Seeding Depth Regulation Controlled by Independent Furrow Openers
for Zero Tillage Systems

— Part 2: Control System of Independent Furrow Openers —

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Abstract

Incorrect seeding depth causes poor seed germination, low seedling emergence and poor crop yields. To address this, a control system employing a unique method of regulating seeding depth via an independent furrow opener was designed and built. This study evaluates the performance of this system. Actual soybean seeding showed significant differences in seeding depth between the controlled and uncontrolled rows in the zero tillage treatments and conventional tillage treatments where the plow and rotary tiller were used. The control system effectively placed seeds at the correct depth and seedling emergence was positively improved.

[Keywords] control systems, precision farming, furrow opener, sensors, tillage, seedling emergence

I Introduction

The main purpose of seeding is to place the seeds at a certain distance and depth in the seedbed (Karayel et al., 2004). The operator must not seed too shallow to avoid predation and seed drying, and not too deep to avoid seeds from consuming their stored nutrients before they reach the soil surface during germination (Ozmerzi et al., 2002). Correct seeding depth plays a crucial role in increasing the success rates on seedling emergence, stand count, and crop yields.

Several studies (Siemens et al., 2007; Bowers et al., 2006; Tasaka et al., 2004; Tessier et al., 1997) have been conducted in controlling seeding depth. Most of these studies control seeding depth by adjusting the position of the gauge wheels of the seeder or by elevating the implement frame. They are mostly tested on conventional tillage (CT) fields where soils are soft and with smooth soil profiles. However, with zero tillage (ZT) fields, achieving correct seeding depth becomes a challenge. The soils are hard to penetrate, the soil profiles are rough and the moisture content varies within the field. Moreover, modifying a Japanese seeder for precise zero tillage seeding on Andosols (high clay content soils) posed a great technical challenge.

As discussed in Part 1 of this study, the first control system had high hydraulic power requirements, poor response times due to the weight of the whole seeder unit, and required enhancements to properly perform. A new hydraulics-based control system that directly adjusts the depth of an isolated furrow opener based on the current soil profile to regulate the seeding depth is presented in this study. The furrow opener was selected in the first part of this study (Burce et al., 2012a).

The objectives of this study are to develop a prototype of the new control system and to evaluate its seeding performance based on seeding depth and seedling emergence.

II Materials and Methods

1. Prototypical control system

A tractor propelled Japanese seeder (Tabata TJEV-4LR), commonly used for conventional tillage seeding, was the seeder selected for testing (Fig. 1). It has four independent seeder units equipped for dual-band seeding and fertilization. Fig. 2 (a) shows the original setup of the seeder unit with the fertilizer unit and some parts omitted.

The seeder unit ❶ is attached to the mainframe ❷ via its arm link system ❸. The mainframe maintains a relative fixed height from the ground via two gauge wheels ❹. The metering system ❺ dispenses the seeds ❻ at the target seeding depth (zacted). The target seeding depth is strongly

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influenced by the working depth of the disc furrow opener attached to the metering system. The front presswheel \( \theta \) and rear presswheel \( \theta \) follows the soil profile to maintain uniform seeding depth as the tractor moves forward. The adjustment lever \( \theta \) lowers and raises the furrow opener via the presswheels to set manually the target seeding depth.

The first control system (Burce et al., 2012b) automatically lowered and raised the whole seeder unit. The seeding performance of the control system was penalized by the weight of the seeder unit that resulted to poor response time and high hydraulic power requirements. To address the problem, the furrow opener attached to the metering system was detached and directly controlled by the control system. This is shown in Fig. 2 (b). The hydraulic load could be decreased with only the furrow opener to control, thus allowing multiple seeder units to be controlled and increasing the cylinder response time.

The tested seeder was then modified and installed with a double acting hydraulic cylinder (Ace System AS0404, 145 mm stroke) held by a cylinder frame. The cylinder frame was attached to the mainframe of the seeder to position the cylinder above the independent furrow opener. A linear rail guide (Misumi SX2WTLZ42-440 and SRZL42-440) stabilized the vertical movement of the furrow opener.

