Site-Specific Application of Fumigants to Minimize Input, Reduce Cost, and Protect the Environment

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Project Leader:
Shrini K. Upadhyaya
Professor
Bio. and Ag. Eng. Dept.
Bainer Hall, University of California Davis
One Shields Ave.
Davis, CA 95616
(530) 752-8770
skupadhyaya@ucdavis.edu

Greg Browne
USDA ARS; Dept. of Plant Pathology
University of California Davis
One Shields Ave.
Davis, CA 95616
(530) 754-9351
gtbrowne@ucdavis.edu

Project Cooperators:
Matt Gillis
Trical Inc.
P.O. Box 1327
Hollister, CA 95024-1327

Interpretive Summary:

The goal of this research was to use recent advances in the global positioning system and computer technology to apply just the right amount of fumigant (0.2 kg/tree) where it is most needed (i.e., in the neighborhood of each tree planting site) to decrease the incidence of replant disease, and achieve the environmental and economical benefits of reducing the application of these toxic chemicals. In this study we have retrofitted a chemical applicator with a high-performance global positioning system receiver (accuracy in the range of 10 to 20 cm) and developed software necessary to accomplish tree-planting-site-specific application of fumigants. The results of accuracy tests indicated that the error in position location depended on vehicle speed and look-ahead value. A look-ahead value of 0.8 s appears to account for the hydraulic system response time. The RMS error was 33.5 cm (13.2 in) when the speed effect was properly accounted for. Although this error is higher than desirable, even at this level of

accuracy the amount of fumigant applied can be reduced by nearly 50% thus realizing significant cost and environmental benefits.

Objectives:

The goal of this research is to use recent advances in the global positioning system and computer technology to apply just the right amount of fumigant (0.2 kg/tree) where it is most needed (i.e., in the neighborhood of each tree planting site) and achieve the environmental and economical benefits of minimizing the application of these toxic chemicals. The specific objectives of this study are:

1. Retrofit a subsoil fumigant applicator with high accuracy fumigant application system to apply fumigant in defined areas centered at tree planting sites.
2. Develop necessary software to create a tree planting map and application zone around each tree so that fumigant applicator can be controlled in real-time to apply just the right amount at the right place.
3. Conduct extensive field tests to ascertain the accuracy and effectiveness of the site-specific fumigant applicator under actual orchard replanting conditions.

Materials and Methods:

Development of a Tree-Planting-Site-Specific Fumigant Applicator

Development of the Global Positioning Systems (GPS) has made high accuracy location determination very convenient anywhere on the surface of the earth. GPS receivers with different accuracies are available depending on the intended applications. For example, inexpensive hand-held GPS receivers that cost only a few hundred dollars can provide accuracies in the range of 3 to 20 m and are suitable for recreational purposes. Some of these devices include WAAS (Wide Area Augmentation System), a satellite based differential correction system that can deliver around 3 m accuracy. Such devices are useful for crop scouting and soil sampling. For most precision farming applications such as yield mapping and variable rate application, it is necessary to use a more expensive (about a couple thousand dollars) GPS receiver that utilizes either Coast Guard beacons or a satellite based differential correction system with a position accuracy of about 1 m (Strickland et al., 1998; Al-Gaadi and Ayers, 1999; Yang, 2001). Coast Guard beacons are free to use, but have a limited range, while satellite based services provide wide area coverage, give weighted corrections from multiple base stations, but have an annual fee. For extremely precise applications such as auto-guidance and accurate planting and mapping of seeds, real-time kinematic GPS (RTK GPS) receivers with an accuracy of 1 cm are available (Abidine, 2004; Ehsani et al., 2004). However, this type of GPS receiver requires a local base station to be able to provide such precise location information. The typical cost of the rover (the receiver on the mobile unit) and the base station is about $40,000 and is very expensive for most applications, although the price is coming down rapidly. A very recent development in GPS technology is the availability of high performance (HP) receivers that are capable of delivering 10 to 20 cm accuracy using a dual frequency, satellite based, differential correction signal. These receivers cost about four thousand dollars and are particularly suited for agricultural chemical applications such as soil fumigation. With this in mind, we decided to retrofit a conventional subsoil shank fumigation system with a high performance differential GPS (HP-DGPS) unit to precisely apply soil fumigants with a location accuracy of about 10 to 20 cm in a square or a rectangular treatment zone around each tree planting site. We retrofitted a shank fumigation tractor (TriCal Inc.[1], Hollister, California, USA) shown in figure 1 with a tree-planting-site fumigant application system shown in figure 2. TriCal Inc. provided a VIPER computer, Raven spray controller (SCS4400), High Performance differential GPS recevier (RPR410, 10 cm accuracy), fast motor flow control valve, and Raven Office software for our use to accomplish the goals of this project (Raven Industries Inc., Sioux Falls, South Dakota, USA).

