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Article

Reducing Digging Losses by Using Automated Steering to Plant and Invert Peanuts

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Abstract: GPS guidance of farm machinery has been increasingly adopted by farmers because of the perceived gains in efficiency that it provides. In the southeastern USA one of the reasons farmers adopt GPS guidance, and specifically automated steering (auto-steer), is that it can theoretically result in large yield gains when used to plant and invert peanuts—one of the region's most important crops. The goal of our study was to quantify the yield benefit of using real time kinematic (RTK)-based auto-steer to plant and invert peanuts under a variety of terrain conditions. Yield benefits result from reduced digging losses. The study was conducted for two consecutive years (2010 and 2011) on a private farm in Georgia, USA. When all data are grouped together, auto-steer outperformed conventional by 579 kg/ha in 2010 and 451 kg/ha in 2011. We also evaluated the performance of auto-steer under different curvature conditions using low, medium, and high curvature rows. The results showed that auto-steer outperformed conventional under all curvature by a minimum of 338 kg/ha. Finally, we evaluated passive implement guidance in combination with auto-steer and found that it holds tremendous potential for further reducing digging losses. In many cases, auto-steer will pay for itself within a year.

Keywords: GPS; auto-steer; RTK; planting; inverting; peanuts; yield benefit; passive implement guidance; digging losses

1. Introduction

GNSS (Global Navigation Satellite System but commonly referred to as GPS) guidance of farm machinery has been adopted by increasingly larger segments of the farming community over the past decade because of the inherent gains in efficiency that it provides [1,2]. The authors of [3] estimated that, in 2010, guidance system adoption on areas planted to maize and soybean in the USA was in the range of 15%–35%. The authors of [4,5] attributed increased crop yields to the use of GNSS guidance for strip tillage operations. The authors of [5,6] also reported yield gains when using GNSS guidance during planting and for optimum input placement. The authors of [3] reported significant reductions in fuel consumption as a result of using auto-steer and [7] reported that auto-steer use increased net returns of a grain farmer in Kentucky by 0.90% (USD8.27/ha). As a result, it is now common to find farmers who own multiple vehicles (tractors, sprayers, and harvesters) equipped with GNSS guidance. In many areas of the USA, the most advanced and expensive form of GNSS guidance, RTK-based automated steering (auto-steer), is also being quickly adopted by farmers. In the southeastern USA one of the reasons farmers are quick to adopt GPS guidance, and specifically auto-steer, is that it can theoretically result in large yield gains when used to plant and invert peanuts—one of the region's most important crops [8].

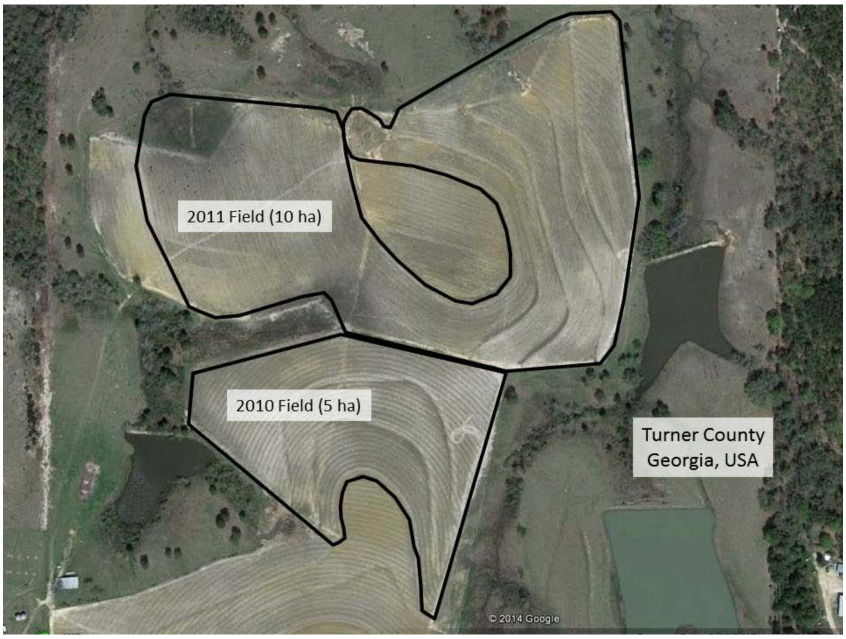
The peanut, or groundnut (*Arachis hypogaea*), is a low growing crop which produces its fruit under-ground much like the potato. As the peanut plant matures, it produces nuts (fruit) on the crown of the plant as well as on vines that extend outwards from the main stem. Much of the yield is found on the vines. Peanut harvesting is a two-step process. First an inverter passes through the field. The inverter undercuts the tap root and inverts the plant so that it is laying on the soil with the leaves down and the nuts lying upwards. This process is commonly referred to as "digging" the peanuts. After a few days of drying in the field, the plants are harvested mechanically. It is very important that the tractor pulling the inverter pass as close as possible over the centerline on which the peanuts were planted otherwise the inverter will cut off sections of the vines and those peanuts will remain in the soil. With most modern "runner" type cultivars, when the peanut plants are mature, their canopy completely covers the soil and it is visually very difficult to identify the centerline on which peanuts were planted. Consequently farmers regularly incur what they call "digging losses"—peanuts lost during inverting. Digging losses are also affected by the tillage system used (conventional *versus* conservation tillage), soil texture, soil moisture conditions at the time of inversion, and peanut maturity. Digging losses may range from 15% to 30% of the peanut crop's potential yield [9].

