Economic and Environmental Impact Assessment of Tractor Guidance Technology

A. J. Ashworth,* K. R. Lindsay, M. P. Popp, and P. R. Owens

Abstract: Tractor guidance technology allows for more spatially precise input applications, which leads to efficiency gains that are difficult to quantify at the systems level. A decision-support tool, Tractor Guidance Analysis (TGA), was developed to quantify carbon equivalent (CE) emission reductions associated with this technology for three scenarios (500 ha each): (i) cotton (Gossypium hirsutum L.), (ii) soybean [Glycine max (L.) Merr.], and (iii) cotton and soybean mixed. Carbon equivalent emission reductions for cotton, soybean, and mixed enterprises were 27.5, 5.6, and 16.5 kg ha\(^{-1}\), with attendant increases in farm profitability ($68,700, $16,900, and, $42,900, respectively). Tractor guidance led to total farm CE emission reductions of 15.7, 3.5, and 9.6 Mg for cotton, soybean, and mixed operations, respectively. These results highlight that CE reductions are (i) crop specific, (ii) scale dependent, and (iii) equipment and input-use specific. Consequently, TGA can improve agricultural sustainability by informing users of economic and environmental repercussions of tractor guidance and may thereby enhance technology adoption.

Core Ideas

- Tractor guidance (TG) technology allows for spatially precise input applications.
- A decision-support tool was developed to quantify environmental and economic impacts of TG.
- Greatest CE equivalent emission reductions and cost savings occurred with Cotton-Only scenario.
- TG was profitable for operations evaluated and led to CE equivalent emissions reductions.
- This tool may improve agricultural sustainability and enhance technology adoption.

Abbreviations: CE, carbon equivalent; GHG, greenhouse gas; TG, tractor guidance; TGA, Tractor Guidance Analysis.
while multiple equipment passes may occur and assigning yield gains to separate field passes is unrealistic. Further, field attributes such as field size, shape, and slope lead to differences in the amount of time a tractor spends turning around at the field edge (during which time inputs are not applied). Finally, it is difficult to quantify these changes in a whole-farm setting when multiple crops may be grown with different input-use intensity. To address these challenges, a decision-support tool, Tractor Guidance Analysis (TGA) (available for free download at https://agribusiness.eark.edu/decision-support-software.php#TGA; Lindsay et al., 2018), was developed using a growing body of on-farm efficiency gain measurements under varying field-operating conditions, as well as measures available in the precision agriculture literature to assist users with quantifying the feasibility and environmental impact of this technology. The objectives of this work were to use TGA to evaluate carbon equivalent (CE) emissions changes and break-even costs associated with the use of TG under three on-farm scenarios: (i) 500 ha of cotton Gossypium hirsutum L.), (ii) 500 ha of soybean [Glycine max (L.) Merr.], and (iii) 250 ha of both cotton and soybean.

**Methods**

Partial budgeting, tailored to farm-specific conditions for up to three user-selected cropping enterprises, develops profitability estimates to TG based on default equipment selection parameters (e.g., age, annual use, purchase price, repair factor, field efficiency, and labor rates) using values reported in ASABE (2011a, 2011b), MSBG (2016), and Watkins et al. (2017) and modifications to default production practices that are crop-dependent (Scott et al., 2016; Watkins et al., 2017; Lindsay et al., 2018). Environmental impacts of TG are tracked by translating changes in fertilizer, fuel, seed, and chemical inputs to their CE emissions by using conversion factors that adjust greenhouse gas (GHG) emissions by their individual global warming potential (e.g., methane [CH₄] is 28 to 36 times more potent than carbon dioxide (CO₂) in terms of global warming potential [Solomon et al., 2007; IPCC, 2014; Long Trail Sustainability, 2016; USEPA, 2017]). As in Thoma et al. (2013), this conversion monitors common GHG emissions of nitrous oxide (N₂O), CH₄, and CO₂ or emissions created during manufacture and transport of inputs and during combustion of fuel and from N₂O emissions that are a function of soil application of N fertilizer and subsequent transformations to non-ammonium N forms and consequences of their presence (nitrification, denitrification, volatilization, leaching, and runoff).

