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SEED-SPECIFIC CHEMICAL APPLICATION SYSTEM: FIELD TESTING AND IMPROVEMENTS

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Abstract

Agricultural engineers at The University of Tennessee have developed a seed-specific chemical delivery system that applies discrete bands of liquid chemical to individual seeds at planting. This system allows farmers to minimize the amount of in-furrow chemical applied between seeds, thus generating cost savings and more efficient production. During 2003, improvements were incorporated into the system, and an updated prototype was field tested. Tests were conducted to evaluate applicator performance in terms of numbers of seeds covered with spray material. Tests included three ground speeds (3.0, 4.5, and 6.0 mph), four spray band lengths (1.5, 2.0, 2.5, and 3.0 in.), and two seed types (cotton and corn). While planting at 3.0 and 4.5 mph, over 84% of seeds were covered using band lengths of at least 2.0 in. Accuracy was reduced, however, when planting at 6.0 mph, with only about 75% of seeds being covered by 2.0-in. bands at that speed. Field observations suggested that seeds often bounce forward in the furrow when the planter is operated at 6.0 mph, so the control system was modified to compensate. An additional test was conducted to allow evaluation of the design change. Substantial performance improvement was demonstrated at 6.0 mph, with at least 85% of corn and cotton seeds covered by 2.0-in. bands. In addition to system performance tests, a two-year field study designed to evaluate the effectiveness seed-specific fungicide application in cotton was completed in 2003. This test included in-furrow treatment with Terraclor Super X 2.5 EC, which was applied both conventionally and seed-specifically. Seed-specific application reduced overall application amounts by about 50%. Plots were inoculated with *Pythium spp.* and *Rhizoctonia solani* fungi, and stand counts were used to quantify disease severity. Significant differences ($\alpha = 0.05$) were not detected between stand count means from plots receiving conventional and those receiving seed-specific treatment in either year. Results suggested that fungicide applied between cottonseeds contributed little to seedling disease control in the study.

Introduction

Agricultural chemicals are commonly applied in-furrow with the seed at planting. For example, cotton producers sometimes use in-furrow liquid fungicides to control seedling disease. In-furrow products are generally applied as a continuous band along the length of the furrow. When low seeding rates are used, an appreciable amount of spray material is applied between seeds where its benefit is questionable. Agricultural engineers with The University of Tennessee have developed a seed-specific application system that applies an individual band of in-furrow liquid chemical over each seed, thus minimizing application between seeds. The design of this system, which was described at the 2003 Beltwide Cotton Conferences in Nashville, Tenn. (Hancock et al. 2003), has been modified to improve performance and ease-of-use. Results of field tests conducted with the improved prototype system are contained herein. In addition to performance testing, a two-year study conducted to evaluate the effectiveness of seed-specific fungicide application in cotton concluded in 2003. Results of the fungicide application study are also included below.

Seed-Specific Applicator Design

Hancock (2003) provided a detailed description of the seed-specific applicator. The system is designed for installation on a row-crop planter. It detects each seed between the seed meter and furrow, predicts seed arrival time at the furrow, and applies a discrete volume of chemical spray to the seed and adjacent soil. The system is comprised of the following major subsystems, as illustrated in figure 1: seed detection, controller, and fluid delivery. Each subsystem is described below.

Seed Detection

Seed detection is a key component of the application system. Use of detection in the seed tube ensures that system performance does not solely depend on delivery of uniformly-spaced seeds. The prototype system uses a standard seed sensor, consisting of paired light emitter and detector arrays mounted opposite one another on the seed tube. The sensor is positioned on the tube as designed by the planter manufacturer (fig. 1). Seed detection accuracy is reported to range from 90% to 100%, depending upon seeding rate and ground speed (John Deere Seeding Group, 2002). Sensor output is active-low, with high-to-low edge transitions indicating a seed event.

Controller

Seed sensor output is interfaced with a programmable microcontroller unit (MCU)-based application control system. The MCU uses an algorithm to predict seed arrival time at the chemical application point. Arrival prediction is based on average seed travel time between the seed sensor and point of chemical application, as determined during system setup. At each predicted arrival time, the MCU outputs an actuation signal to the fluid delivery system. Actuation pulse-width corresponds with time required to produce the desired spray band length along the furrow.

