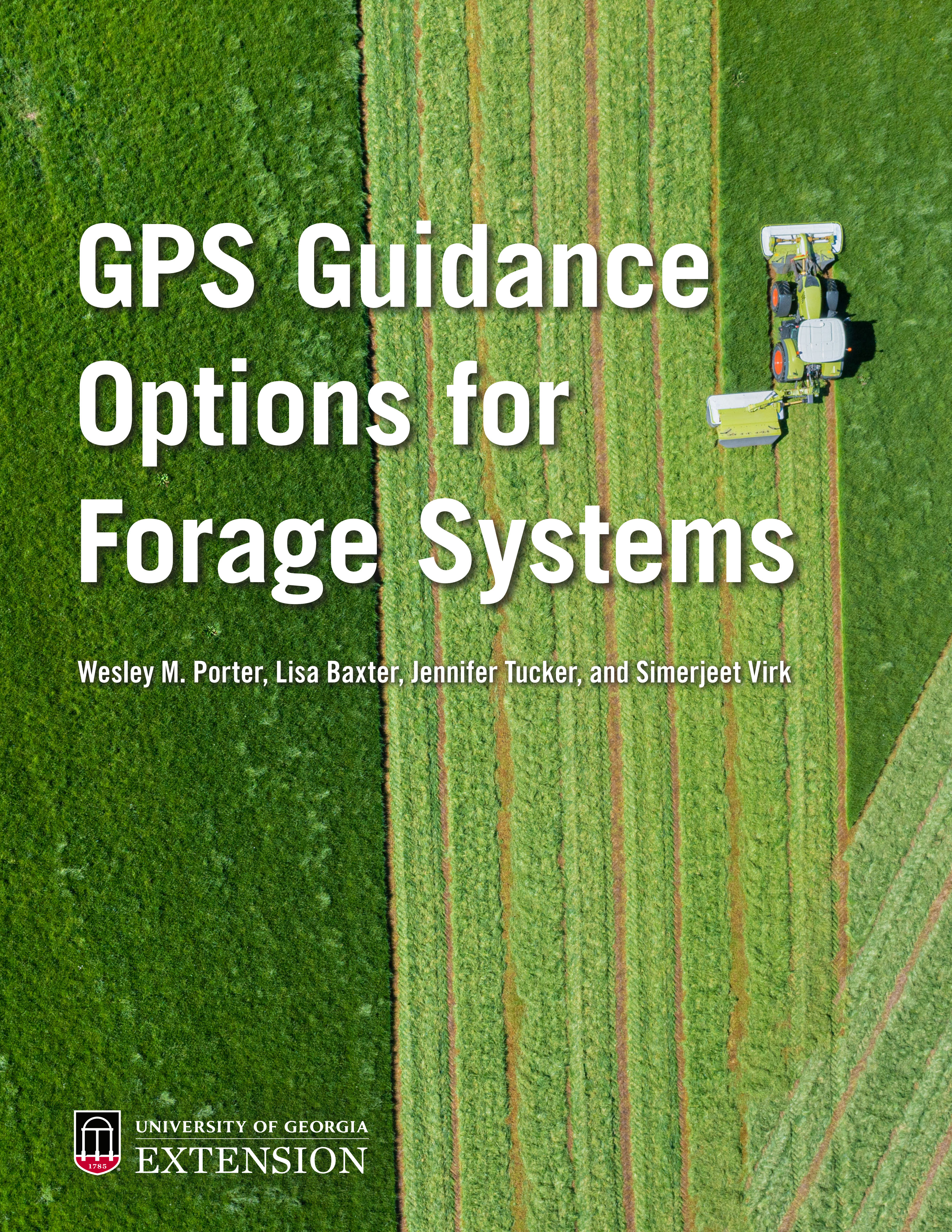

GPS Guidance Options for Forage Systems

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Some of the most widely adopted precision agriculture technologies include guidance systems with a Global Positioning System (GPS). Although these technologies are mostly used in row-crop agricultural systems, they also have many potential benefits in forage-based production systems. With so many different options to choose from, it can be a daunting task to determine which technologies are the best fit for a specific farming application and budget. When coupled with GPS augmentation systems (which are available in various correction accuracies), the accuracy of these guidance systems can be greatly improved. The main goal of this fact sheet is to discuss the GPS guidance options that currently are available for forage production systems.