In this paper, we estimated economic and environmental implications of TG using TGA. Three fictitious farm operations of the same size (500 ha) were modeled using real-world production data. A "Cotton-Only" operation grows only cotton either with or without TG. A second operation plants all soybean as the "Soybean-Only" scenario with and without TG. This operation is much less input intensive than the first, given soybean’s ability to fix N. Thus, less commercial fertilizer is needed compared with cotton. In turn, N fertilizer savings lead not only to substantial energy savings during its manufacture but also to rather large reductions in N₂O emissions, as discussed above. To show whether splitting land among the two crop choices leads to a simple weighted average of economic and environmental implications estimated for the first two farm scenarios, a third "50:50 Mixed" operation with 250 ha each of cotton and soybean was modeled. For all operations, environmental implications were shown together with changes in farm profitability resulting from changes in production practices with and without the use of TG. Further, TGA quantifies at what size of operation TG technology begins to pay for itself, holding crop rotation and equipment used constant. At the same time, sensitivity analyses were conducted to address what yield gains, equipment efficiency gains, and input use savings are needed for TG technology to be beneficial for the given size of operation and crop(s) grown.

Default production practices, expected yield, cost for inputs, and crop prices were used (MSBG, 2016; Watkins et al., 2017; Lindsay et al., 2018). Equipment efficiency and input cost changes, as well as equipment information, are provided in Table 1. Table 2 lists the conversion factors used to convert input use to CE emissions. Yield gains were conservatively estimated not to change as a result of using

<p>| <strong>Table 1. Equipment impacts for field operations performed and efficiency gains using tractor guidance (TG) machinery.</strong> |</p>
<table>
<thead>
<tr>
<th><strong>Machinery</strong></th>
<th><strong>Size</strong></th>
<th><strong>Purchase price†,‡</strong></th>
<th><strong>Estimated salvage value§</strong></th>
<th><strong>Estimated useful life¶</strong></th>
<th><strong>Increase in field efficiency†</strong></th>
<th><strong>Input use savings‡</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Tractor Guidance System</td>
<td>–</td>
<td>$8,000#</td>
<td>50</td>
<td>4 yr</td>
<td>na</td>
<td>–</td>
</tr>
<tr>
<td>MFWD tractor</td>
<td>143 kW</td>
<td>$186,000‡</td>
<td>$18,800</td>
<td>16,000 h</td>
<td>na</td>
<td>–</td>
</tr>
<tr>
<td>Row planter</td>
<td>8R-30 (6m)</td>
<td>$41,000‡</td>
<td>$19,600</td>
<td>900 h</td>
<td>6.9</td>
<td>2.3†</td>
</tr>
<tr>
<td>Over the top sprayer</td>
<td>36.6 m</td>
<td>$76,600‡</td>
<td>$31,300</td>
<td>1,500 h</td>
<td>21.9</td>
<td>22.0†</td>
</tr>
<tr>
<td>Post-directed sprayer</td>
<td>8R-30</td>
<td>$12,700‡</td>
<td>$5,000</td>
<td>1,600 h</td>
<td>9.0</td>
<td>9.1†</td>
</tr>
<tr>
<td>Fertilizer spreader</td>
<td>12.2 m</td>
<td>$11,800‡</td>
<td>$3,700</td>
<td>1,200 h</td>
<td>11.0</td>
<td>2.2†</td>
</tr>
</tbody>
</table>

† Shockley et al., 2011.
‡ Mississippi State Budget Generator v. 6.0 (MSBG, 2016) and rounded to nearest US$100.
§ Calculated using remaining value coefficients provided by the American Society of Agricultural and Biological Engineers (ASABE, 2011a, 2011b) and rounded to nearest US$100.
¶ American Society of Agricultural and Biological Engineers, except for useful life years for tractor guidance equipment. Useful life of tractor guidance equipment is set by the user with a default of 4 yr. Included also is a default annual technical support fee.
# The tractor guidance system denotes submeter receiver technology for autosteer equipment sourced from JohnDeere.com for Starfire 6000 SF3 equipment as valued early 2018. John Deere (2018), for example, suggests ±3 cm pass-to-pass accuracy.
TG given difficulties described above. Cotton had a default yield of 1350 kg ha\(^{-1}\) assuming irrigated production at a price of $1.50 kg\(^{-1}\). Irrigated soybean had a default yield of 4040 kg ha\(^{-1}\) at a price of $0.37 kg\(^{-1}\) (all prices listed here are in US dollars).

