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Accuracy of Two Types of Fertilizer Rate Control Systems in a Variable Rate Fertilizer Applicator

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ABSTRACT

Today, thanks to modern agricultural technologies, not only mechanized farm practices have become faster, but also agricultural input consumption is equivalent to needs in different parts of a farm. This reduces costs and energy consumption, as well as the pollution resulting from agricultural input consumption. Precision farming is a modern farm management method, with variable rate technology being its most important sector. Conventional machines can be changed into variable rate by mounting an electronic control system. The fluted wheel metering system is the most common in fertilizer applicators used in Iran. Response time of control systems is an important factor affecting the accuracy of variable rate fertilizer applicators. The accuracy of two different fertilizer rate control systems was evaluated in Imam Khomeyni Higher Education Center. The first (single-parameter) system controls fertilizing rate by adjusting the opening of the metering device. The second (dual-parameter) system controls fertilizing rate by adjusting both opening length and rotation speed of its axle. The fertilizing rate accuracy was measured for 50, 100, 150 and 200 kg/ha intervals and for both ascending and descending variations. The data were analyzed in a factorial design by Design Expert. The results showed that both control systems are significantly different in terms of their fertilizing rate accuracy at all fertilizing rate changes. The fertilizing rate error was lower at 50 kg/ha rate in the single-parameter control system than the dual-parameter one; however, it was higher in the single-parameter control system at 100, 150 and 200 kg/ha rates.

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INTRODUCTION

In recent decades, with increasing demand for agricultural products, their production has also grown significantly, leaving environmental impacts. Agricultural energy and costs as well as increased environmental pollution were resulted from consumption of agricultural inputs. Agricultural chemical inputs consumption is most important reason of groundwater contamination [3]. According to 2007 Iranian Agricultural Yearbook, 2699920 tons of chemical fertilizers are used annually in Iran. If fertilizers can be used based on soil analysis results and pilot studies, crop production yield will be optimized. Crop production is decreased due to applying fertilizers higher or lower than soil needs [10]. Production costs and energy consumption are increased with over-application of fertilizers. Soil's fertility is not equal throughout a farm. Traditional practices (uniform chemical application) failed to consider this heterogeneity of soil fertility potential; therefore, some parts of farms received more-than-enough fertilizer while other received less than what was needed. Granular fertilizers should be used in carefully prescribed values to optimize the production yield [9]. Site-Specific Crop Management (SSCM) has an important impact on the development of precision agriculture as a technology that collects and analyzes data. One of the main components of SSCM is the variable rate technology. In this technique, all farm operations (such as planting, fertilizer and chemicals applications and irrigation) are done based on local needs of any location on the farm, and it is the most common technology in precision farming [7].

Most fertilizers are used in the granular form. Chemical granular fertilizers can be used in fertilizer distributers, applicators or planters. Fertilizer distributors have a high field capacity as an advantage factor.

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Fertilizer applicators and planters increase efficiency and location accuracy of applied fertilizers and reduce their related costs because fertilizers are applied near crop rows [6]. Fertilizer planters have the highest efficiency; because they bury fertilizers and prevent their sublimation.

Previous studies show that large bodies of research on variable rate applications of fertilizers have been carried out on fertilizer distribution machines. A designed control system for variable-rate phosphorus granular fertilizer was mounted on an Amazone seed-fertilizer planter. The system measured the soil phosphorus content by a spectrophotometer sensor [8]. The system adjusted the fertilizing rate by changing the location of gearbox lever and metering device axle rotation speed [5]. Jafari [1] developed and an auger type granular fertilizer metering device [1]. Loghavi and Forouzanmehr developed and evaluated a map-based variable rate fertilizer applicator. The variable rate fertilizer applicator had the auger type granular fertilizer metering device. The axle of the metering device was driven by a coupled stepper motor. Fertilizing rate was adjusted by changing the rotation speed ratio of stepper motor to traveling speed [4].

A conventional uniform rate application machine can be changed into variable rate type by installing a fertilizing rate control system [2]. Since most fertilizer applicator metering devices in Iran are with fluted wheel, this study was carried out on this type of metering devices. On the other hand, one of the important factors that contributes to the quality of variable rate application machines is how accurate their fertilizing rates are. Machines with low response time have high fertilizing rate accuracy. Therefore, in this study, two types of control systems (single-and dual-parameter) were developed and mounted on a four-row fertilizer applicator. Then the accuracies of both systems were evaluated by workshop tests.