Figure 1. TriCal fumigation tractor with subsoiler shanks.

[1] Mention of trade names is not an endorsement of the product by the authors or the University of California Davis.

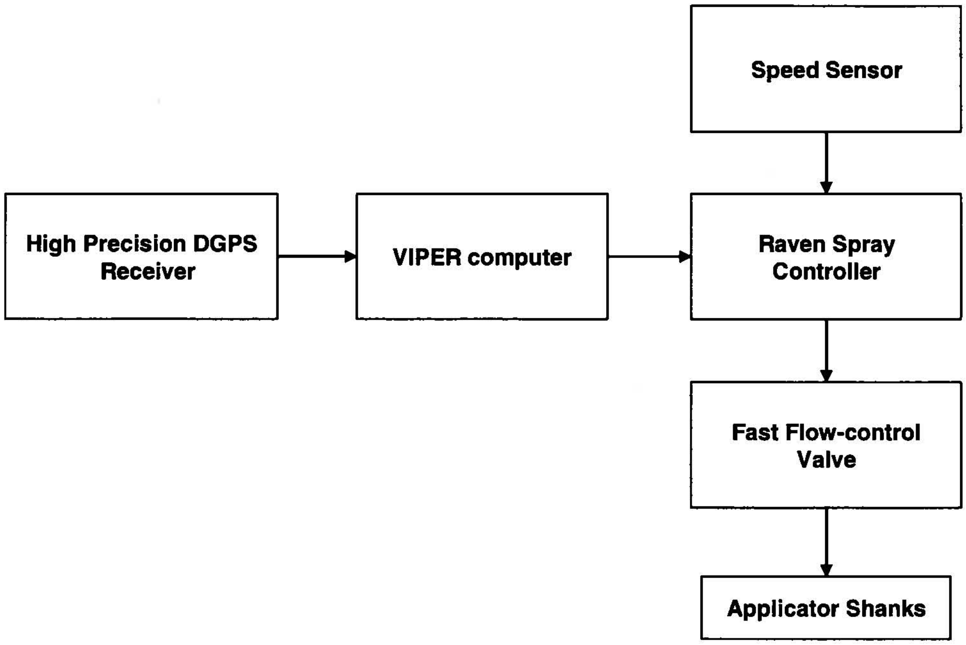

Figure 2. Schematic of the tree-planting-site-specific fumigant application system.

The system was tested at the Western Center for Agricultural Equipment (WCAE) on the UC Davis campus. Preliminary tests indicated that the system turned on and off as expected. We checked the accuracy of the system by conducting controlled tests along a roadway at the WCAE. A treatment map was created and loaded on the VIPER computer (figure 3). The fumigant tank was filled with water instead of fumigant and was driven once on each side of the road so that water was sprayed on the pavement twice in each treatment zone. This provided a total of 12 on/off accuracy measurements per test. The distance between each spray band and treatment zone edge was measured (negative values denote the system turned on or off late, positive values denote the system turned on or off early). The test was conducted at several forward speeds (4.8, 6.8, and 8 kmph) with different values for "look-ahead" (0, 1, 1.5, and 2s). To correct for such factors as fluid lag, the look-ahead causes the control system to turn on and off earlier (positive look-ahead) or later (negative look-ahead) than it would without.