Figure 1. Example of a spinner-disc spreader application pass. This demonstrates the difficulty of determining pass-to-pass distance without skips or overlaps.

Why use GPS guidance in forage operations?

The primary advantage of using GPS devices, specifically guidance aids, is the ability to follow a fixed guidance path. This reduces application errors, such as overlaps and skips, during common field operations. Recent studies show that operators who use foam markers during chemical application tend to overlap about 5% of the application width on each pass. Guidance aids, such as lightbars, can help reduce the overlap to less than 3% without increasing the number of skipped areas. This translates to more efficient chemical use. When operating applicators like spinner-disc fertilizer spreaders (Figure 1) or boomless sprayers, it is very hard to determine the exact location of the previous or next pass in the field.

Figure 2. This field shows areas missed during a spray application prior to no-till planting. A guidance system was not used during application, and the skipped areas can be seen across the field.

Much of the agricultural equipment that is used in forage-based production systems can benefit from GPS guidance aids, including chemical or fertilizer sprayers, spinner-disc spreaders, seed drills, and even forage harvesting equipment. Operators not using guidance systems often rely on tire tracks or soil disturbances to determine the next pass, which has obvious disadvantages and can cause overlaps and skips (Figure 2). These can be eliminated using a guidance aid to maintain an effective application width, resulting in fewer total passes and increased field efficiency. This leads to less time, fuel, chemicals, and seed used.

There are numerous GPS guidance aids available on the market, ranging from smartphone applications to automated steering aids. There is a wide range of prices, applications, and degrees of accuracy in these systems—from free options with low position accuracy to very expensive options that are accurate within an inch. Producers should decide what level of accuracy is needed for their operations, which will help narrow down the product range for their farms.

Guidance aids

Smartphone and tablet applications for manual steering

Searching for "agriculture GPS guidance" or "farm GPS guidance" in either the Google Play Store or Apple's App Store will reveal a whole range of applications (see Figure 3 for one example). A few considerations when selecting and using one of these applications are discussed here.

Accuracy of the GPS on the device being used for guidance. Smartphone GPS accuracy is primarily dependent upon the GPS signal and the towers currently being used for service. Generally, the internal GPS on a smartphone or tablet is not very accurate when operating alone, with its precision ranging from less than 3 ft to ± 30 ft. Newer smartphones can use cellular towers to increase the GPS accuracy in a process known as **assisted GPS**. A tablet without a cellular signal relies primarily on the accuracy of its internal GPS. Without a reliable cellular signal, these GPS systems are not designed to be accurate or repeatable at the level that is needed for agricultural work that requires precision to the foot or inch.

Update rate of GPS location on smartphones and tablets. The update rate on these devices typically is in the range of 1 Hz, which means that the system updates its location once per second, while most commercial GPS systems have an update rate of 5 or 10 Hz. A 1 Hz rate may seem fast enough, but when spreading fertilizer or spraying at 10 mph, about 15 ft would be covered before the system updated its location again. Thus, an update rate this slow would lead to too much error during field operations that occur at higher speeds.

Battery life of the smartphone or tablet. Smartphones and tablets are not designed to be operated continuously; doing so rapidly drains their batteries. Though it is not ideal, the system could be plugged in to avoid this issue. Before using a smartphone a guidance aid, carefully consider what other tasks you might use the phone for during operation. Texts, phone calls, emails, and other interruptions will distract an operator from using the system as a guidance aid.

Device mounting location in the vehicle. Ideally, the system will be mounted securely in the tractor so that it is easily visible and accessible to the driver but does not interfere with other in-tractor systems (e.g., baler monitor).