The cylinder lowered and raised the furrow opener based on the current soil profile monitored by a look-ahead soil profile sensor (Keyence UD320, 1 mm resolution) and an amplifier (Keyence UD300). The soil profile sensor was attached on the mainframe, in front of the seeder unit, and in-line to where the seeds are dropped. The soil profile sensor measured the relative distance (height) from the sensor head to the surface of the soil profile. An electro-hydraulic valve (Ace System TSB-2339) acted as a bi-directional switch that controlled the flow of the hydraulic fluids from the tractor auxiliary port to the cylinder and vice versa. A stroke sensor (Ace System AS0801, 145 mm stroke) measured the linear displacement of the cylinder stroke. Fig. 3 shows the developed control system.

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**Fig. 1** Tested Japanese seeder

![Fig. 1 Tested Japanese seeder](image1)

**Fig. 2** Modification with new control system

![Fig. 2 Modification with new control system](image2)

**Fig. 3** Major components of new control system

![Fig. 3 Major components of new control system](image3)
The amplifier for the soil profile sensor, the stroke sensor, and the driver circuit for the electro-hydraulic valve were connected to a personal computer (PC) (IBM ThinkPad T43, 1.7 GHz) via an A/D IO card interface (Interface CBI-320312) and an IO terminal block (Contec EDP-50A). The PC executed the developed software control program (Microsoft Visual Studio C#.Net) that computes for the target seeding depth based on the differential readings of the soil profile sensor every 100 ms.

The difference in the present and previous readings of the soil profile sensor determined if there was an observed change in the soil profile. Based on the magnitude and the sign of the difference, the control program generated the appropriate control signals to the valve to either lower or raise the target position of the cylinder stroke. The adjustment of the cylinder stroke translates to the adjustment of the actual seeding depth via the depth of the furrow opener.

The control signals to the valve were pulse-width modulated to achieve the equivalent movements of the cylinder stroke in either up or down direction. A simple time lag function was introduced in generating the control signals to the valve to compensate for the look-ahead distance of the soil profile sensor and the actual drop-off point of the seeds.

2. Performance of control system

After a prototypical control system was installed on one of the seeder units, the performance of the system in placing the seeds at the correct seeding depth was evaluated by a number of tests. First, the cylinder stroke sensor and the soil profile sensor were calibrated to determine the relationship between the sensor readings and the sensor voltage output. Ten voltage outputs (between 0-5 V) from each sensor were measured over the full range of each sensor reading: 0-145 mm for cylinder stroke, and 300-1200 mm for soil profile sensor. Second, the force and the speed of the cylinder were calculated based on the piston (35 mm) and rod (20 mm) diameter of the cylinder and the input flow rate (18.6 L/min) and pressure (16.7 MPa at 1500 rpm) of the hydraulic fluid. Third, examination of the time delay, resolution, and settling time of the cylinder stroke with the attached furrow opener load was done. The cylinder stroke was extended and retracted to its maximum and minimum stroke range at an engine speed of 900 rpm while a data logger (Keyence NR600) measured the readings during the test.

An indoor soil bin test was also conducted for comparing the seeding performance of the original configuration of the seeder unit to the developed control system. The original configuration was based on the manufacturer’s recommended specifications for the seeder unit with the disc furrow opener. The developed control system modified the configuration of the seeder unit installed with the seeding depth control system and the hoe furrow opener. The hoe furrow opener is required by the developed control system as discussed in Part 1 of the study.

Different soil profile undulations were created along a 3 × 20 m test area of the soil bin. Before the simulated seeding test, the rear presswheels of the seeder units were replaced, and positioned at the sides of each seeder units to ensure that the furrow shapes were not disturbed. A laser scanner (Sick LMS290) mounted on the front of a trailing car scanned the soil profile before and after the test shown in Fig. 4. The laser scanner readings were then converted to generate the cross-sectional images of the furrows. There were three sampling locations (labeled locA, locB, and locC) along the seeding row for each of the furrow opener where the cross-sections were taken. Ten cross-sectional samples of the furrow were gathered at each sampling location. Sampling location locA are ridges while locB and locC are furrows.

The sampled cross-sections were then grouped with a common base point for the comparison of the furrow depth, which represents the actual seeding depth. The lowest point of the furrow depth of each furrow cross-section was adjusted to have a common base point using a translation function. The depth of each furrow was then measured and an analysis of variance (ANOVA) with Tukey post-hoc test was conducted to compare the consistency of the furrow depths between the sampling locations.