MATERIALS AND METHODS

The control systems:

In this study, first two types of fertilizer metering device control systems were separately mounted on a fertilizer applicator (Tarashkadeh Company), and then their accuracies were evaluated. The fertilizer applicator had a fluted wheel (Mini-Max) type metering device. Fertilizing rate of the machine was adjusted by changing both gate opening length and rotation speed of the metering device.

Single-parameter control system:

The system consisted of traveling speed and gate position sensors, metering device gate actuator, gate movement mechanism and an electronic control unit (Figure 1).

a) traveling speed sensor:

The sensor is a shaft encoder that was coupled to the ground driven wheel shaft (Figure 1, part 1). The sensor sends signals to an electronic control unit, based on the machine’s displacement on the farm. Traveling speed can be calculated by dividing displacement to traveling time.

b) Electronic Control Unit:

The unit included an electronic board that contained an AVR microprocessor Atmega32 model. The electronic control unit analyzed the data collected by the sensors and made proper decisions based on the machine’s working conditions (Figure 1, part 2).

C) GPS Receiver:

A GPS receiver (Model NEO-5QGPS, manufactured by U-blox AG Company, Switzerland) with a 2.5m Circular Error Probable (CEP) was used as the positioning system. The receiver had a magnetic antenna (Figure1, part3) that was mounted on the middle of the machine.

d) Gate position sensor:

A linear potentiometer with 100m strokes was attached to the gate of the metering device (Fig.1, part 5). The sensor output voltage was adjusted by moving the gate position and the sensor rod.

e) Actuator of metering device gate:

A 12-volt electromotor was used as the actuator of all gates (Figure 1, part4). All gates were immediately moved when the electromotor axle rotated clockwise or counterclockwise.

f) Gates moving mechanism:

electromotor rotation was transmitted to all gates by a mechanism that consisted of four gearboxes and an axle (Fig.1, part 5).

Advances in Environmental Biology, 8(12) July 2014, Pages: 306-313

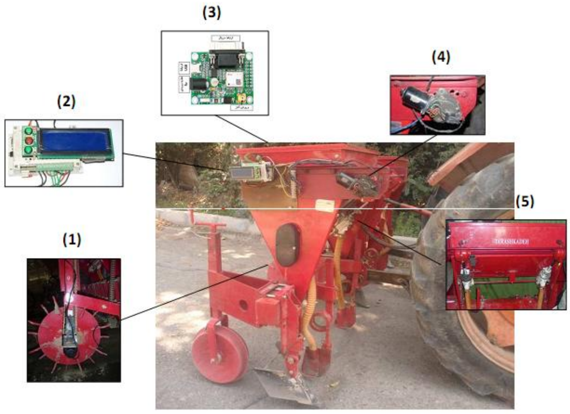

Fig. 1: Single-parameter control system.

Position (latitude and longitude) of the machine was determined by the GPS receiver. The electronic control system calculated the fertilizing rate based on the position of the machine and fertilizing prescription map. The electronic control unit determined the gate's opening based on the traveling speed and fertilizing rate, and then sent proper signals to the actuator. The gate position sensor sent proper feedback signals continuously based on the gate position (Figure 2). Once the gate was at a proper position, the electronic control unit stopped sending signals.

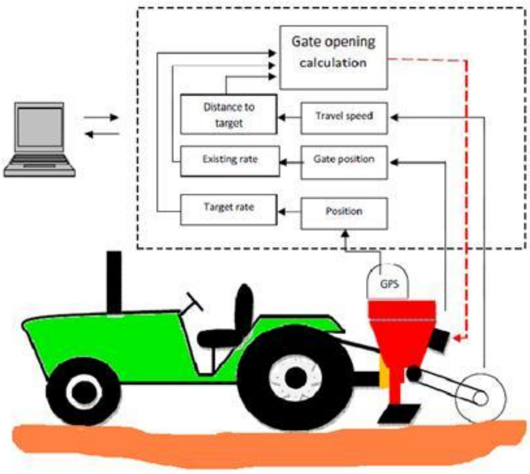

Fig. 2: Single-parameter control system work flow.

