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Metering Characteristics Accompanying Rate Changes Necessary for Precision Farming

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ABSTRACT

Agricultural machines used in precision farming must adjust application rates according to the needs of each cell within a field. Changing from an initial application rate to a new rate while the machine travels from one cell to another in the field is accompanied with some misapplication. The severity of this misapplication depends on the down-the-row delivery characteristics of the metering system and the magnitude of the rate change from cell to cell.

On-the-go rate change tests evaluated the down-the-row performance of an operator controlled metering system when increasing and decreasing wheat seeding rates by 10 and 20 kg/ha steps. The transition time from one cell to another ranged from 3 to 9 s depending upon the magnitude of the application rate change.

The difference between the initial and final seeding rate was based on a simple index. This separation index was based upon the initial and final down-the-row seeding rate distributions. When the separation index was greater than or equal to zero, the difference between the initial and final application rate was considered to be suitable for precision farming. The separation criterion was always satisfied with 20 kg/ha rate changes. For 10 kg/ha rate changes, the separation index was negative in most cases. This indicated that rate changes of 10 kg/ha or less were unlikely to provide detectable rate differences as the metering rate variability exceeded the magnitude of the 10 kg/ha rate change.

INTRODUCTION

Precision farming requires that a machine deliver the correct application rate at each field site. Some machines may require mechanical design changes to incorporate sensors and controllers to provide adequate rate modulation (Robert et al., 1992).

When evaluating grain drills for the ability to apply a uniform rate of seed or fertilizer, the Prairie Agricultural Machinery Institute of Canada (PAMI)

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considers a coefficient of variation (CV) of 15% or less as acceptable variation among row units for grain and fertilizer (PAMI, 1987). Most grain drills have less variability than the criterion. However, seed type, lateral slope, and slope in the direction of travel alters the variability in seeding and fertilizing application rates for many grain drills. The PAMI tests do not provide a down-the-row measure of variability. Bashford (1993) found the down-the-row CV when metering soybeans ranged from 12 to 40%, and from 12 to 20% for wheat using drills with external fluted metering mechanisms. He concluded that these CV values are probably too high to be acceptable for site specific crop management (SSCM).

Metering systems designed to apply uniform application rates must be controlled for spatially variable application. Incremental changes in application rates may not be possible with such applicators (Gaultney, 1989). Metering systems for granular material applicators are designed to apply a constant application rate per area with variable field speed. With SSCM, these metering mechanisms must be revaluated for their ability to deliver varying rates from site to site within a field. Application rate changes must be made on-the-go. Set points defined by a control map must be achieved quickly (Schueller, 1992). A transition phase accompanies the change from one application rate to another.

There is a transition time when changing the application rate while a machine is traveling across a field. For this time duration, a varying application rate occurs during the rate transition. Ollilia et al. (1990) used a Field Grid Sense system to spatially control field inputs for specific site requirements. With this system, 49.4 seconds were required to adjust to a new application rate. At a field speed of 8 km/h, the applicator traveled about 110 meters before attaining the new rate. Schueller (1991) reported that one spatially-variable dry fertilizer applicator had a transition time of 4 seconds. At 8 km/h, the machine traveled 8.9 meters before the new rate was achieved.

The effect of this transition on the application rate was addressed in this study for a conventional grain drill modified for on-the-go variable rate application. Specifically, the down-the-row and among metering unit variabilities were determined for a grain drill. Following the variability investigation, seeding rate changes were made, and the transition from an initial to a final rate was determined.

METHODS AND MATERIALS

A grain drill equipped with internal fluted cup metering units was used in the investigation. It was equipped with a roller chain drive from a ground drive to the metering system. An electric motor, rotary actuator, with the speed controlled by a rheostat replaced the ground drive in order to vary the application rate on-the-go. The open loop rotary control system was actuated by the tractor operator. This rotary control system provided seeding rate change increments of 10 or 20 kg/ha (Bahri, 1995). Rheostat positions were matched to rates of 70, 80, 90, 100, 110, and 120 kg/ha.