3. Performance of seeding depth

Actual cultivation of sugar beet (Beta vulgaris L., Kachimaru) and soybean (Glycine max L., Tasty) under zero tillage (ZT) and conventional tillage (CT) were conducted using the control system at the Experiment Farm of Field Science Center for Northern Biosphere (43° 4’ N, 141° 20’ E) in Hokkaido University, Japan. The farm soil was a silt clay loam (silt 50.5 %, clay 28.9 %, and sand 19.7 %) based on International Soil Science Society (ISSS) standards.

The test field was 160×3 m in dimension for each crop. The...
field was equally divided into two plots for two tillage treatments: 80 m of zero tillage, and 80 m of conventional tillage as shown in Fig. 5. The two tillage treatments were applied to determine how the control system performed on both soft and hard soils. In this study, conventional tillage employed a single-pass moldboard plowing and two-passes of rotary tilling, while zero tillage applied no plowing and no rotary tilling. The plots were further subdivided into two equal subplots at 40 m each. The control system was tested on each subplot.

A cone penetrometer with a 30° cone angle and a 16 mm base diameter measured the cone index value of the soil resistance at every 50 mm depth level for each plot and there were five samples per plot. A 3-phase sensor measured the soil moisture content taken from three depth levels (0-50 mm, 50-100 mm and 100-150 mm) with three samples per depth level for each of the tillage treatment. The average amount of plant residues in the tested field was 229 g/m². The actual working speed was lower than the target working speed with an average of 0.3 m/s. The mean cone index value in the conventional tillage plots was 0.3 MPa while on the zero tillage plots was 1.3 MPa. Soil moisture content at 0-150 mm depth level on the zero tillage plots was 33.6 % d.b. and 26.2 % d.b. on the conventional tillage plot. Table 1 shows the summary of the settings during seeding.

For the entire cultivation period, all efforts had been applied to ensure that all the plots on both crops received the same crop management handling (fertilization, irrigation, weeding, pesticides, etc.) to limit the variation between the controlled and uncontrolled rows. Statistical treatments using t-test and ANOVA were calculated using a significance level of \( \alpha = 0.05 \). Hence, a \( p \)-value that was less than 0.05 meant that the difference was significant. The mean, standard deviation (SD), and degrees of freedom (df) were used to calculate the \( t \)-statistic (\( t \)-stat) and \( t \)-critical values (\( t \)-crit), as well as the \( F \)-statistic (\( F \)-stat) for a given number of samples.

For the cylinder stroke calibration, the linear relationship of the sensor output voltage \((y)\) against the length of the cylinder stroke \((x)\) was expressed as \( y = -29.66x + 147.75 \), with a coefficient of determination of \( R^2 = 0.9978 \). The control system utilized the equation to determine the exact position or length of the cylinder stroke. The length of the cylinder stroke corresponds to the current seeding depth.

For the soil profile sensor calibration, the linear relationship of the sensor output voltage \((x)\) against the relative distance to the soil surface of the soil profile sensor \((y)\) was expressed as \( y = 310.38x - 72.22 \) with \( R^2 = 0.9999 \). The control system applied the equation to determine the measured distance from the sensor head to the surface of the soil. The calculated push force (lower furrow opener) and pull force (raise furrow opener) of the cylinder was 16 kN and 10.3 kN, respectively, with a push speed of 208 mm/s and a pull speed of 309 mm/s. The resolution of the cylinder stroke was 15 mm. The time delay was 0.18 s for stroke retraction.