Reliability of the smartphone application. Some applications may have bugs and issues and may randomly restart or shut down. This will cause interruptions in field operations.

Demand on and availability of a cellular data connection. If cellular data is required to operate the application, consider whether reliable service is available in the area. Many applications do not work as desired because of the lack of connectivity.

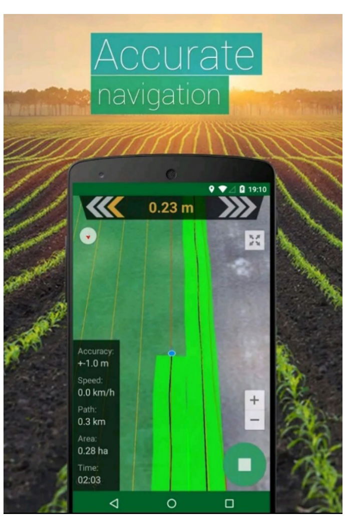

Figure 3. Example of the Field Navigator application by Farmis that can be used as a guidance aid on a smartphone or tablet.

Figure 4. An example of straight guidance lines or passes across a field set at the equipment width.

Manual steering aids

Entry-level guidance systems require manual steering, and manual steering aids were specifically designed for these systems, providing a virtual guideline (Figure 4) for the operator to follow. They provide instant feedback on how far off and in which direction from the actual guidance line the operator is steering (Figure 5). The most common manual guidance aid is a lightbar system, which helps agricultural machine operators steer along uniformly-spaced passes across a field. Lightbar guidance systems have been around for almost 30 years and are very simple to set up and use. Most lightbar systems include a differential GPS (DGPS) or GPS augmentation receiver and antenna, a computer or microprocessor, and a lightbar or graphics display.

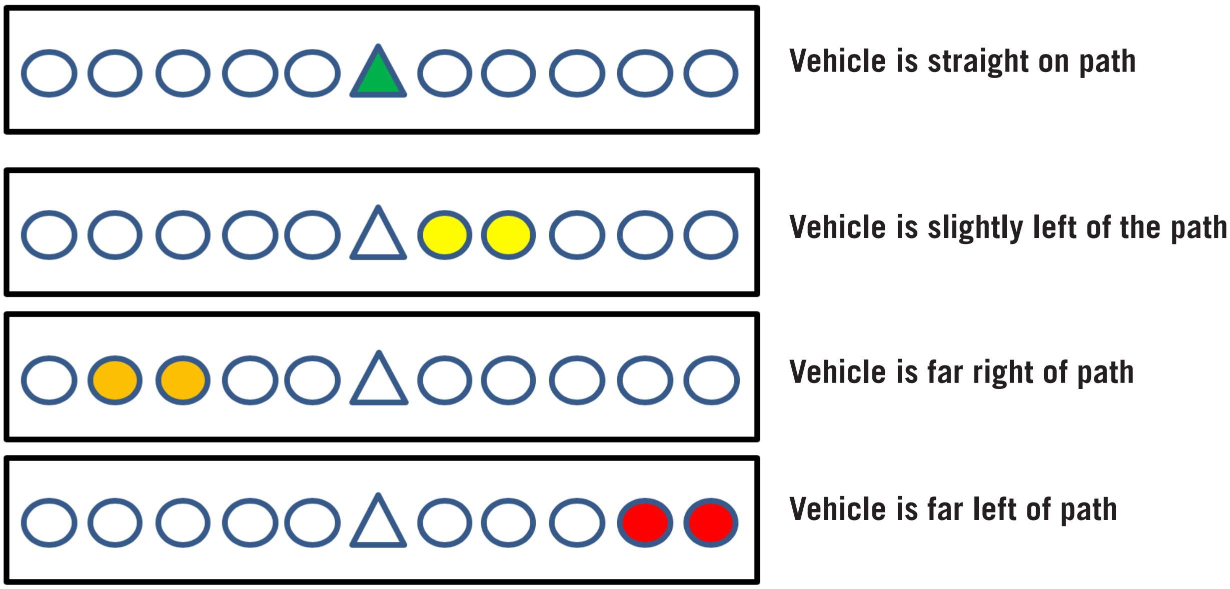

Figure 5. Illustration of lightbar guidance with four different equipment positions relative to the center line. The triangle in the center represents the vehicle, and the lights represent the location of the path to be followed.