Two types of tests were conducted. First, the metering variability down-the-row was determined. Winter wheat seed was collected on micro cell mats (Astroturf door mats) 0.48 m long (Bahri, 1995). The drill was operated on a paved parking lot over a length of 60 micro cells at a speed of about 6 km/h.

Second, the ability of the drill metering and variable rate control system to deliver variable seeding rates was evaluated over the same mats for a distance of about 30 m. Wheat seeds delivered from three metering units were collected on the line of micro cells. Before passing over the micro cells, the drill was operated to reach steady state operation. This rate continued to be delivered over the micro cells for a distance of 10 m. At this point the operator changed the application rate, and the transition from the initial to the final rate was determined (Bahri, 1995).

Because variability occurs in both the initial and final delivery rates, the concept of Separation (S) was used to describe the overlap or coincidence of the two distributions of the rates. Separation serves as a simple criterion to identify an acceptable difference in two rates for SSCM.

Separation is the difference between the final rate at minus one standard deviation and plus one standard deviation for the initial rate for an increasing rate change, Fig. 1. For example, when S = 0, as illustrated in Figure 1, 84% of the final rate distribution (lightly shaded area) overlaps only 16% of the initial rate distribution (dark shaded area).

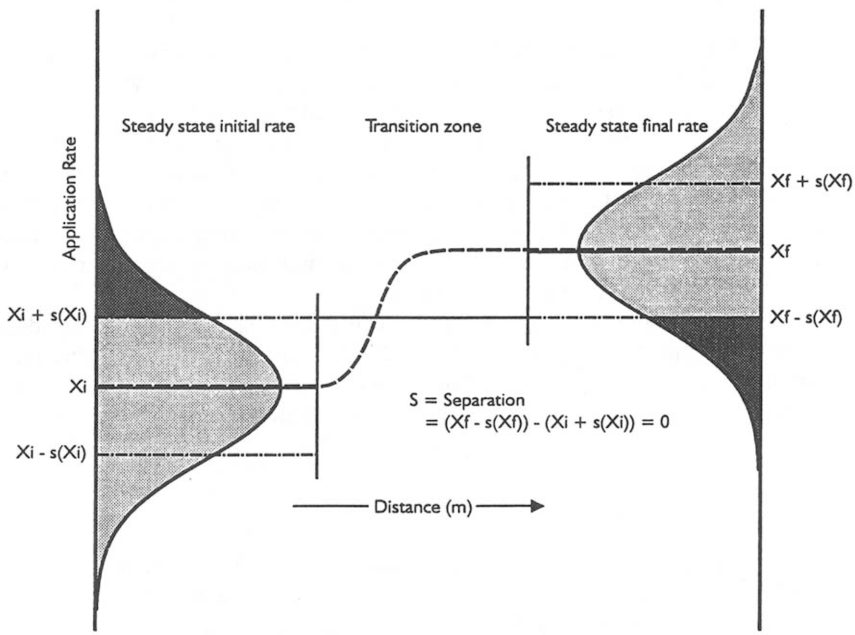

Figure 1. A graphical representation of the separation of an initial and a final seeding rate. Depicted is the situation where S = 0.

Separation for a rate increase is:

$$S = [X_f - s(X_f)] - [X_i + s(X_i)]$$

For a rate decrease,

$$S = [X_i - s(X_i)] - [X_f + s(X_f)]$$

where:

X_i = The mean of the initial steady state rate
X_f = the mean of the final steady state rate
$s(X_i)$ = the standard deviation of X_i
$s(X_f)$ = the standard deviation of X_f

RESULTS AND DISCUSSION

Metering Uniformity

Typical down-the-row and among metering units seeding variability is illustrated in Table 1 for an 80 kg/ha wheat seeding rate. The data were collected on 0.48 m long micro cells. When combining all data, the 6 metering units over the 8 micro cells for a distance of 3.84 m, the mean seeding rate was 81.53 kg/ha with a CV of 2.56 % among the metering units. Considering individual micro cells, the highest rate was 104.52 kg/ha and the lowest was 58.53 kg/ha, a considerable difference for precision farming. Down-the-row CVs for the 6 metering units considered ranged from 10.4 to 18.5 %. Down-the-row variability for other seeding rates were similar and are given in Table 2.