Dual-parameter control system:

In addition to the components of the single-parameter system discussed above, the system had also a mechanism for controlling speed of metering device axles. The mechanism included a gearbox (Figure 3, part d), gear box lever position sensor (b), gearbox lever actuator (d) and a hydraulic contrl unit(c).

As the hydraulic jack's piston is displaced, gear box lever rotates and the ratio of metering device axle speed to ground driven wheel speed (K) then changes. The speed ratio varies between 0.25 <K <1. The lever of gear box stops at the middle of the course (K = 0.5) when the system is in normal operation condition (except while changing the fertilizing rate). The electronic control unit calculates the opening length based on operating conditions of the machine (fertilizing rate target, traveling speed and position of the lever of gearbox or K = 0.5). When fertilizing rate target changes, the electronic control unit calculates the new position of the gate based on the normal position of the gear box lever (K = 0.5) and sends proper signals to the hydraulic actuator. The gate and the gear box lever start moving towards the target positions, simultaneously. The gear box lever reaches to the target position faster than the gate. Therefore, the gear box lever returns to its operation (normal) position (K = 0.5) while the gate is moving towards the target position (Figure 4). The electronic control system estimates the position of the lever based on instantaneous gate position. In other words, when the gate reaches the target point, the gearbox lever reaches to its working position (K=0.5). Since the gear box speed adjustment mechanism is used to reduce the error of fertilizing rate, when change of the fertilizing rate is low (less than x in Figure 4) the mechanism is not used.

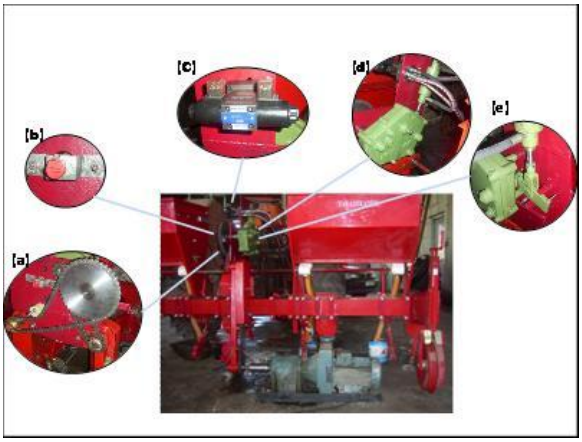

Fig. 3: Components for adjusting rotation speed of axles: (a) sprocket and chain unit (b) gear box lever position sensor (c) hydraulic flow control valve (d) gear box and hydraulic actuator of gear box lever (e) gear box lever.

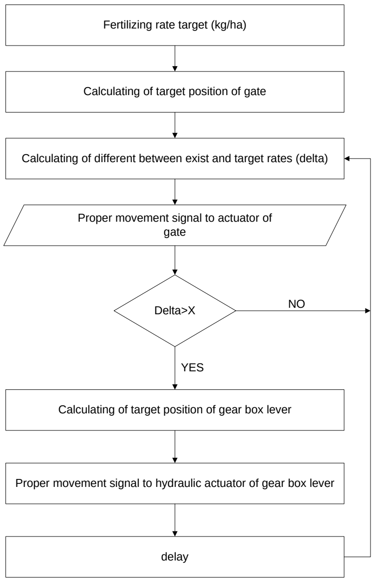

Fig. 4: Algorithm of the dual-parameter control system operation.

Field tests:

Speed sensor calibration:

To calibrate the speed sensor, the machine was operated on a corn field within the speed range proper for fertilizer applicators (3.5, 5.75 and 8 km/h), each with five replications. The traveled distance was measured per 10 revolutions of the ground driven wheel. These operations were performed separately for each system (single and dual-parameter). The average number of pulses sent from the sensor to traverse the said distance was measured. The distance factor of the speed sensor was calculated by dividing the average traveled distance to the average number of pulses. This was 1.74 and 1.79 cm per pulse for the single-parameter and the dual-parameter control systems, respectively.

Fertilizer Applicator Operation Simulation:

Since the workshop tests must be carried out in actual working conditions of the fertilizer applicator, the traveling speed of the machine was simulated in workshop. For this purpose, the ground driven wheel was replaced by a gear box and an electromotor unit (Fig. 5). It was possible to continuously adjust the output speed within the proper traveling speed range.