The simplest lightbar displays are made of a single horizontal row of lights. The center light, which is sometimes a different color or shape, indicates the guidance path. As the vehicle deviates left or right of the path, the lights are turned on to represent the path location (as seen in Figure 5). The operator's goal is to keep the vehicle on the center of the path. The display will usually indicate the error distance to alert the operator of how far off the intended path they are. Lightbar displays come in many variations; some have a single row of lights, as shown in Figure 5, while others may have two rows of lights. Some systems even have LCD displays with 2-D and 3-D representations of the field and guidance paths.

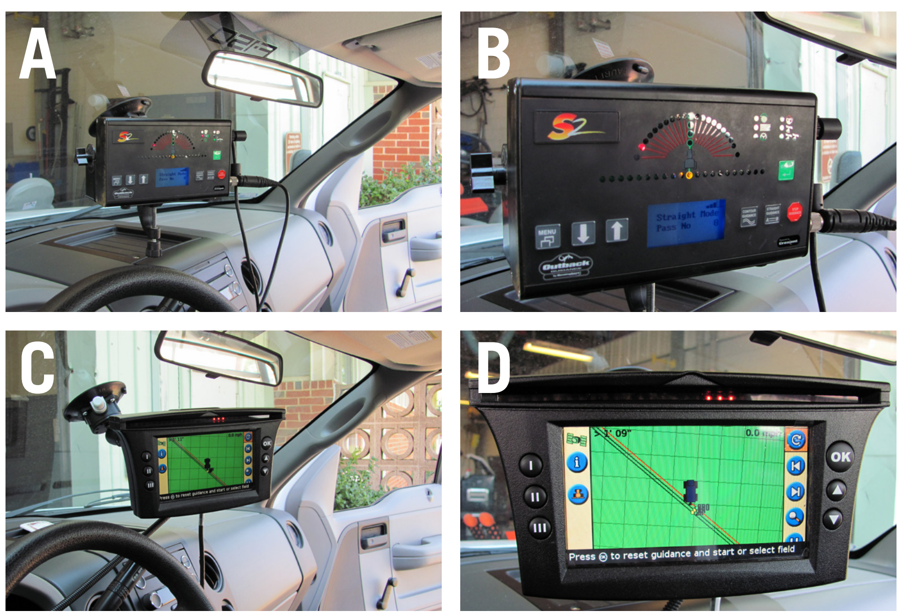

Figure 6. Examples of different types of lightbar guidance systems. A and B show the Outback Guidance system, which uses only lights to keep the driver on the line. C and D show the Trimble EZ-Guide, which has a row of lights at the top and an LCD display showing the guidance lines and current vehicle position in the field. As shown here, most manual steering aids can be used in any vehicle and are not limited to just tractors.

Some of the earliest systems were only able to create straight, parallel swaths. However, modern systems can guide along curved paths as well as other various field patterns, such as contour strips, irregularly shaped fields, and circular patterns for center-pivot irrigated fields.

Lightbar guidance aids can help reduce driver fatigue by having the guidance aid right in front of the operator rather than out in the field. This allows the operator to focus on driving rather than looking for row or foam markers. The operator also can pay attention to other machine functions and displays. When using a manual guidance system, it is important for the operator to remain alert, as guidance paths are independent of any obstacles in the field. The system will not provide a warning if there is a tree, terrace, hole, or any other obstacle. The operator must drive around the obstacle and line back up on the guidance path. In some of the newer units (especially those with LCD displays), these obstacles can be marked and displayed on the unit in the field, and the system can warn of their approach.