Seed sensor placement complicated control system design. With the sensor and valve positioned as shown in figure 1, average seed travel times between the sensor and application point ranged from 99 to 127 ms in field experiments conducted with corn and cotton. At a representative seeding rate of 65,000 seed ac^{-1} planted at 6.0 mph on 40-in. rows, each seed tube delivers 44 seeds per second. At that seed delivery rate, at least four seeds are always in transit between the seed sensor and application point. Since time between seeds is less than seed travel time between the points of interest, a single input/single output delay timer can not be used to control valve actuation. Instead, use of an MCU allows simultaneous processing of multiple seed-arrival times.

Fluid Delivery

The fluid delivery system is designed to apply individual chemical bands in response to controller-generated actuation signals. Fluid delivery system components included a high-speed electromechanical valve, a valve driver circuit, and a nozzle. A high-volume fuel injector is used for fluid pulse generation. This device has a cycle time of less than 5 ms and will allow flow rates of up to 0.23 gpm. The fuel injector is mounted at the seed tube outlet, as shown in figure 2. Valve-driver circuitry electrically isolates the valve from the controller and controls current through the valve to minimizes response time requirements. Driver components included an optoisolator, a power transistor, and a peak-and-hold integrated circuit. A 5005 FlatJet nozzle (Spraying Systems Co., Wheaton, Ill.) is integrated with the valve body, and it distributes chemical spray across the furrow width.

System Modification

The original prototype, tested in 2002, was designed to be installed on a planter, and then operated in setup mode until system settings could be determined. During setup, the planter closing device was disabled, and the furrow was left open to allow the operator to observe seeds and corresponding spray bands. The delay setting was adjusted until an optimum value was achieved and the number of seeds adequately covered with chemical was maximized. This manual setup procedure was difficult and time-consuming, so an alternative solution was investigated.

To simplify calibration and automate delay time determination, a function was developed that relates delay time to planter speed, desired spray band length, valve installation geometry, and variables influenced by seed type and seed tube geometry (fig. 2). Delay time was subdivided into two periods. The first ($period_1$) consists of seed travel time between the seed sensor and seed tube outlet, while the second ($period_2$) consists of seed travel time between the seed tube outlet and chemical application point. $Period_1$ is assumed constant for a particular seed tube and seed type combination. Its value is determined through measurement using a stationary planter and seed meter operated at the rotational speed to be used in the field. In order to make this measurement, a second sensor is positioned at the seed tube outlet, and time elapsed between upper and lower seed sensor pulses is calculated. An expression for $period_2$ was developed using kinematic analysis (Hancock, 2003). This expression includes the values labeled in figure 2.

Two assumptions made to simplify expression development were instantaneous valve response and instantaneous fluid delivery. An additional term, c, was added to the delay time function to correct for these assumptions. The value of c is specific to a particular valve and can be determined empirically by analyzing error between equation-predicted and known delay times for an existing data set. For the valve used in system testing, magnitude of the empirical adjustment factor, c, is -1.0 ms, while overall predicted delay times range from 99 to 127 ms.

Field Testing

Field evaluation of the seed-specific application system during 2003 focused on accuracy of spray band placement. The system was evaluated over a range of planting conditions to investigate possible effects of seed type, planter speed, and spray band length on performance. Testing procedures and results are described below.

Procedures

The valve and nozzle assembly was installed on a John Deere MaxEmerge Plus row-unit. The spray nozzle was located 3.0 in. from the seed tube outlet. Furrow-closing wheels were removed from the row unit so that the furrow remained open to assess spray band placement and seed location in the furrow. Seeds were coated with fluorescent powder to make them easier to locate in the furrow, and the seed-specific applicator sprayed a dye solution. Tests were conducted at the University of Tennessee Milan Experiment Station in a no-till cotton field with light crop residue.

Field tests were designed to assess application system performance under typical planting conditions. Seed type, planting speed, and spray band length were varied in the tests. Corn and cotton were the crops planted in the evaluation at planter speeds of 3.0, 4.5, and 6.0 mph. Spray band lengths of 1.5, 2.0, 2.5, and 3.0 in. were used. Treatment order was randomized, and a 200-ft row was planted for each of the 24 treatments.

The system was set up as described above. Parameters related to valve installation geometry were initially measured and remained constant for all treatments. Seed travel time within the seed tube and seed velocity at the tube outlet were also measured and considered constant for the duration of the tests. Treatment-specific variables, including planter speed and spray band length, changed with each treatment.

Test data were based on simple visual inspection. Each seed located within the first 40 ft of row was classified as a hit or miss. A hit was defined as a seed completely within a sprayed band, with no portion of the seed contacting unsprayed soil. Percent of seeds thus covered was calculated and used as indication of band placement accuracy.