**Results**

Impacts of TG on CE emission changes and profitability under three on-farm scenarios are described below. Results outline the feasibility and estimated profitability of this potential best management practice to reduce overapplication of inputs, energy use, and production of GHG emissions in cropping systems.

**Tractor Guidance Profitability**

The profitability of TG technology is a function of revenue increases with yield gains and cost changes for field operations performed. As shown in the top section ($ yr\(^{-1}\) of Table 3, profitability gains using the default input use and equipment efficiency gains reported by Shockley et al. (2011) are quite large at the chosen farm size. Without yield gains, the leading category of cost savings is associated with chemical and fertilizer cost savings. For the 50:50 Mixed farm operation, performance statistics are the simple weighted average of the values reported for Cotton-Only and Soybean-Only. Although TG has been widely accepted on large farming operations, small farms (defined as a farm with <$250,000 commodity sales) account for more than 88% of all farms and 23% of agricultural production (NASS, 2016). Therefore, TGA could also be used to identify what acreage would be required for break even for a given technology investment.

**Sensitivity Analysis of Cropping Systems**

The break-even farm size was estimated holding equipment and proportion of land use assigned to different crops constant. With the savings generated, the break-even amount of land needed to pay for the annualized cost of TG equipment of $3,280 is quite small, ranging from approximately 10 to 50 ha. Note that this number does not reflect the amount of land it takes to operate the farm profitably. Break-even yield changes are quite low, as are input cost savings and efficiency gains when compared to the parameters used for the different types of equipment as reported in Table 1. Noteworthy here is that the sensitivity analysis shown for the 50:50 Mixed operation is no longer a simple average of the Cotton-Only and Soybean-Only columns as TG use depends on crop grown and therefore break-even calculations are more complex than a simple weighted average.

**Environmental and Economic Impact of Tractor Guidance**

The environmental impacts shown in the bottom section (kg ha\(^{-1}\) of CE emissions reductions) of Table 3 show changes in global warming potential on a per hectare basis in the form of the CE emissions. Cotton proves to be a much more input-intensive crop, and hence, the environmental implications of TG use are much larger in comparison to soybean. As expected, the 50:50 Mixed operation has an intermediate environmental impact. Importantly, environmental impact can be lessened with TG use with an increase in profitability. For policymakers and the agricultural industry, this suggests that producers may be encouraged to invest in this technology and that this investment is profitable at a small scale (break-even operation scale is small for the crops analyzed).

For the Cotton-Only scenario, seed, agrochemical, and operating costs were reduced $3,500, $58,300, and $10,100, respectively. Tractor use declined by 70 h and labor decreased by 105 h as some field operations require not only the tractor driver but also added personnel for supplying inputs for the equipment operated. Total CE emissions reductions were 31.37 kg ha\(^{-1}\) (3.92, 6.97, and 20.47 kg ha\(^{-1}\) reductions from fuel, fertilizer [including NO\(_x\) emissions from N applications], and agrochemical applications, respectively). Under the Soybean-Only scenario, profitability of TG at standard yield was $16,900 ($2,300, $13,800, and $4,100 for seed, agrochemical, and operating costs, respectively). Overall tractor use and labor declined by 25 and 38 h, respectively. Reductions of CE emissions were 6.98 kg ha\(^{-1}\) (1.42, 0.96, and 4.59 kg ha\(^{-1}\) from fuel, fertilizer, and agrochemicals). Finally, under the 50:50 Mixed scenario, estimated TG profitability was $42,900 for the 500-ha farm ($2,900, $36,100, and $7,200 for seed, agrochemical, and operating costs, respectively). Tractor use and labor declined by 48 and 72 h, respectively. Carbon equivalent emissions reductions for the 50:50 Mixed enterprise were 19.18 kg ha\(^{-1}\) (2.67, 3.97, and 12.54 kg ha\(^{-1}\) from fuel, fertilizer, and