To set up and operate a lightbar system, the user must input basic parameters, such as the widths of the field, machine, and implement, and the agricultural operation being performed. Then the driver begins by steering the first pass through the field, selecting the type of A–B line they want to set up by pressing a button at the beginning (A) and end (B) of the pass. In some systems, marking A and providing a heading will set up the guidance lines, and a driven pass may not be required. The computer records the location of each point and uses the implement width to determine the location of each subsequent parallel pass across the field. The operator must perform the headland turns and position the vehicle onto to the next guidance line. The actual GPS position of the vehicle is compared to the calculated paths by the computer. The error and direction to the nearest line is shown on the display unit, so the operator knows which way to steer the vehicle to stay on the right path. The operator must pay close attention when using a lightbar, since the process involves manual steering and errors can still occur.

Figure 7. This device shows an area that was missed during alfalfa planting when using a lightbar guidance system. The area not covered is shown on the lightbar on the left, and this area in the field can easily be identified later in the season because the area was not planted.

A majority of lightbar systems record the path of the machine through the field. Some also record a coverage path that indicates if the machine was actively applying a product (see Figure 7). A coverage map can be a valuable resource of records for producers who wish to know the exact amounts of input and the locations where inputs were applied, along with the time of application. Lightbars also can improve machine operation in poor visibility. Glare during sunrise and sunset can make it difficult to see markers and references in the field, while the lightbar is still easily visible. Heavy vegetative cover can make it difficult to see the correct path in subsequent passes, and lightbars also solve this problem.

Automatic steering aids

For producers who want a more advanced guidance system, an automatic steering aid or auto-steer system is the next option. Auto-steer systems come in many different forms and accuracies, ranging from retrofit systems that clamp onto the steering column or steering wheel (Figure 8) to systems installed at the factory that fully control the hydraulic or electric steering on the tractor. While the cost of auto-steer systems can be significantly higher than lightbars and other guidance aids, they can prove useful on the farm. It can be difficult to justify purchasing guidance aids with a higher cost and accuracy, especially in low-input forage production systems that may not have the return on investment when compared to higher value crops (e.g., peanuts). While automatic guidance systems may not be beneficial in pasture-based systems used for grazing, they can be of significant benefit in high-quality forage operations.

Figure 8. A Trimble EZ-Steer clamp-on auto-steer system, in which the system controls the steering wheel to keep it centered on the guidance path. *Photo: Trimble Inc.*

Auto-steer systems are coupled with a GPS augmentation system and a field computer, which work together to steer the vehicle based on its current heading, speed, and location. These systems can come in many different types and brands. Their standard accuracy is less than 3 ft, but accuracy can be increased with a paid subscription, either through a satellite-correction signal or a radio-tower or cellular-phone correction network. These correction systems can increase accuracy to within an inch.

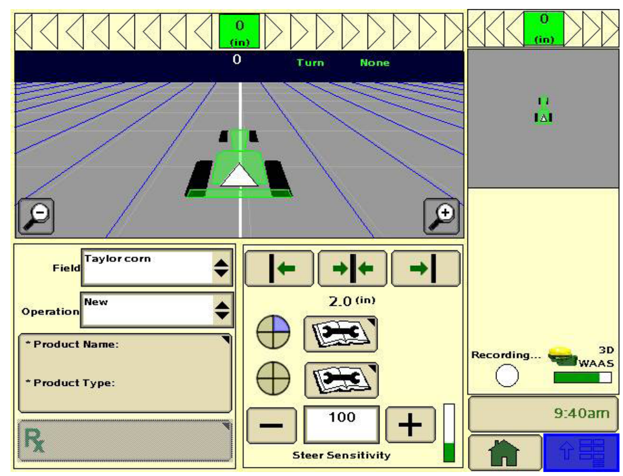

Figure 9. Screen capture of straight guidance lines, current GPS correction signal, and other information from a John Deere GPS auto-steer system.