Results

Field test results of spray band placement accuracy are presented in table 1. Performance varied with spray band length, planter speed, and crop. Accuracy increased with spray band length. This was expected since lengthening spray bands increased furrow coverage, thus improving the probability of hitting each seed. As band length doubled from 1.5 to 3.0 in., number of seeds covered with spray increased 12% to 17% in corn and 11% to 35% in cotton. The largest step-wise increase in accuracy was obtained when bands were lengthened from 1.5 to 2.0 in.

Band placement accuracy decreased as planter speed increased. While more than 84% of seeds were covered with 2.0, 2.5, and 3.0-in. bands at 3.0 and 4.5 mph, accuracy was reduced when the planter speed increased to 6.0 mph. Only about 75% of seeds were covered with 2-in. bands at that speed.

Field observations suggested that seeds often bounce forward in the furrow when the planter is operated at 6.0 mph. The control system was modified to shift material bands forward when traveling at that speed, and an additional test was conducted to evaluate the design change. Cotton and corn seeds were planted at a ground speed of 6.0 mph. Dye was applied in 2.0-in. bands, and hits and misses were evaluated for 100 consecutive seeds in the row. In this test, at least 85% of seeds were covered with spray, suggesting substantial improvement.

Seed-Specific Fungicide Application Study

Seed-specific fungicide application was evaluated for effectiveness in combating cotton seedling disease during two growing seasons in Jackson, Tenn. Location varied each year, but experimental parameters remained the same. Cotton variety Delta Pine 451 BGRR treated with imidacloprid (Gaucho®) was planted at a speed of 3.0 mph and rate of 3.0 seeds per row-ft. *Pythium spp.* and *Rhizoctonia solani* were cultured on millet seed and used as inoculum to increase the risk of seedling disease in the tests. Plots were arranged as a randomized complete block design with five blocks. Each plot consisted of two, 30-ft rows planted on 38-in. centers. Within each block, five fungicide treatments (an untreated control, two rates applied conventionally, and two rates applied seed-specifically) were evaluated. Two inoculum treatments (with or without) were also randomly-applied, thus generating a total of 10 treatments per block. Blocks were separated by 20-ft alleys.

Test Locations

In 2002, plots were planted on 18 April into light cotton stubble at a Jackson-area private farm. This location had been cropped in cotton for five consecutive years and had a history of moderate-to-severe seedling disease pressure. Conditions were favorable at planting, with soil temperature measuring 64°F at 2.0-in. depth; however, soil temperature dropped to 54°F a week later. In 2003, plots were planted on 28 April under conventional tillage at a site on the West Tennessee Experiment Station. Soybeans and wheat had been planted at this location for the preceding five years. The soil was moist and cool (57°F at 2.0-in. depth) at planting, but warmed to 70°F the following week. Rainfall was extremely heavy in early May; precipitation for the month totaled 9.8 in., compared to normal May precipitation of 6.0 in. (1971-2000 normal value for Jackson Experiment Station: National Climatic Data Center, Asheville, NC).

Fungicide Treatments

The fungicide used in this study was Terraclor Super X® 2.5EC (TSX), a formulation of pentachloronitrobenzene (PCNB) and etridiazole. Experimental treatments included conventional applications at low (0.75 lb PCNB ac^{-1} + 0.19 lb etridiazole ac^{-1}) and high (1.0 lb PCNB ac^{-1} + 0.25 lb etridiazole ac^{-1}) rates, seed-specific applications at the same rates, and an untreated control.

Conventional treatments were mixed with water and applied as a continuous band using flat-fan nozzles. On each row-unit, the spray nozzle was located between the seed tube outlet and furrow closing device to direct spray into the open furrow, and was oriented to produce a 1-in. wide pattern. Seed-specific treatments were applied in a water solution using the system described above. The applicator was set up to apply a spray band that measured 1 in. wide by 2 in. long (along the furrow) around each seed. The concentration of active ingredient (lb ac^{-1}) within the sprayed bands was identical to that in the conventional treatment of equivalent rate (low or high). However, since seeds were planted at a spacing of 4 in., seed-specific application reduced the overall amount of material applied by approximately 50%.