### Table 1 Seeding specification

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Soybean</th>
<th>Sugar Beet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Target tractor working speed</td>
<td>0.5 m/s</td>
<td>0.5 m/s</td>
</tr>
<tr>
<td>Seeder vacuum pressure</td>
<td>8 kPa</td>
<td>10 kPa</td>
</tr>
<tr>
<td>Target seeding depth</td>
<td>50 mm</td>
<td>30 mm</td>
</tr>
<tr>
<td>No. of seeds per spacing</td>
<td>2 seeds</td>
<td>1 seed</td>
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<tr>
<td>Target seed spacing</td>
<td>170 mm</td>
<td>150 mm</td>
</tr>
<tr>
<td>Row spacing</td>
<td>750 mm</td>
<td>750 mm</td>
</tr>
</tbody>
</table>

### III Results and Discussion

#### 1. Performance of control system

For the cylinder stroke calibration, the linear relationship of the sensor output voltage \((x)\) against the length of the cylinder stroke \((y)\) was expressed as \( y = -29.66x + 147.75 \), with a coefficient of determination of \( R^2 = 0.9978 \). The control system utilized the equation to determine the exact position or length of the cylinder stroke. The length of the cylinder stroke corresponds to the current seeding depth.

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and 0.24 s for stroke extension.

Fig. 6 shows the relationship of the cylinder retraction and extension at 900 rpm engine speed. Based on the slope of the regression line for the cylinder retraction (red line) and extension (blue line), the amount of time required for a 15 mm stroke adjustment was 0.14 s for retraction and 0.12 s for extension. Therefore making the total settling time 0.32 s for retraction and 0.36 s for extension. The performance of the control system was found to be sufficient for the application in actual seeding.

An example for the result of the base point translation of the furrow cross-sections for the disc furrow opener in the uncontrolled row is shown in Fig. 7. The figure shows the sampled cross-sections of the furrows taken from one of the sampling location. Compared to the furrow reference shape, each sampled cross-section differed in terms of furrow depth and furrow width. To compare each sampled cross-section, the maximum depth of each furrow shape (which corresponds to the actual seeding depth) served as the base point for the comparison of the furrow depth. Table 2 shows that the results for the comparison of the furrow depth means in locations locA, locB, and locC of the uncontrolled row showed significant differences ($p$-value $< 0.05$, $F$-stat $= 10.49$, $R^2 = 0.44$, $df = 2$) by ANOVA test. The furrow depths were shallow and the furrow shapes were inconsistent. The Tukey post-hoc test revealed a significant variation in furrow depth found between location locA x locC with mean difference of 9.0 mm and between location locB x locC with a mean difference of 9.8 mm. The result suggests that the uncontrolled row with the disc furrow opener had an inconsistent furrow depth along the seeding row. This was due to the passive control method of regulating the seeding depth by the original setup of the tested seeder where soil penetration was not effective.

In contrast, the results of the controlled row shows no significant difference ($p$-value $= 0.08$, $F$-stat $= 2.76$, $R^2 = 0.170$, $df = 2$) in the furrow depths for all three sampling locations along the seeding row using ANOVA as shown in Fig. 8. The results suggest that the controlled row was consistent in maintaining the target seeding depth (5 mm max. difference) along the sampled locations of the seeding row. According to the results of Part 1 of this study, the factor of controlling the seeding depth is more effective than the type of opener because of the added downward force exerted by the control system on the furrow opener for improved soil penetration consistent with the soil profile. If the furrow opener’s original configuration was altered without the addition of the control system, the control of the seeding depth was not effective. Thus, this test confirms that the newly developed control system with an active control for the seeding depth regulation has the capability of correctly placing the seeds at the desired seeding depth.

![Fig. 6 Calibration of cylinder stroke](image)

![Fig. 7 Cross-sections of furrows on uncontrolled row](image)

![Fig. 8 Cross-sections of furrow on controlled row](image)

<table>
<thead>
<tr>
<th>Table 2</th>
<th>Furrow depth comparison in sampling locations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Furrow type</td>
<td>Location</td>
</tr>
<tr>
<td>uncontrolled</td>
<td>locA</td>
</tr>
<tr>
<td></td>
<td>locB</td>
</tr>
<tr>
<td></td>
<td>locC</td>
</tr>
<tr>
<td>controlled</td>
<td>locA</td>
</tr>
<tr>
<td></td>
<td>locB</td>
</tr>
<tr>
<td></td>
<td>locC</td>
</tr>
</tbody>
</table>

Means within a group followed by the same letter are not significantly different at $\alpha = 0.05$ by Tukey multiple comparison test, SD = standard deviation, $n$ = number of sampled cross-sections.