RTK-based auto-steer offers peanut farmers the potential of being able to follow the planting centerline with both accuracy and precision when inverting their peanuts [9] used auto-steer to intentionally invert peanuts at increasing distances from the planting centerline and showed that peanut yields decreased with distance. The goal of this study was to quantify the yield benefit of using RTK-based auto-steer to plant and invert peanuts on the farm under a variety of terrain conditions.

2. Methods

The study was conducted for two consecutive years (2010 and 2011) on a commercial farm in Georgia, USA. Georgia is the leading peanut-producing state in the USA. During each year a field with sloped land and field rows with varying degrees of curvature was selected for the study. In addition, both fields contained steep earthen terraces installed decades ago to reduce erosion. These terraces were not parallel to each other nor were they parallel to the row pattern currently used by the farmer. As a result, the tractor and implement were required to cross these terraces at various angles during all field operations. The fields were adjacent to each other (Figure 1) and were irrigated with center pivot irrigation systems. Field size was 5 ha in 2010 and 10 ha in 2011. The fields were divided into alternating strips representing treatments.

Figure 1. Google Earth image of the two fields used in the study. The field used in 2011 was expanded to the black boundaries shown in the figure to accommodate a new center pivot irrigation system. The tear drop-shaped area in the middle of the field was not used for the study. Non-parallel earthen terraces used to control erosion are clearly seen in both fields.



2.1. Treatments

In 2010 there were two treatments—conventional and auto-steer (Figure 2). In 2011 there were three treatments—conventional, auto-steer, and auto-steer with passive implement guidance (Figure 3). Each strip consisted of three passes of four row equipment (12 rows, 4 rows per pass). The same farm equipment (tractor, planter, and inverter) were used for all treatments—the auto-steer was either engaged or not engaged depending on the treatment. The tractor belonged to the University of Georgia (UGA) Precision Agriculture Team while the implements belonged to the cooperating farmer. Conventional treatments were planted and inverted without using GNSS guidance. Auto-steer treatments were planted and inverted using a Trimble AgGPS Autopilot™ auto-steer system with tower-based RTK correction and ±2.5 cm (1 in) accuracy and ±2.5 cm (1 in) year-to-year repeatability. The RTK tower-based correction system is maintained by Ag Technologies LLC (Cordele, GA, USA). The auto-steer with passive implement guidance treatments were planted and inverted using the Trimble AgGPS Autopilot™ auto-steer system with AgGPS Trueguide™ implement guidance. A single A–B line created prior to planting along the innermost curve of the field (Figures 2 and 3) was used for all subsequent auto-steer passes during planting and inverting.

Figure 2. Experimental design used in 2010. Each replicate (colored strip) = 12 rows of peanuts or three 4-row passes. Numbers indicate strips used during data analysis.

