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Evaluation of three tractor-guidance methods for parallel swathing at two field speeds

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ABSTRACT

This study compared the accuracy (mean error and rms error) and precision (standard deviation of error) of three tractor-guidance methods (foam-marker, light-bar, and assisted-steering systems) at two field speeds (5.6 – and 11.5 km/h) for parallel swathing operations. Eighty-four replications of each combination of guidance method and field speed were conducted between 15 October and 22 December 2006 (504 total field passes). The foam-marker system was found to be significantly less accurate [larger mean error ($p < .0001$) and had a larger rms error ($p < .0001$)] than either the light-bar or the assisted-steering system. There was no significant difference in mean error ($p = .6718$) or rms error ($p = .8841$) by field speed. There was a significant interaction between guidance method and field speed for both mean error ($p = .0009$) and rms error ($p = .003$). Mean and rms errors for the foam-marker and the assisted-steering systems increased at higher field speed, while the mean and rms errors for the light-bar system decreased at higher speed. The assisted-steering system had a significantly lower ($p = .0164$) standard deviation of error (higher precision) than the foam-marker or the light-bar systems. There was no significant difference in the standard deviation of error by field speed ($p = .6258$) or by the interaction of guidance method and field speed ($p = .2748$).

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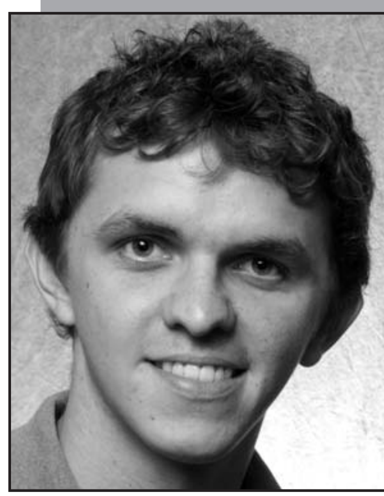
MEET THE STUDENT-AUTHORS

Garris Hudson

I graduated from Siloam Springs High School, Siloam Springs, Ark., in 2003. After spending my freshman year of college at Northwest Arkansas Community College, Bentonville, Ark., I enrolled at the University of Arkansas in fall 2004, majoring in agricultural education. I was awarded the Alpha Tau Alpha Outstanding Sophomore Award in 2005 and in 2007 my research partner, Robby Shofner, and I won the Gamma Sigma Delta Undergraduate Research Poster Contest. For three years I was actively involved in the University of Arkansas Collegiate FFA Chapter. I graduated in May 2007 with a major in agricultural education and a minor in agricultural systems, technology, and management. I currently live in my home town of Siloam Springs, Ark., with my wife, Serena. I would like to thank Dr. Donald Johnson and Dr. George Wardlow for assisting me and Robby in this research project and for giving me the opportunity to be a part of something as special as this.



Robby Shofner

I am 23 years old and from Bentonville, Ark., where I grew up on a production agriculture farm where we raise purebred and commercial beef cattle. We also managed a 20-acre apple and peach orchard until recently. I graduated from Bentonville High School in 2002 and this spring finished up my undergraduate work at the University of Arkansas majoring in agricultural education. I will be getting married in June and my fiancé and I hope to continue the family farm for many years.

INTRODUCTION

Many row crop operations such as tillage, planting, spraying, and spreading require that a tractor and implement make multiple, equal-width parallel swaths through the field. To maximize field efficiency and crop yields, operators must drive accurately to avoid excessive overlaps or gaps in field coverage. Traditionally, visual guidance systems such as mechanical and foam markers have been used as operator guidance aids. With increased machinery working widths, higher field speeds, and extended hours of operation, visual guidance systems have been rendered less effective (Ehsani et al., 2002).

Newer systems are available that use differential global positioning system (DGPS) signals to provide field guidance (Grisso and Alley, 2002). A light-bar (Fig. 1a) provides visual guidance information to the operator, allowing the operator to make manual steering corrections (Trimble Navigation, Ltd., 2005). An assisted-steering system makes these adjustments automatically. One common assisted-steering system (Fig. 1b) incorporates a servo-motor that moves the tractor steering wheel to make these corrections automatically (Trimble Navigation, Ltd., 2005). With assisted-steering systems, the operator only steers the tractor when making turns at the end of the field (Grisso and Alley, 2002).

GPS-based guidance varies in accuracy, depending on type of differential correction signal used. Real-time kinematic (RTK) GPS uses a local base station that transmits a correction signal to the RTK GPS unit located on the tractor, resulting in dynamic position accuracies of <2.54 cm (Taylor, 2004). The cost for these systems may exceed $40,000 (Stephens et al., 2005).

Two types of differential GPS (DGPS) are used for guidance. Subscription DGPS uses a commercial signal for differential correction with dynamic accuracies of <10 cm (Taylor, 2004). The annual subscription fee for one common correction signal is approximately $800 - $1500, depending on options (OmniSTAR, 2007). Non-subscription DGPS uses correction signals from the Wide-Area Augmentation System (WAAS) provided at no charge by the US Federal Aviation Administration (Trimble, 2005). WAAS-based DGPS has a dynamic accuracy of <25 cm (Taylor, 2004).