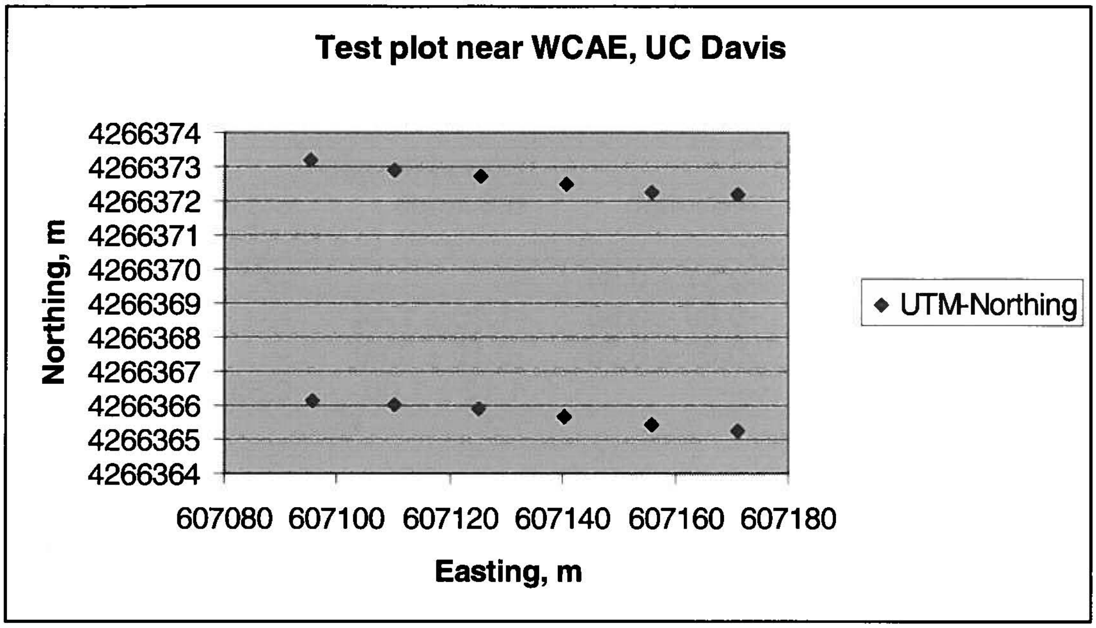

Figure 3. Test plot used for accuracy testing of the site-specific fumigant application system. A rectangular treatment zone was created around each point shown in the figure and loaded to the Viper computer during these accuracy tests.

The means and standard deviations in the measured accuracies are listed in table 1 for ground speed values in the range of 4.8 to 8 kmph and look-ahead values of 0 to 2 seconds. The results indicate that as look-ahead duration increased from 0 to 2 seconds, average error changed with a minimum value around 1.5 seconds. However, the surprising outcome was that standard deviation remained quite high irrespective of the look-ahead value. For a typical 6.8 kmph forward speed the standard deviation was about 99 cm (39 in) when the look-ahead duration was 1.5 seconds. This means that to be confident that every tree in the plot (with a tree spacing of 5.5 m (18 ft) along the row) received at least a 1.5 m (5 ft) treatment zone 95% of the time (+/- 2 * standard deviation), continuous strip treatment would be required. The source of this error was not clear. Since the VIPER was designed for typical variable rate chemical application in a precision farming system that uses sub-meter accuracy GPS, this level of accuracy (small variance in response time) may be acceptable for such an application. However, this level of variability in spray location is unacceptable for tree-planting-site fumigant application. Because of the level of inaccuracy, we designed a new data acquisition and control system that operated a separate solenoid valve using custom written software.

Table 1. Treatment location error at various ground speeds and look-ahead values.