When among metering unit variability was based upon data from individual micro cells, the CV ranged from 7.3 to 21.3 % for the 80 kg/ha seeding rate. Similar among metering unit variability was observed for the other seeding rates, Table 3. It can be noted that the CVs appear to decrease as the seeding rate increases.

Rate Changes

The seeding rate profile, Figure 2, was typical for a 10 kg/ha rate increase. Each data point represents the combined seeding rate from 3 metering units collected on a 0.48 m long micro cell. The distance traveled before the new rate was attained ranged from 8 to 15 m at a 6 km/h travel speed (Bahri, 1995). The corresponding response time was 4.8 to 9.0 s.

At the 20 kg/ha rate change, the response time was faster. The average travel distance before reaching the new rate was 5 m (Bahri, 1995). Further, it was more difficult with the control system used to make the 10 kg/ha increment changes than the 20 kg/ha changes.

Table 1. Seeding rate for a nominal 80 kg/ha setting

	Meter						Among metering units		
Cell	1	2	4	4	5	6	Mean	SD	CV
	kg/ha								%
1	79.4	92.0	96.2	87.8	96.2	96.2	91.3	6.7	7.3
2	100.3	75.3	92.0	66.9	75.3	79.4	81.5	12.3	15.1
3	83.6	83.6	87.8	83.6	67.0	71.1	79.4	8.4	10.5
4	71.1	75.3	83.6	71.1	92.0	96.2	81.5	10.8	13.3
5	96.2	75.3	71.1	66.9	104.5	62.7	79.4	16.9	21.3
6	62.7	96.2	71.1	96.2	62.7	92.0	80.1	16.4	20.5
7	83.6	75.3	92.0	58.5	79.4	71.1	76.7	11.4	14.9
8	75.3	87.8	79.4	92.0	71.1	87.8	82.2	8.2	10.0
Down the row									
Mean kg/ha	81.5	82.6	84.2	77.9	81.0	82.1	81.5	2.1	2.6
SD kg/ha	12.4	8.7	9.6	13.8	15.0	12.8			
CV %	15.3	10.4	11.4	17.7	18.5	15.6			

Table 2. Down-the-row variability

	Coefficient of Variation, %	
Seeding Rate, kg/ha	lowest	highest
70	12.3	18.5
80	10.4	18.5
90	11.1	18.9
100	10.7	17.5
110	8.2	12.8
120	10.5	12.2

