation of the results, ANOVA statistical analysis was applied to the collected observations for the two operating speeds.

The ANOVA 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 return back beyond the fluted wheel cells as a result of high speeds.

3.5 Control System Response to Variable Rate Application

Fig. 9 shows an example of the pattern of the control system response to step changes in the target fertilizer rate at a pre-determined traveled distance intervals (30 m) for operating speeds (1.9, 1.3 m/s). Variable fertilizer application rates were simulated in the developed computer program (namely: 400, 200, 325, 100, 250, and 150 kg/ha). The selected fertilizer application rates were set to be changed each 30 m of the traveled distance. From Fig. 10, it is clear that the developed control system could be used efficiently for the granular fertilizer variable rate application. 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 (1.9 and 1.3 m/s) was calculated and evaluated. The amounts of the measured output errors for both the under and over fertilization are shown in Figure (10).

Table (1). Step changes for variable rate application

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

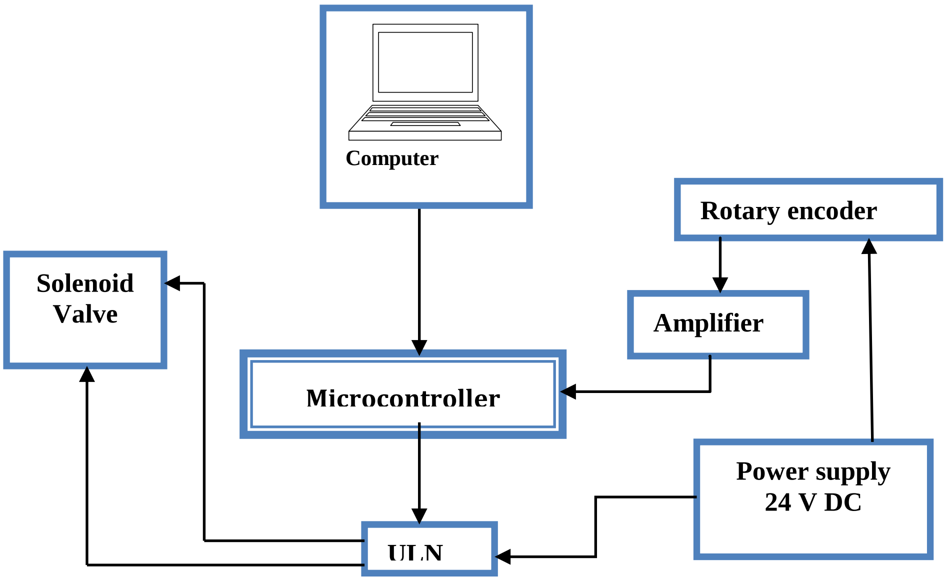

Fig (6). Fertilizer control system block diagram

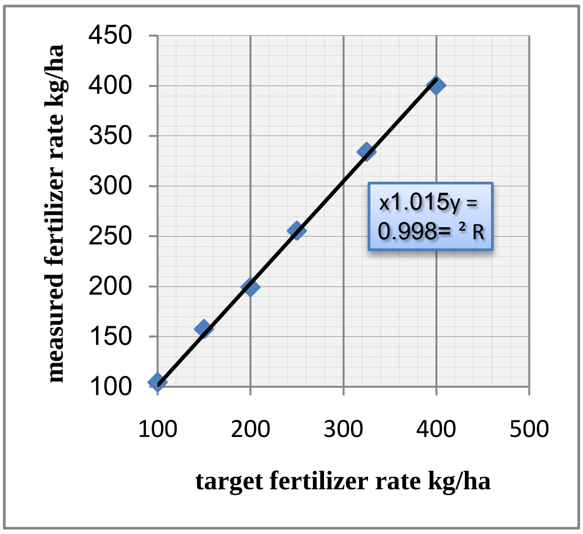

Fig (7). System output rate and target fertilizer rate

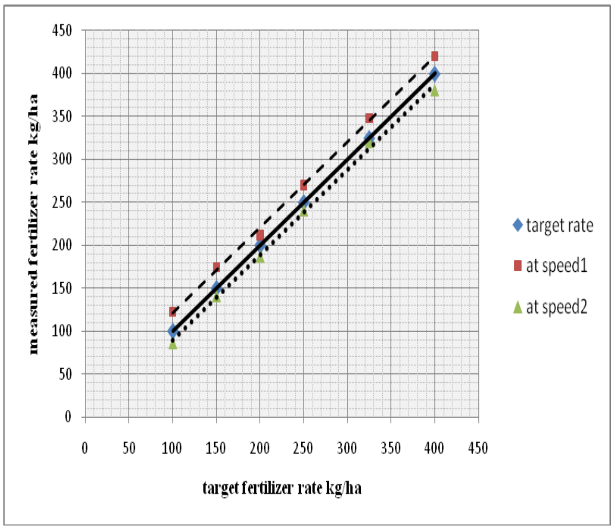

Fig (8). System output rate and target fertilizer rate at tested speeds

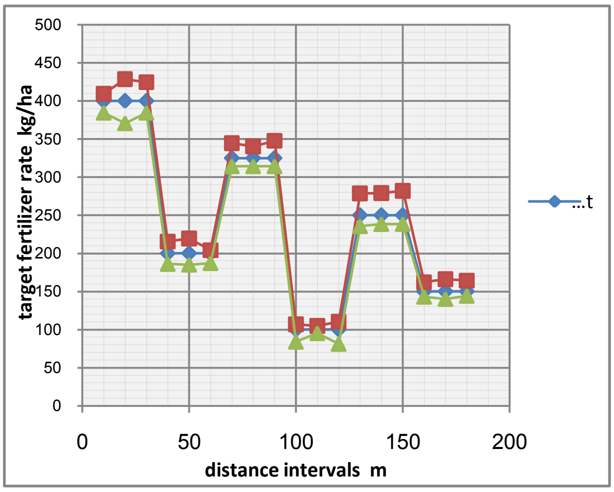

Fig (9). The system response to the variable rate application

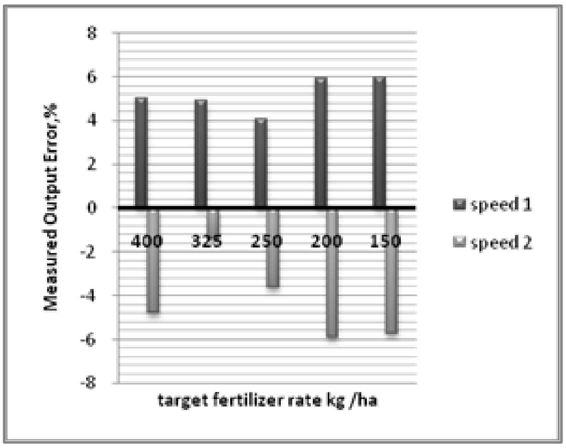

Fig (10). Output errors for both the under and over fertilization

From figure 10, it is seen that the overall system errors are within the range of ±6%. These amounts of the system errors are relatively low compared to the performance of many granular fertilizer control systems already used for variable application.

Finally, the control system was evaluated against its response to the transition time from one step change to the other needed to adjust the fertilizer rate setting lever, during the variable rate application experiments. That indicated the response time to step change adjustments is within the range of 0.08 – 1.00 seconds.

4. CONCLUSIONS and Recommendations

4.1 Conclusions

This study was carried out to modify the mechanical fertilizer rate adjustment system to be an automatic setting system.

The following conclusions could be drawn from the obtained results:

1. The automatic setting of the target fertilizer application rate was performed efficiently.
2. The developed system was precisely used for granular fertilizer variable rate application.
3. The collected observations indicated that the developed system was significantly used for granular fertilizer variable rate applications with overall system errors (from the target rate) in the range of ±6%.
4. during the variable rate application experiments the response time to step change adjustments (the transition period from one fertilizer rate to the other) is within the range of 0.08 – 1.00 seconds.

4.2 Recommendations

The following agenda could be suggested for future researches:

1. Upgrade the control system by adding real time sensor to measure the output fertilizer rate (control feedback).

2. 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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