Fig. 5: Simulation of fertilizer applicator field operation conditions in workshop.

Determining the accuracy of control systems:

The fertilizing rate error of each system was determined as the difference between the actual and target rates. With larger changes in the fertilizing rate, its accuracy decreased due to an increase in the response time. Therefore, the fertilizing error was determined for four rates of 50, 100, 150 and 200 kg/ha. The longitudinal spacing for each fertilizing zone (cell) was 20 m (distance travelled by the implement). The fertilizing rate was first changed from lower to higher and then from higher to lower rates in each series of tests (as shown in Table 1). The tests were carried out in the range of proper traveling speed (3.5, 5.75 and 8 km/h) in three replications.

Table 1: properties of fertilizing rates in all rate changes.

Change of fertilizing rate (kg/ha)	Fertilizing rate (Kg/ha)						
	50	100	150	200	250	350	450
50	*	*	*	*	*		
100	*		*		*	*	
150	*			*		*	
200	*				*		*

The implement’s electronic control unit was programmed with the four above-mentioned series. Primary settings (such as traveling speed and filed fertilizer in funnel) were carried out, and before tests, a container was placed underneath each fertilizer drop tube. Each test started by an on/off button. When a test was started, the electromotor (that was replaced on the ground driven wheel) was turned on and the electronic control system controlled the fertilizing rate of the implement, simultaneously. The system changed the fertilizing rate when the ground driven wheel axle rotated an equivalent of 20 meters distance. The sampling containers were replaced immediately once the system began to change the fertilizing rate. Fertilizer samples in each container were weighed after each test. Weights of fertilizer samples were converted to kilograms per hectare as for actual fertilizing rates. Fertilizing rate errors were calculated using Equation 1.

Effects of traveling speed, fertilizer rate variations (declining or increasing), fertilizing rate, and control system type (single- or dual-parameter) on fertilizing error were analyzed as a factorial design.

$$a_C = \left| \frac{F_a - F_t}{F_t} \right| \times 100 \quad (1)$$

where, a_c is the system error (percent); F_a denotes the actual fertilizing rate (kg/ha); and F_t stands for the target fertilizing rate (kg/ha).

RESULTS AND DISCUSSION

At 50 kg/ha fertilizing rate, effects of fertilizing rate and control system type were significant at the level of 1%; however, the effect of traveling speed was nonsignificant (Table 2).

Table 2: ANOVA results of the effect of studied parameters on mean error of the fertilizing operation (percent), at 50 kg/ha.

Variances	df	Sum of squares	Mean squares
Traveling speed	2	46.11	23.05
Fertilizing rate	3	563.38	187.79**

Control system type	1	324.00	324.00**
Rate change direction	1	802.77	802.77**
error	96	2595.25	

The mean squares are marked with the symbol ** indicates a significant difference at the one percent level

At 100 kg/ha, Effects of all factors on error of fertilizing were had significant at the 1% level (Table 3).

Table 3: ANOVA results of the effect of studied parameters on mean error of the fertilizing operation (percent), at 100 kg/ha.

Variances	df	Sum of squares	Mean squares
Traveling speed	2	3817.35	1908.67**
Fertilizing rate	2	4057.21	2028.60**
Control system type	1	5594.88	5594.88**
Rate change direction	1	8344.75	8344.75**
error	72	670.51	

The mean squares are marked with the symbol ** indicates a significant difference at the one percent level

Effects of fertilizing rate, control system type and fertilizing rate variation direction were significant at the level of 1%. This was true for the effect of traveling speed at the level of 5% (Table 4).

Table 4: ANOVA results of the effect of studied parameters on mean error of the fertilizing operation (percent), at 150 kg/ha.

Variances	df	Sum of squares	Mean squares
Traveling speed	2	230.33	115.16*
Fertilizing rate	1	676.3	676.30**
Control system type	1	1452.00	1425.00**
Rate change direction	1	3334.72	3334.72**
error	48	1626.07	

The mean squares are marked with the symbols ** and * indicates a significant difference under levels of 1% and 5% respectively.

All factors had a significant effect on fertilizing rate error at the 1% level for 200 kg/ha treatment (Table 5).

Table 5: ANOVA results of the effect of studied parameters on mean error of the fertilizing operation (percent), at 200 kg/ha.