Molin et al. (2002), evaluated the accuracy of a DGPS light-bar guidance system for parallel swathing (5.0-m swath width) at four field speeds between 5.0 and 20.0 km/h. The researchers found that 54% of all errors were ± 0.5 m and that there was no significant difference ($p <$ .05) in mean error by field speed. Karimi et al. (2006) compared seven light-bar guidance systems and found root mean square errors (rms errors) of between 11.1 and 18.6 cm.

There is a paucity of published research evaluating the accuracy and precision of assisted-steering systems. Adamchuk (2007) presented data collected during an extension service field day and determined that RTK, subscription DGPS, and WAAS DGPS assisted-steering systems had mean pass-to-pass errors of 0.76, -3.8, and 24.3 cm, respectively. Adamchuk (2007) indicated that guidance error is affected by GPS error, field conditions, implement tracking, and vehicle dynamics.

The purpose of this study was to determine if there were significant differences ($p < .05$) in parallel swathing errors by guidance method (foam marker, light bar, or assisted steering), field speed (5.6 – or 11.5 km/h), or the interaction of guidance method and field speed.

MATERIALS AND METHODS

A 73.1-m by 73.1-m test plot was surveyed and hub stakes were located at the SW and SE corners to establish the AB baseline for all parallel swathing operations. Six hub stakes were located along this baseline at 13.1-m intervals (Fig. 2a). All measurements were made relative to these six interior stakes. All field passes were made along the east-west axis. Ehsani et al. (2003) and Wu et al. (2005) determined that east-west travel minimizes cross-track errors. Time and weather constraints did not allow including travel axis as an independent variable in the current study.

A John Deere 2355 2WD tractor was equipped with a Trimble AgGPS 132 DGPS receiver, an EZ-Guide light bar (AgLeader Technologies, Ames, Iowa), and an EZ-Steer assisted steering system with a T2 terrain compensation module (AgLeader Technologies, Ames, Iowa). The DGPS receiver was enabled to receive the WAAS correction signal from the Sallisaw, Okla., beacon. The DGPS-based light-bar guidance and assisted-steering systems were configured according to the manufacturer's instructions (Trimble, 2005; Trimble 2006). A swath width of 3.66 m was set and the light bar was configured so that each LED segment represented 15.2 cm off-line. The assisted-steering system was configured for slightly moderate steering aggressiveness.

A 3-point hitch-mounted toolbar (3.66-m wide) was fitted with a center-mounted spring-tooth shank (5-cm wide) to engage the soil and mark the centerline of tractor travel. The tool bar was also equipped with a foam-marker system with drop tubes located at each end (Fig. 2b).

Eighty-four replications of each combination of guidance method (3 methods) and field speed (2 speeds) were conducted between 15 October and 22 December 2006 (504 total field passes). An AB line was established and 21 parallel swaths were made with the shank engaged with the soil. Right-angle measurements were made between each of the six reference hub stakes and each resulting shank furrow and these distances were recorded. The test plot was dragged after each series of field passes in order to fill the furrows.

For each swath, mean error (m_j), root mean square (rms_j) error, and standard deviation of error (std_j) were calculated using the following equations:

$$m_j = \frac{1}{N}\sum_{i=1}^{N} ij$$

$$rms_j = \sqrt{\frac{1}{N}\sum_{i=1}^{N} e_{ij}^2}$$

$$std_j = \sqrt{\frac{1}{N}\sum_{i-1}^{N}\left(e_{ij} - m_j\right)^2}$$

Where,

N = the number of data points obtained per swath (6)

e_{ij} = the distance from point i to its desired position (j) (error)

Both mean error and rms error are measures of accuracy, while the standard deviation of error is a measure of precision (Ehsani et al., 2002).

The same driver operated the tractor throughout the experiment. This operator could be characterized as a farm-reared college student with previous tractor operating experience, but with no experience in row-crop farming. Prior to training for this study, the operator had no experience with foam-marker, light-bar, or assisted-steering systems.

RESULTS AND DISCUSSION

All mean errors were negative, indicating swath overlap as opposed to swath skips. A 2 X 3 factorial ANOVA indicated mean error for the foam marker was significantly higher ($p < .0001$) than for the light-bar or the assisted-steering system. There was no significant difference ($p = .6718$) in mean error by field speed. There was a significant interaction ($p = .0009$) between guidance method and field speed. The assisted-steering system and the foam-marker were more system accurate at low field speed, while the light-bar guidance system was more accurate at the high field speed (Fig. 3).

Results of a 2 x 3 factorial ANOVA indicated rms error for the foam marker was significantly ($p < .0001$) higher than for the other two guidance methods. There was no significant difference ($p = .8841$) in rms error by field speed. There was a significant ($p =.003$) interaction between guidance method and field speed (Fig. 4).

A 2 x 3 factorial ANOVA indicated that there was a significant ($p = .0164$) difference in the standard deviation of error, with the assisted-steering system being more precise than the other two systems (Fig. 4). There was no significant difference in precision by field speed ($p = .6285$) or by the interaction of guidance method and field speed ($p = .2748$).