Data Analysis

Plant stands were counted at approximately three weeks after planting in both years. All viable plants in each plot were counted. Data from each year were analyzed separately, as tillage system and environment varied. Analysis of variance was performed using a mixed model procedure (Littell et al., 1996), and treatment effects were considered significant when $P \leq 0.05$. Means were separated using the Tukey-Kramer method at $\alpha = 0.05$. There was little evidence of seedling disease in the uninoculated plots during either year of the study, so data from those treatments were omitted from the analysis.

2002 Season Results

Emergence was poor in all 2002 plots (table 1). Stand establishment at 21 days after planting (DAP) averaged less than 50% of the seeded rate. Analysis of variance indicated that fungicide treatment had a detectable ($P < 0.001$) effect on cotton stand establishment. Stands averaged less than 0.25 plants per row-ft in the untreated control. Stands were significantly better in plots that received in-furrow fungicide treatments. At 21 DAP, average stands in these plots ranged from 1.25 plants ft^{-1} to 1.52 plants ft^{-1} . There were no significant differences in stand counts between the in-furrow fungicide treatments at 21 DAP, regardless of application rate or method.

2003 Season Results

Early season emergence was much better in 2003 (table 1). Low stand counts in the untreated control plots suggested the presence of seedling disease. Fungicide treatment again had a detectable ($P < 0.001$) effect at 24 DAP. Stand counts in untreated control plots averaged less than 0.60 plants per row-ft, while stands averaged more than 2.0 plants per row-ft in plots that received in-furrow fungicide. Differences between mean stand counts from untreated and treated plots were statistically significant; however, differences in stand count means between the four in-furrow fungicide treatments were not.

Conclusion

A seed-specific application system has been developed to deliver individual pulses of liquid chemical formulations to seeds and surrounding soil at planting. This system has potential to reduce in-furrow chemical inputs significantly by eliminating material applied between seeds and focusing application in a localized zone around each seed. During 2003, the applicator was modified to simplify the setup procedure. The modified prototype was installed on a row-crop planter and configured for field testing. Tests were conducted with both corn and cotton seeds planted at three ground speeds. When a spray band length of at least 2 in. was used, over 84% of seeds were accurately sprayed at 3.0 and 4.5 mph; however, accuracy decreased to 75% when 2-in. bands were used at 6.0 mph. Field observations indicated that seeds tend to bounce forward in the furrow when the planter is operated at 6.0 mph. The applicator was modified to shift spray band placement forward when planting at that speed. This modification resulted in substantially better results, with over 85% of seeds covered during a subsequent test.

A two-year field study conducted to evaluate the effectiveness of seed-specific fungicide application in cotton ended in 2003. During both years, TSX was applied both conventionally and seed-specifically to cotton plots inoculated with *Pythium spp.* and *Rhizoctonia solani* fungi. Stand counts were made at approximately three weeks after planting both years. Fungicide treatment resulted in statistically greater mean stand counts in every case, when compared to the untreated check. No significant differences between conventional and seed-specific treatments were detected.

Seed-specific application of in-furrow chemicals presents important advantages over conventional continuous application. From an economic standpoint, seed-specific application has potential to substantially reduce the amount of in-furrow chemical needed to achieve the desired results. This reduces variable costs, which may increase profitability. In addition to the economic benefit, environmental benefits may also result as overall agrochemical application amounts are reduced.

Additional design refinements are needed before the application system described above will be ready for general application in cotton production. The most important change will involve selection of an alternative electromechanical valve to replace the corrosion-prone fuel injector currently used for fluid delivery. Future work will focus on this task, as well as continued evaluation of the seed-specific chemical application concept.

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Table 1. Accuracy results (% seeds located within a sprayed band) as a function of seed type, planter speed, and spray band length.

Crop	Speed (mph)	Spray Band Length (in.)			
		1.5	**2.0**	**2.5**	**3.0**
Corn	3.0	85.1%	90.4%	94.2%	96.6%
	4.5	80.3	84.0	84.1	93.9
	6.0	63.9	76.4	74.5	81.1
Cotton	3.0	85.7	92.8	98.0	96.4
	4.5	73.5	94.5	92.3	97.7
	6.0	56.1	74.6	90.6	90.8

Table 2. Effect of conventional and seed-specific fungicide treatments on cotton stand establishment in field plots inoculated with *Pythium spp.* and *Rhizoctonia solani*.