Variances	df	Sum of squares	Mean squares
Traveling speed	2	2757.67	1378.84**
Fertilizing rate	1	470.22	470.22**
Control system type	1	4629.35	4629.35**
Rate change direction	1	8653.43	8653.43**
error	48	494.81	

The mean squares are marked with the symbol ** indicates a significant difference at the one percent level

In all tests, the effect of control system type was highly significant at all four rate changes (50, 100, 150 and 200 kg/ha). The mean error of fertilizing rate for the dual-parameter system was higher than the single-parameter control at 50 kg/ha treatment, however it was lower than that of the single-parameter control system

Advances in Environmental Biology, 8(12) July 2014, Pages: 306-313

at other rates (Figure 6). This is true in all fertilizing rate variation directions (declining, increasing, and average) (as shown in Figures 6, 7 and 8).

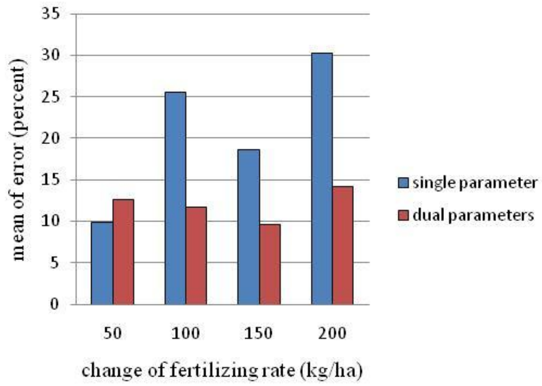

Fig. 6: Mean error (percent) for two types of control systems in all fertilizing rates.

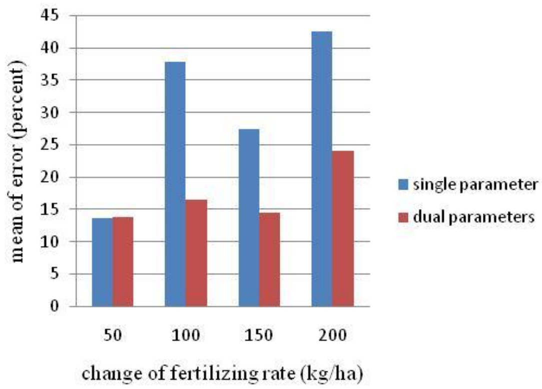

Fig. 7: Mean error (percent) for two types of control systems in declining rate variations.

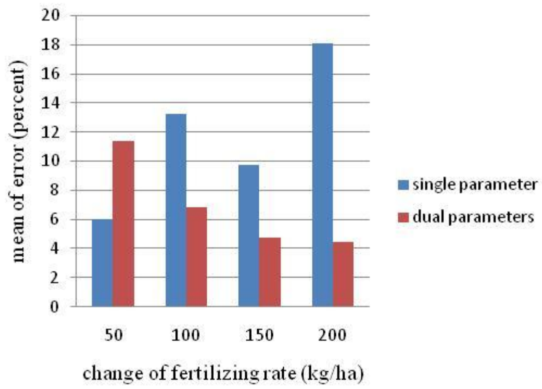

Fig. 8: Mean error (percent) for two types of control systems in increasing rate variations.

Since the gate should slide shorter distances when the fertilizing rate variation is small (less than 50 kg/ha), it can reach its target position in a shorter time, bringing about a lower error in the single-parameter system. On the other hand, changing the speed ratio may increase indisposition and the fertilizing rate error in the dual-parameter control system at low changes in the fertilizing rate (50 kg/ha). In general, according to the results, it

Advances in Environmental Biology, 8(12) July 2014, Pages: 306-313

can be stated that the dual-parameter control system have a greater positive impact than the single-parameter system at fertilizing rate variations more than 50 kg/ha.

Then program of control system was changed. When fertilizing rate change is equal or less than 50 kg/ha the system controls fertilizing rate by gate position change only but controls by position gate and speed ratio changes in fertilizing rate change more than 50 kg/ha in the new program.

Conclusions:

The difference in fertilizing rate errors between two types of control systems was very significant in all rate variations. The fertilizing rate error for the single-parameter control system was less than the other system at 50 kg/ha, while at 100, 150 and 200kg/ha, the dual-parameter system's error was less than the other system.

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