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A decision-support system for analyzing tractor guidance technology

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ABSTRACT

A decision-support system was developed to assist small-scale producers, consultants, and extension agents with analyzing expected yield improvements, input cost savings, and equipment efficiency gains associated with global positioning system guidance on tractors using farm-specific details. Default parameters may be modified to perform partial budgeting and break-even analyses on a whole-farm basis. Findings suggest that this technology is profitable on as few as 49 ha, considered small-scale in the region, and under farm conditions assessed within. Further, tractor guidance is more feasible the more input-intensive the crops (e.g. cotton production vs. pasture maintenance) and the more expensive the equipment (e.g. using newer equipment). Changing input use affects greenhouse gas emissions that are reported as carbon equivalent footprint changes due to tractor guidance. For example, changing to tractors with lower horsepower to save on capital investment needs without changing the size of implement drawn, lowers fuel footprint as long as technically feasible and possible from a perspective of completing field work in a timely manner. Also, using manure instead of synthetic fertilizer, while economically advantageous, will increase the footprint of fertilizer applications given, among other factors, lesser nutrient density and thereby greater handling costs with manures. Quantifying these impacts across a whole farm is cumbersome since tractor guidance affects annual equipment use hours that are difficult to track and yet economically important. Hence, the decision support system was designed to capture farm-specific detail. The ability to perform whole-farm planning and sensitivity analyses in an automated, user-friendly, and flexible fashion is expected to increase technology adoption by small-scale producers.

1. Introduction

Auto-guidance, also known as automated steering or auto-steer, uses the global positioning system (GPS) to guide agricultural machinery in production operations (Shockley et al., 2011). Designed for use on tractors and self-propelled machinery, tractor guidance (TG) has been shown to increase efficiency of agricultural production practices, such as planting, herbicide, insecticide, and fertilizer applications (Shockley et al., 2011, 2012a). Two prominent TG technologies used for planting and chemical application are the "bolt-on auto-steer system" that utilizes a "sub-meter receiver", and the "integral valve system" which uses a Real Time Kinematic (RTK) GPS receiver permanently attached to a tractor (Shockley et al., 2011). The RTK-GPS system has greater accuracy as well as a higher purchase price. The TG technology analyzed in this study used tractor-mounted equipment receiving a GPS signal that allows ± 2.5 cm accuracy for field operations involving pull-type equipment and 'hands free' steering of the tractor. With an annual technological support fee, the equipment is considered an investment decision of moderate size on most small-scale agricultural operations.

Benefits of using automatic guidance systems include: (i) reduction of input use by minimizing over and/or under application of chemicals, manures, and seed; (ii) longer workdays due to reduced operator fatigue and ability to work beyond daylight hours; and, (iii) lowered machinery costs resulting from an increase in machinery field capacity (Shockley et al., 2011, 2012a). Vellidis et al. (2014) used peanut (*Arachis hypogaea* L.) yield calculations to evaluate the accuracy of planting operations and found a tractor equipped with RTK-GPS TG increased yields and thereby profitability when compared to a conventional tractor. Economic analysis of automatic section control with TG for planting operations and whole-farm operations performed showed improved yields and profitability that, in part, were a function of using cheaper, reduced-size equipment for farming the same area of land (Velandia et al., 2013; Shockley et al., 2012b).

Shockley et al. (2011) analyzed the profitability and risk involved

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with adopting TG technology and performed a break-even analysis of TG technology to determine the minimum land needed to achieve positive net returns. They also calculated payback periods and analyzed what combinations of equipment would be optimal for a given set of resource conditions. The study found that the addition of TG technology may decrease the size of machinery required or alternatively allow for an increase in farm size without changing equipment size.

Previous studies identified several factors affecting the adoption of precision agriculture technology among agricultural producers. These factors included: (i) profitability and “perceived” benefit of precision technology (D’Antoni et al., 2012; Aubert et al., 2012); (ii) farm size (Banerjee et al., 2008; Paxton et al., 2011; D’Antoni et al., 2012); (iii) farm operator age, years of formal education, years of farming experience, prior use of decision-support systems (DSS), and/or adoption of other forms of technology (Banerjee et al., 2008; Paxton et al., 2011; Paudel et al., 2011); (iv) within-field yield variation (Paxton et al., 2011; Paudel et al., 2011); and (v) use of manure fertilizer (Paudel et al., 2011). These studies found a positive correlation between adoption of precision technology and operator level of education, prior use of technology, and farm size, suggesting that the use of educational tools and programs would increase adoption rates among operators with these characteristics. Educational programs that include the use of decision-support systems may be useful for educating agricultural producers about the benefits of adopting TG technology, such as improved yields, reduced machine ownership and operation expenses, input costs savings (i.e. fuel, labor, chemical, and seed costs), and subsequent increased profitability. Brown et al. (2016) noted that the adoption of precision agriculture technologies, such as TG, may allow smaller producers to compete with larger operations. To improve adoption by small farming operations, a DSS should consider operating and ownership costs of smaller machinery on less land for those farming operations considering TG technology. In addition, consideration should be given to financial assistance available through government-funded programs, such as the Conservation Reserve Program and Environmental Quality Incentives Programs, to incentivize both large and small operations to invest in these technologies (Brown et al., 2016).