Cost analysis and return on investment

System costs and associated accuracy

Just as with any aspect of farming, producers get what they pay for. The individual costs of these technologies are based on specific needs. The typical price for new lightbars ranges from around $400 to $2,000. While this seems like a large range for a guidance aid, remember that the lower end of the price range likely will be a lightbar that just has a single row of LED lights and a Wide Area Augmentation System (WAAS)-compatible GPS. If you are able to spend more money, features such as an LED screen and higher accuracy GPS are available. Auto-steer systems range from around $2,000 for retrofit clamp-on systems to around $20,000 for higher accuracy integrated systems. As shown in Table 1, cost generally is tied to the accuracy of the system. In most cases, two accuracy measurements are provided for GPS systems: a GPS correction and repeatability accuracy, and a pass-to-pass accuracy. The repeatability accuracy is the guaranteed accuracy of the system when used over any time period, while the pass-to-pass accuracy is the guaranteed accuracy of the system during a single event. The pass-to-pass accuracy is much higher than the GPS repeatability accuracy because the system is using the same satellite constellation while the field operation is being performed.

Table 1. Accuracy and cost of common guidance aids used in forage production systems.

GPS system	Approximate accuracy	Cost range
Smart phone or tablet application	± 15–18 ft	Free
Manual steering aid: Light-only lightbar	± 1–3 ft	\$200 (used) to \$1,000 (new)
Manual steering aid: Virtual screen lightbar	± 1–3 ft	\$1,000 to \$4,000
Automatic steering aid: Clamp-on auto-steer	± 4–12 in.	\$2,000 (used) to \$15,000 (new)
Automatic steering aid: Retrofit/integrated real-time kinematic (RTK) auto-steer	± 0.5–6 in.	\$20,000 to \$30,000

Anticipated return on investment

In addition to the cost of a system, the cost of misapplication (either because of skips or overlaps) can be a major issue in forage production. Table 2 illustrates the estimated costs for 1%, 5%, and 10% overlaps in both hayfields and pastures. The calculations were made using common forage management practices applied annually to a hybrid bermudagrass pasture or hayfield. These calculations do not account for fixed costs (e.g., equipment), variable costs related to the application of the products, or additional products such as insecticides. The average cost per acre was calculated to be \$342.41 and \$236.79 for a hayfield and pasture, respectively, using the assumptions detailed below.

Following University of Georgia Cooperative Extension recommendations, we assumed that fertilizer was applied at a rate of 300 lb N, 60 lb P_2O_5, and 250 lb K_2O per acre for hayfields; and 200 lb N, 30 lb P_2O_5, and 120 lb K_2O per acre for pastures. Nitrogen was applied as urea-ammonium nitrate (32% N), phosphorus was applied as monoammonium phosphate (52% P_2O_5), and potassium was applied as muriate of potash (60% K_2O). Calculations included one ton of dolomitic limestone, regardless of management. All fertilizer and lime prices were based on DTN reports from January 2021.

Since UGA offers a variety of herbicide recommendations, we followed a typical protocol based on producer calls from the past year. For the hayfield scenarios, we assumed indaziflam was applied at 6 oz per acre per year, nicosulfuron + metsulfuron at 1.5 oz per acre per year, and aminopyralid + 2,4-D at 20 oz per acre per year. For the pasture scenarios, we assumed aminopyralid + 2,4-D was applied at 20 oz per acre per year. All herbicide prices were based on average quotes from farm supply stores in southwest Georgia.

Most livestock producers overseed their bermudagrass pastures with a winter annual forage to extend the grazing season. For our calculations, we assumed rye was planted at 90 lb of pure live seed per acre and fertilized with 100 lb N (urea-ammonium nitrate) per acre.

As expected, the costs increase as overlaps increase because of the overapplication of fertilizer, herbicide, and seed inputs (Table 2). This difference is likely much larger if you consider application costs, such as the amount of time spent applying and the number of passes across the field.