Both the light-bar and the assisted-steering systems were more accurate than the foam marker in parallel swathing. The assisted-steering system was more accurate at low field speed, while the light-bar was more accurate at high speed. When using the light-bar at the low field speed, the operator noted a tendency to overcorrect; at the high field speed, less time was available for over-correction. When using the assisted-steering system at the high speed, the tractor traveled a greater distance while the automatic steering adjustments were being made, resulting in somewhat larger errors. Additional research should be conducted to determine if increasing steering aggressiveness would increase accuracy at higher speeds.

The assisted-steering system resulted in an overall higher level of precision (as indicated by a lower standard deviation of error) than did the light-bar or the foam-marker guidance systems. This finding was as expected, since automatic systems tend to have a higher degree of repeatability.

Where accurate parallel swathing operations are necessary, farmers should consider use of either a light-bar or an assisted-steering guidance system. Where both accuracy and precision are important, preference should be given to the assisted-steering system.

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Fig. 1. Light-bar (left) and assisted-steering (right) guidance systems.

Fig. 2. Field layout (left) and equipment (right) used in evaluation of guidance methods.

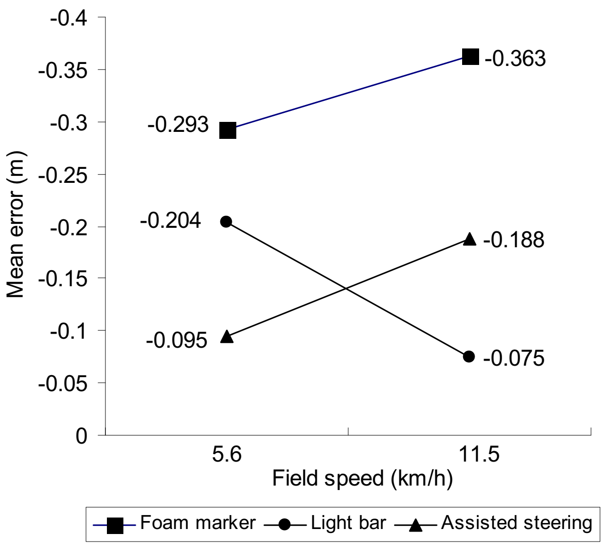

Fig. 3. Mean error by guidance method and field speed.

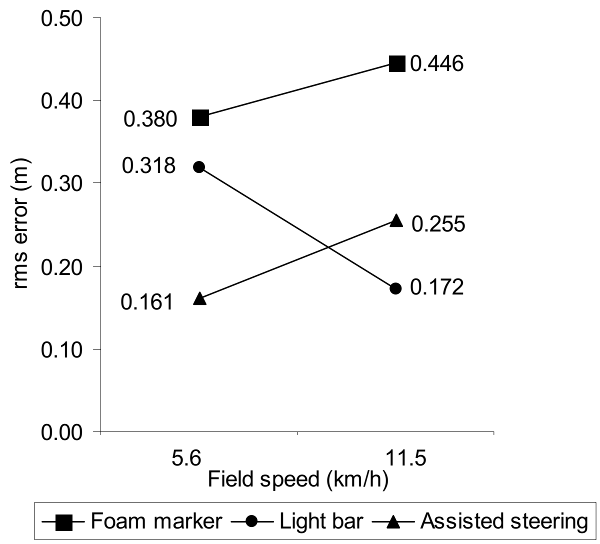

Fig. 4. RMS error by guidance method and field speed.

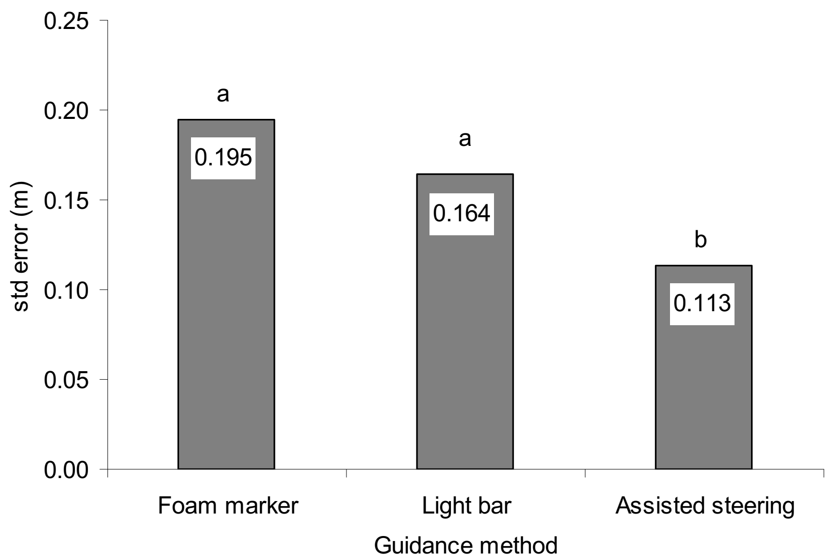

Fig. 5. STD of error by guidance method and speed. Bars with different letters are significantly different.