Average accuracy ± Standard deviation (m)			
	Speed (kmph)		
Look-ahead (s)	4.8 kmph	6.8 kmph	8.0 kmph
0.0	-2.17 ± 0.64	---	---
1.0	-0.69 ± 0.56	-1.15 ± 1.44	---
1.5	-0.07 ± 0.33	-0.10 ± 0.99	---
2.0	---	1.12 ± 1.00	0.69 ± 0.82

Redesigned System

Figure 4 shows a schematic diagram of the new system developed. The VIPER computer was replaced by an embedded controller (Tern Inc., Davis, California, USA) which was programmed to read the HP DGPS serial data to determine the position of the tractor shanks (applicator). The HP DGPS coordinates were compared with the tree site coordinates from a test plot at the WCAE (figure 5). The treatment zone edges were calculated on the fly by the embedded controller based on the desired treatment zone size (i.e., 1.5 m). When the applicator entered the treatment zone, it turned on the solenoid valve. The process was as follows:

1. Read the current location of the applicator.
2. Determine which tree planting site was nearest to the applicator and was being approached.
3. Once the applicator was close enough to the tree planting site, do the following:
    a. Determine the speed of the applicator based on several consecutive HP DGPS points immediately preceding the current value (at least five points) using a regression approach,
    b. Determine if the applicator was expected to be within the treatment zone before the next HP DGPS point would be obtained (i.e., the sampling time of 0.2 s),
    c. Estimate when the applicator would arrive at the treatment zone based on the speed of the applicator. If it would be within the treatment zone before the next sampling interval (say, "t" milliseconds), then the solenoid valve was opened in t milliseconds. If the applicator would not arrive at the treatment zone before the next sampling interval, then the system would wait for the next HP DGPS position.
    d. The logic to close the solenoid valve was similar to the logic to open the valve as described in step 3c.

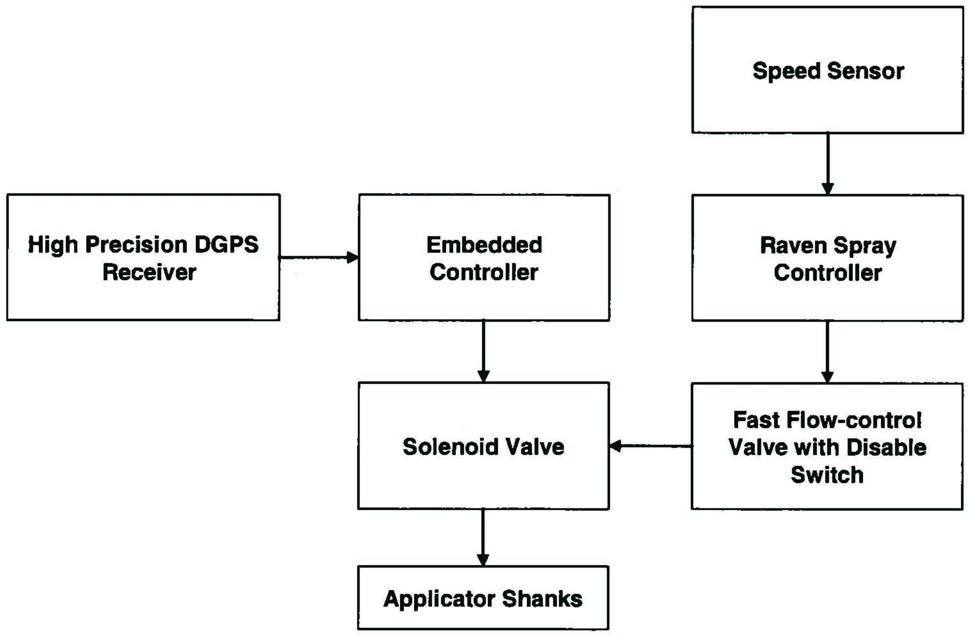

Figure 4. Schematic of the modified tree-planting-site fumigant application system

This improved system was tested using twelve locations marked as mock tree sites along the fog lines of the WCAE roadway (figure 5). The test used four level of speeds (3.2, 4.8, 6.4, and 8.0 kmph) and four levels of look-ahead value (0, 0.8, 1.6 and 2.4 s). Each treatment (speed/look-ahead combination) resulted in 24 accuracy data points (12 corresponding to turning "on" and 12 corresponding to turning "off" the solenoid value). This experimental plan resulted in 384 data points. Half the tests were conducted with clockwise tractor driving direction and the other half corresponded to the counter-clockwise direction of travel. Tests were completed in a randomized order.