Treatment	Rate	Average Plants per ft of Row			
		2002 (21 DAP)		**2003 (24 DAP)**	
None		0.20	b1[z]	0.54	b2
TSX, Conventional	Low[x]	1.47	a1	2.43	a2
TSX, Conventional	High[x]	1.41	a1	2.25	a2
TSX, Seed-Specific	Low[y]	1.25	a1	2.12	a2
TSX, Seed-Specific	High[y]	1.52	a1	2.21	a2

[x] Active ingredient application rates were classified as LOW (0.75 lb PCNB ac^{-1} + 0.19 lb etridiazole ac^{-1}) and HIGH (1.0 lb PCNB ac^{-1} + 0.25 lb etridiazole ac^{-1}).

[y] Active ingredient application rates within sprayed area were identical to the conventional treatments (see note x); however, overall amount applied was reduced by 50% because sprayed area was reduced by half.

[z] Means with the same letter were not significantly different (Tukey-Kramer method, $\alpha = 0.05$).

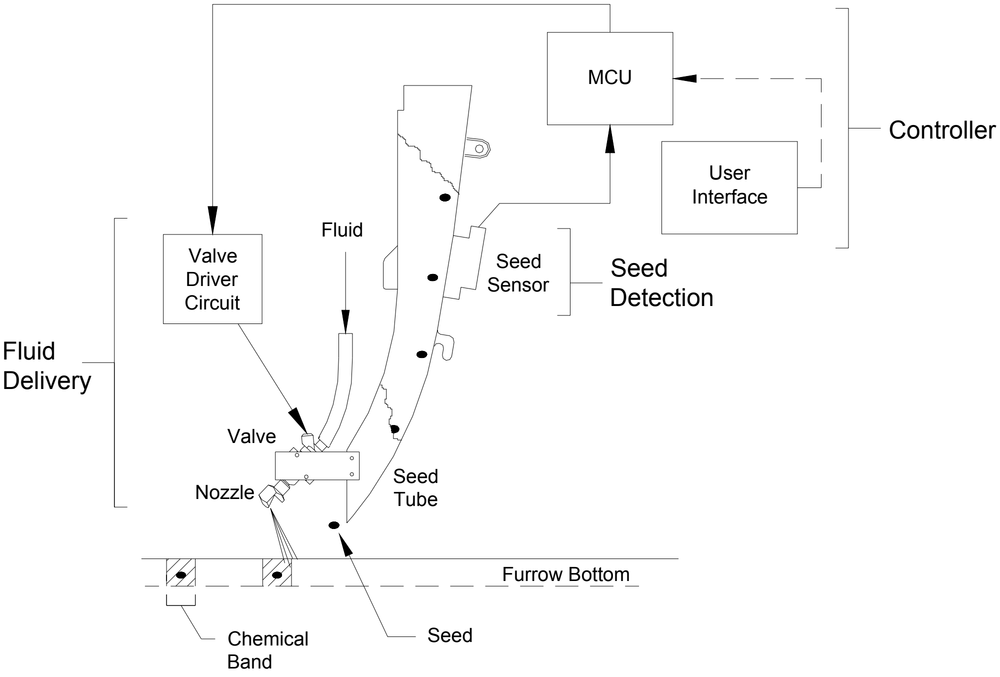

Figure 1. Block diagram of system components.

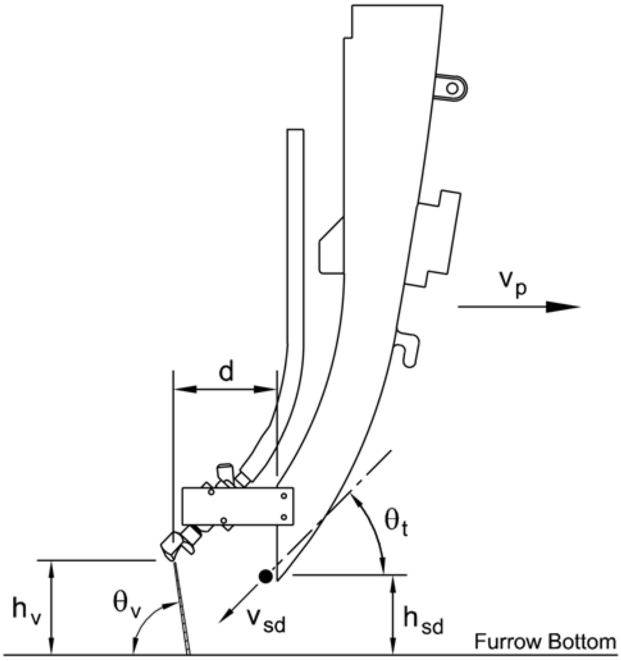

Figure 2. Parameters used in the delay time function.