In a standard calculation, skips can be perceived as savings and can continue to accumulate with increasing acreages (Table 3), but so will the consequences. Cost estimates for skipped areas decrease because fewer inputs were applied—likely resulting in significant yield loss and

Table 2. Estimated costs of common inputs when overapplied to hybrid bermudagrass forage.

	Total cost per acre	
Percent overlapped	**Hayfield[1]**	**Pasture[2]**
10%	\$376.65	\$260.47
5%	\$359.53	\$248.63
1%	\$345.83	\$239.16
Average standard application cost	\$342.41	\$236.79

Note. Please refer to the text under "return on investment" for the full list of assumptions.

[1] Hayfield costs assume anticipated fertilizer and herbicide expenses.

[2] Pasture costs assume anticipated fertilizer, herbicide, and winter annual forage expenses.

pest problems in the field due to the lack of application. These consequences are difficult to quantify and can differ for each farm, but can include the following problems:

- Lower forage yield, lower forage quality, and poorer stand persistence from fertilizer skips
- Decreased nutrient availability from lime skips
- Increased weed pressure, increased livestock refusal, and increased likelihood of problem weeds from herbicide skips
- Poorer establishment of annual crop from fertilizer, lime, herbicide, and/or seed skips
- Fewer grazing days or fewer bales harvested because of fertilizer, lime, herbicide, and/or seed skips

Table 3. Estimated additional costs or savings of common inputs over- or underapplied to hybrid bermudagrass forage.

	Added cost or savings	
Percentage overlapped or skipped	**Hayfield**	**Pasture**
Difference for 1 acre		
1%	$3.42	$2.37
5%	$17.12	$11.84
10%	$34.24	$23.68
Difference for 100 acres		
1%	$342.41	$236.79
5%	$1,712.05	$1,183.97
10%	$3,424.10	$2,367.93
Difference for 250 acres		
1%	$856.02	$591.98
5%	$4,280.12	$2,959.91
10%	$8,560.24	$5,919.83

Table 3 shows the differences in the total costs or savings for 1, 100, and 250 acres when inputs are over- or underapplied. While the difference for one acre is minimal, as more acres are covered the difference becomes significant very quickly. Based on the results in Table 3, a producer could cover the cost of a lightbar and virtual-screen system with the potential savings in just 1 year if the producer is managing 100 or 250 acres.

Devices that are unacceptable for use as agricultural guidance systems

Because of their past popularity and affordability, a lot of people may own a standard handheld GPS device (Figure 10). Handheld GPS devices can be found at most sporting goods stores for a cost of $100 to $500. Since so many people may already own a handheld GPS, it is only natural to want to use it for guidance. However, these are not designed for agricultural guidance applications. These handheld units are great for marking points, paths, and boundaries, and navigating back to them. However, they do not have the capability to act as a guidance aid because they are not designed to follow a sequential set of guidance lines in a straight trajectory across a field. Other common GPS devices that are not acceptable for using as guidance aids are mobile car-navigation systems, as they rely specifically on preprogrammed road map layers for navigation and are not usable for off-road navigation.

Figure 10. Two typical brands of handheld GPS units.

Conclusion

There are many GPS devices available on the market, with prices ranging from free to thousands of dollars. Each device has its own intended use and specific functions, so not every GPS-enabled device can be used as a guidance aid. Forage operations provide a unique situation where a guidance aid can be extremely useful and valuable when properly integrated into the production system. Producers should choose the guidance aid that best fits their budget and desired level of accuracy. A lightbar-style system is an excellent choice for an entry-level guidance option because they are a low-cost technology that can bring many advantages to farming operations. These technologies have been around and utilized in row-crop production systems for many years. Therefore, there may be an ample amount of used equipment available. Purchasing a used, older (simpler) model can be a great option when starting out to determine the effectiveness within a producer's system. The selection of the appropriate guidance aid for a hay and/or pasture operation has the potential not only to cover its investment cost in a year or less, but also to make the farm more profitable by reducing the misapplication of critical inputs. This saves chemicals and fertilizers and also increases yield.

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