Figure 5. Mock tree sites used for accuracy testing of redesigned site-specific fumigant application system (background aerial from Google Maps).

Prior to accuracy testing (due to time constraints), this system was used in an orchard-replant fumigation trial which tested different combinations of fumigant type, rate, and application method (Paramount Farming (Columbia Ranch), Firebaugh, California, USA). Twelve of 80 subplots used the redesigned tree-planting-site-specific fumigant application system. Each subplot contained 24 trees. New almond trees were subsequently planted in the treated soil. The effect of each treatment on preventing or reducing replant disease will not be apparent for a year or more. Results from this trial will be presented at that time.

Results and Discussion:

The results of the accuracy tests indicated that the direction of travel did not influence the accuracy of this system. Both the travel speed and look-ahead values influenced the system accuracy. The error tended to increase from a negative value (system was late) as the look-ahead value increased (system became less late, then early). The mean error was zero at a look-ahead value of 0.8 s. This look-ahead value most likely corresponds to lag in the fluid lines. The error tended to be positive at low ground speeds and became negative as speed increased (system actuated later). Table 2 shows the average error and standard deviation for each combination of factors. The maximum standard deviation was 47 cm.

Table 2. Treatment location error at various ground speeds and look-ahead values for redesigned system.

Average accuracy ± Standard deviation (m)				
	Speed (kmph)			
Look-ahead (s)	3.2 kmph	4.8 kmph	6.4 kmph	8.0 kmph
0.0	-0.07 ± 0.16	-0.50 ± 0.28	-0.58 ± 0.27	-0.95 ± 0.31
0.8	0.61 ± 0.21	0.39 ± 0.34	-0.27 ± 0.39	-0.30 ± 0.43
1.6	0.91 ± 0.27	0.43 ± 0.26	0.16 ± 0.37	-0.22 ± 0.47
2.4	0.89 ± 0.29	0.18 ± 0.30	0.04 ± 0.33	-0.27 ± 0.44

Analysis of each individual combination provided an incidence table that showed interaction effects. These results show that the redesigned system was much more accurate. A regression analysis of the data indicated that the error was significantly influenced by speed, $(\text{speed})^2$, look-ahead value, $(\text{look-ahead value})^2$, and interaction between speed and look-ahead value. The RMS error was 33.5 cm (13.1in). This means that to ensure a 1.5 m (5ft) long zone receives fumigation 95% of the time, a 2.8 m (9.3 ft) long zone needs to be treated. For the HP GPS system we expected a RMS accuracy in the range of 10 to 20 cm. A 33.5 cm RMS error is greater than this, indicating that there are sources of error other than those associated with the GPS system. However, even with this error a savings of 48% in chemicals can be realized if the tree spacing is 5.5 m (18 ft). We are currently enhancing the system to obtain a positional error in the range of 20 to 30 cm (8 to 12 in).

Conclusions

Based on this study in which a shank-type fumigant applicator was used to develop a tree-planting-site-specific fumigant system, we reached the following conclusions.

1. The redesigned system that utilized a HP GPS system and a solenoid value as shown in figure 4 worked satisfactorily.
2. The treatment location error of the system did not depend on the direction of travel of the tractor. However, it did depend on the applicator forward speed and look-ahead value in a predictable manner. A look-ahead value of 0.8 s should minimize error by correcting for the fluid lag time.
3. The RMS accuracy of this system, when the speed effect was properly accounted for, was 33.5 cm (13.2 in). Although this level of accuracy needs further improvement, the amount of fumigant applied can be cut down by nearly 50% thus reducing cost and environmental pollution significantly.

Recent Publications:

Coates, R., S. Shafii, S. K. Upadhyaya, and G. Brown. 2007. Site-specific fumigant applicator for prevention of almond replant disease. ASABE Paper No. 071080. ASABE St. Joseph, MI 49085.