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**Table 2. Carbon equivalent emission factors.**

<table>
<thead>
<tr>
<th>Input</th>
<th>Carbon equivalent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel (kg or L)</td>
<td>0.89†</td>
</tr>
<tr>
<td>Diesel (L)</td>
<td>1.21§</td>
</tr>
<tr>
<td>Fertilizer (kg) (N–P–K)</td>
<td>0.52</td>
</tr>
<tr>
<td>Urea (46–0–0)</td>
<td>0.79</td>
</tr>
<tr>
<td>Ammonium sulfate (21–0–0)§</td>
<td>0.11</td>
</tr>
<tr>
<td>Diammonium phosphate (18–46–0)</td>
<td>0.30</td>
</tr>
<tr>
<td>Potash (muriate of potash) (0–0–60)</td>
<td>3.33</td>
</tr>
<tr>
<td>Sodium borate (15% boron)</td>
<td>3.39</td>
</tr>
<tr>
<td>Average herbicides (kg or L)</td>
<td>5.65</td>
</tr>
<tr>
<td>Average fungicides (kg or L)</td>
<td>2.55</td>
</tr>
<tr>
<td>Average insecticides (kg or L)</td>
<td>3.73</td>
</tr>
</tbody>
</table>

† Carbon equivalent (CE) emission factors for multiple greenhouse gases (GHGs) created from using different inputs for growing cotton and soybean are adjusted for their global warming potential (IPCC, 2014; Long Trail Sustainability, 2016; USEPA, 2017) in CO\(_2\) equivalents. CO\(_2\) equivalents are multiplied by 12/44 to stoichiometrically arrive at CE. 1 Mg of CE = CO\(_2\) emissions from using one barrel of oil (USEPA, 2018).

‡ Chemicals are applied in both liquid and granular form. The average is used and reported here as a large number of chemicals are used in small quantities with negligible loss of accuracy.

§ Long Trail Sustainability (2016), reports GHG emissions during manufacture of various N fertilizers. 1.505 kg of CE are added per kg of N applied to account for N\(_2\)O emissions per kg of N applied in the field (IPCC, 2014). Transport of inputs is assessed a constant footprint of 0.03 kg of CE per kg of material moved from regional warehouses to farms (Thoma et al., 2013).

¶ Ammonium sulfate commonly contains 24% sulfate.
agrochemicals, respectively). Consequently, total farm reduction of CE emissions was 15.7, 3.5, and 9.6 Mg for cotton, soybean, and cotton–soybean operations.

**Conclusions**

These results show that economic and environmental impacts of TG use are (i) crop specific, (ii) scale dependent, and (iii) equipment and input-use specific (only partially shown here). Hence, the use of TGA has the potential to improve agricultural sustainability by optimizing nutrient and seed inputs while simultaneously decreasing fuel usage. Additionally, TGA can be used to estimate environmental implications (GHG emissions) of TG, as well as promote more judicious applications of nutrients that may enter water systems when overapplication is due to swath overlap in non-TG systems. Further, by providing producers an estimate of both economic and environmental repercussions of TG, adoption of this technology is expected to increase.

This is especially important as TGA estimates TG use to be cost-effective at the small scale. Hence, mid- to small-scale producers, who may be apprehensive about investing in technology that might be perceived as costly and/or requiring a long time for investment returns, may be convinced to adopt TG as they can tailor analysis of TG feasibility to their farm operating parameters using TGA. In the future, more robust environmental analyses are needed (e.g., life cycle assessment) to ascertain potential environmental impacts of implementing TG systems based on field shape, slope, and cropping system type across US farmscapes.

**References**

American Society of Agricultural and Biological Engineers (ASABE). 2011a. Standard ASAE EP496.3. ASABE, St. Joseph, MI.

American Society of Agricultural and Biological Engineers (ASABE). 2011b. Standard ASAE D497.7. ASABE, St. Joseph, MI.