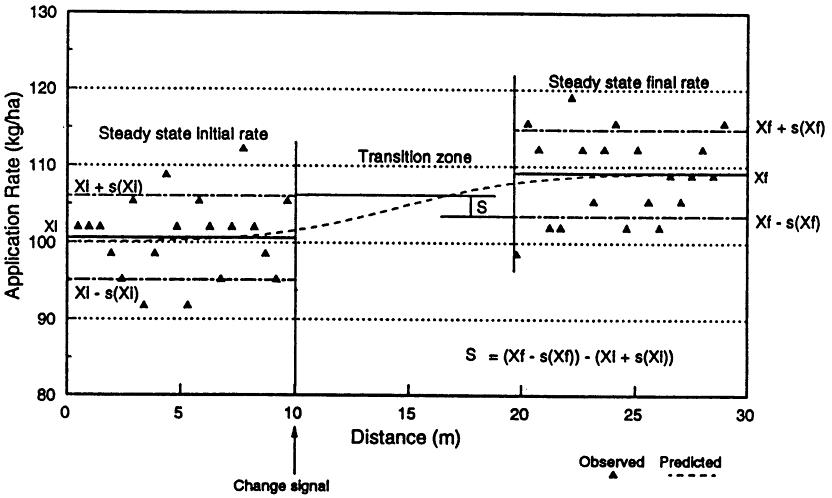

Figure 2. Rate overlap with a rate increase from 100 to 110 kg/ha, S = -3.06

Table 3. Variability Among Metering Units

Seeding Rate kg/ha	Coefficient of Variation, %: 0.48 m Micro cell length, lowest	0.48 m Micro cell length, highest	3.84 m distance, composite
70	9.2	19.4	3.51
80	7.3	21.3	2.56
90	7.4	21.0	4.57
100	9.3	21.7	3.98
110	4.5	15.1	2.48
120	4.8	13.3	1.32

Table 4. Separation of initial and final rate distributions

Separation, S	Final and Initial Rate Overlap
kg/ha	% final ∩ % initial
10	84% ∩ 0
5	84% ∩ 2
0	84% ∩ 16
-5	84% ∩ 50
-10	84% ∩ 84

Separation

The single value separation index is a simple measure of the difference between an initial and a final rate. Both the rate difference and rate variability are considered. Separation measures the non-coincidence (lack of overlap) in the initial and final seeding rates for an on-the-go rate change. Consider an example situation where the standard deviation of both distributions is 5 kg/ha. When $S = 0$, the rate difference was considered a true rate difference for SSCM, and is illustrated in Figure 1. Table 4 illustrates the coincidence for several values of separation.

A typical 10 kg/ha rate change is illustrated in Figure 2. The separation index was -3.06, indicating considerable overlap in the distribution of the initial and final rate. In general, separation values for the 20 kg/ha rate change were greater than those for the 10 kg/ha changes, Table 5. For good variable rate adjustment for SSCM, an incremental change greater than 10 kg/ha is indicated for the rotary actuated metering system. The separation width ($S \geq 0$) was always satisfied with 20 kg/ha rate changes. For the 10 kg/ha rate change, S was negative in most cases, thus, indicating that 10 kg/ha rate changes did not provide a real rate change.

CONCLUSIONS

In general when considering seeding rates on a micro cell basis (0.48 in length), seeding rates were quite variable with the internal fluted metering mechanism investigated. The down-the-row CVs ranged from 10 to 19 %. This variability makes it difficult to discern a small rate difference when adjusting rates on-the-go in SSCM.

The open loop rotary control system for variable rate adjustment would provide initial to final seed application rate differences for incremental changes greater than 10 kg/ha. A separation index based upon the standard deviations of the initial and final seeding rates provided a quantifiable measure of the difference between the rates. When 10 kg/ha rate changes were made, the separation index was small and negative in four of seven tests.

Table 5. Separation (S) for indicated seeding rate changes

Rate change	X_i	s (X_i)	X_f	s (X_f)	S
			kg/ha		
70 to 80	69.17	4.02	80.73	3.80	3.74
90 to 100	85.49	5.65	96.36	7.42	-2.20
100 to 110	97.89	5.69	111.15	8.26	-0.69
100 to 110	100.97	5.32	108.77	5.73	-3.06
80 to 70	81.24	6.88	68.49	4.71	1.16
100 to 90	101.46	6.64	90.24	5.67	-1.06
110 to 100	110.03	5.20	100.44	3.90	0.49
70 to 90	70.19	4.45	90.75	6.25	9.86
80 to 100	82.09	4.71	98.74	5.99	5.95
80 to 100	82.60	4.69	97.55	8.48	1.78
100 to 120	100.95	6.72	122.20	10.89	3.64
90 to 70	89.73	4.60	69.51	3.02	12.60
100 to 80	100.95	5.74	82.77	7.17	5.27
120 to 100	119.14	5.88	103.33	7.43	2.50

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