Using data from the USDA-ARS Dale Bumpers Small Farm Research center in Booneville, Arkansas (AR), this paper describes potential uses of a DSS named Tractor Guidance Analysis (TGA), recently developed to quantify the effects of TG technology on livestock and crop farms using default values for efficiency gains obtained from measurements observed at the research station and/or from literature review (Lindsay et al., 2018). Similar to existing DSS developed by Dhuyvetter et al. (2010), TGA allows joint or separate analyses of the use of planting, fertilizer, manure, and chemical applications to assess the feasibility of adoption in terms of enhanced profitability, breakeven, and capital investment requirements. At the same time, TGA allows for the modification of default parameters to further tailor results to reflect user-specified machine costs and operating decisions using a line-by-line budget format. Finally, TGA measures fertilizer, fuel, manure, and chemical use, with and without TG technology, to capture greenhouse gas (GHG) emissions changes that are reported as TG technology-driven carbon footprint changes.

The objective of this manuscript is to highlight the conceptual framework of TGA. In addition, a hypothetical farm case situation (Baseline) illustrates the tool’s use by (i) demonstrating the effect of land reallocation to a less input-intensive crop (Hay); (ii) showcasing an analysis of new vs. used equipment (Smaller Used Tractor); and (iii) analyzing the effect of custom work (Custom Plant). In this assessment, economic and environmental implications are quantified for the whole farm but results pertain mainly to direct and measurable impacts of employing TG technology. That is, not all field operations and equipment requirements for the whole farm are modeled, and, consequently, the tool does not report on whole-farm profitability.

2. Materials and methods

2.1. Overview of TGA

Small and large-scale agricultural producers throughout the Mid Southern United States can benefit from use of TGA as it monitors changes such as improved yields, reduced input costs, and subsequent increased profitability that are associated with the use of TG technology. To promote adoption of TG technology, TGA quantifies effects of operating and ownership costs for field operations involving planting, fertilizing, and chemical applications. This DSS allows the user to specify their own operation’s parameters such as area farmed, equipment purchase price, salvage value, and annual use, along with input use decisions that can deviate from provided default values for corn (*Zea mays* L.), cotton (*Gossypium hirsutum* L.), hay/pasture, peanut, sorghum (*Sorghum bicolor* L. Moench ssp. *bicolor*), full-season soybean (*Glycine max* L. Merr.), wheat (*Triticum aestivum* L.), and rice (*Oryza sativa* L.). The DSS and manual are available as a free download from https://tinyurl.com/TGAv1-3 as of the spring of 2018.

The TGA program was designed to address several factors that may influence the use of a DSS, such as user-friendliness, software flexibility, accessibility, and applicability to the user (Rossi et al., 2014; Rose et al., 2016). Thus, TGA utilizes the Microsoft Excel® platform because most users will be familiar with the software, making TGA an accessible educational tool with great outreach potential (Lacoste and Powles, 2016). To further improve TGA accessibility, Visual Basic for Applications (VBA) programming language created software-like features with a full-screen appearance and visual enhancement. Command buttons use VBA programming to perform optimizations, to guide user navigation through the DSS interface, and to allow modification of user input for parameter specifications according to their existing operation. Visual Basic programming is also used to restrict user access to code and provides drop-down menus and data validation lists that limit user specifications to a pre-selected set of options to maintain the integrity of TGA’s calculations. Moreover, conditional formatting is used to perform error checking by highlighting user modifications that may lead to errors.

2.2. Efficiency gain calculations

Efficiency improvements resulting from TG, such as equipment efficiency gains, input use savings, and yield gains are used to calculate the profitability and GHG emissions changes of adopting TG technology. Equipment efficiency gains are measured by tracking changes in equipment speed and thereby performance rate as illustrated with the example of two adjacent hay fields shown in Fig. 1. The field on the left was fertilized with the same equipment as the field on the right, but, importantly, the field on the left utilized TG technology to avoid overlap and gaps that are apparent on the right field where the technology was turned off. As shown in Fig. 1, operating speed was greater with TG and hence the performance rate improvement lead to fuel, labor, and equipment efficiency gains as hourly operating and capital recovery cost can now be spread over more area farmed. In the case of Fig. 1, a 2.21% increase in field speed due to TG captures equipment efficiency gains by increasing the performance rate and thereby reducing cost per unit area of land farmed. Using speed change alone is a very conservative measure of efficiency gains as reduction in overlap also enhances application coverage area and thereby field efficiency. As noted below, this field speed increase can be modified by the user and is again analyzed in the final output screen using sensitivity analysis. In this study, the tool uses this same equipment efficiency gain rate for fertilizer, planting, and chemical applications for demonstration purposes. Further field data collection will lead to refined equipment efficiency gain estimates for future upgrades to TGA. Note, however, that if area farmed is not increased, efficiency gains lead to lesser annual use of implements and tractors, which will increase the capital recovery