2. Performance of seeding depth

Actual seeding test of the control system was also conducted in the field. The results for the seeding
The calibration of the target depth was achieved by the controlled row (UCR). The mean emergence count was consistent along the center of the tested seeder. With the control system installed, the seeds were placed closer to the target seeding depth. The result for the soybean and seedling emergence is shown in Table 3. The seeding depths of the controlled rows (CCR) were closer to the target seeding depth of 50 mm as compared to the uncontrolled row (UCR). The t-stat values were bigger than the t-crit values, which imply that the null hypothesis (equal seeding depths) must be rejected, and the alternative hypothesis (significant difference in seeding depths between controlled and uncontrolled row) must be accepted.

In summary, the application of the control system for seeding depth regulation affected the seeding performance of the tested seeder. With the control system installed, the seeds were placed closer to the target seeding depth as compared to having no control system installed.

3. Performance of seeding emergence

The result for the soybean and seedling emergence is shown in Table 4. The number of soybean seedling emergence on the conventional tillage treatment was much lower than the zero tillage treatments. This was due to the differences in the sizes of the aggregates in the conventional tillage treatment (30-50 mm diameter) as compared to the zero tillage treatment (20-20 mm diameter). The mean difference of the count in seedling emergence between the controlled and uncontrolled rows was not significantly different (p-value > 0.05, t-stat = 0.051) for the conventional tillage treatment. However, for the zero tillage treatment, the mean difference in the count of emergence between the controlled and uncontrolled rows was significantly different at about 108 seedlings (p-value < 0.01, t-stat = 4.118). Overall, the application of the control system accounted for 18.25% of the variation in seedling emergence with a p-value of 0.0381.

Fig. 9 shows the result for the seedling emergence of sugar beet. The symbol “r” above the bars represent the standard error of the mean. The mean difference in seedling emergence between the controlled and uncontrolled row in the zero tillage treatment was about 40 seedlings and was found to be significantly different (p-value < 0.001, t-stat = 5.967).

![Fig. 9 Sugar beet seedling emergence comparison](image)

Table 4 Performance of seedling emergence

<table>
<thead>
<tr>
<th></th>
<th>UCR</th>
<th>CCR</th>
<th>Difference</th>
<th>95% CI of diff.</th>
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<tr>
<td>soybean CT</td>
<td>112.00</td>
<td>107.70</td>
<td>25.24 to 190.10</td>
<td></td>
</tr>
<tr>
<td>sugar beet CT</td>
<td>20.00</td>
<td>60.33</td>
<td>-81.10 to 83.76</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>

For the conventional tillage treatment, the difference was insignificant (p-value > 0.05, t-stat = 1.036). Overall, the effect of applying the control system accounted for 56.34% of the variation in seedling emergence with a p-value less than 0.001. In both crops, the results suggest that the control system had an effect in the number of seedling emergence. When seeds are placed at the optimum seeding depth by the application of the seeding depth control system, it may contribute to higher seedling emergence if environmental factors like aggregate size, soil moisture content, nutrient content, soil temperature, and others are kept at optimum levels.

IV Summary and Conclusions

The objective of this study was to develop the prototype for the new control system and to evaluate its seeding performance based on seeding depth and seedling emergence. A prototype of the hydraulics-based control system that regulated seeding depth through the direct manipulation of an independent hoe furrow opener was developed. The seeding depth was automatically adjusted based on the soil profile. The results of the performance evaluation showed that the control system maintained a consistent seeding depth along the seeding row (p-value = 0.08, F-stat = 2.76, R² = 0.170, df = 2) during the preliminary tests. Actual seeding of soybean
also showed significant differences in seeding depth between the controlled and uncontrolled row in the zero tillage treatments \[ t\text{-stat}(0.05) = 8.033, \text{ df} = 139 \] and the conventional tillage treatments \[ t\text{-stat}(0.05) = 17.720, \text{ df} = 132 \]. For both crops, the control system accounted for 18.25\% of sugar beet and 56.34\% of soybean, of the total variation in seedling emergence in the controlled row that were both found to be significant. In conclusion, seeding depth regulation through the direct control of the depth of the furrow opener implemented by the developed control system effectively placed the seeds at the correct seeding depth with positive improvements on seedling emergence.

References


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