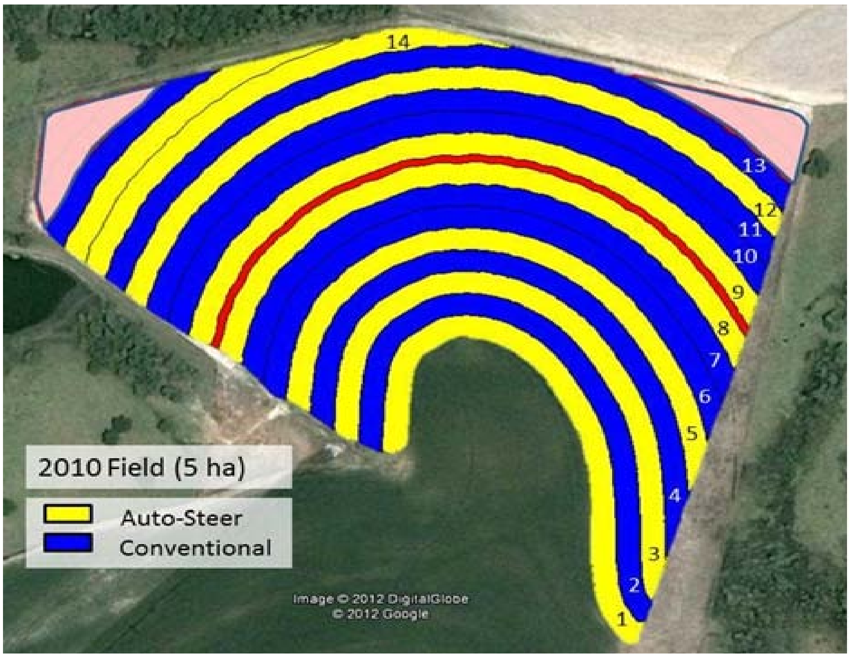
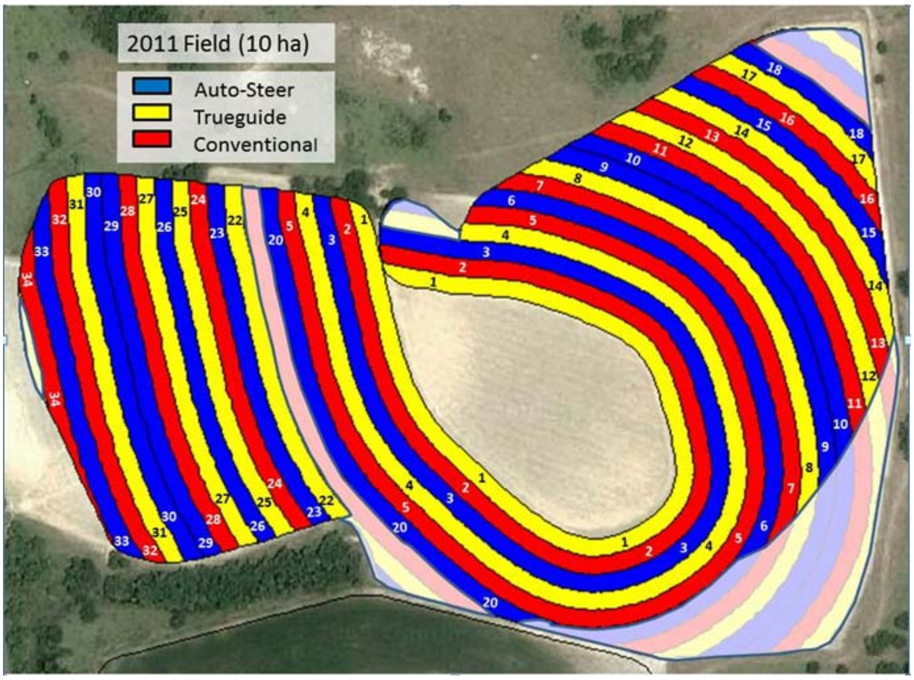


Figure 3. Experimental design used in 2011. Each replicate (colored strip) = 12 rows of peanuts or three 4-row passes. Numbers indicate strips used during data analysis.



The Trueguide™ system is a "passive" guidance system that affects the position of the implement by adjusting the path of the tractor to place the implement on the centerline. Implement guidance is particularly useful when working on sloped lands with curvature where the implement tends to drift off the centerline. To be fully effective, the Trueguide™ system requires the implement to be towed rather than mounted. This allows the tractor's longitudinal axis to be in a different orientation from that of the implement's and permits the automated steering system to adjust the direction of travel of the tractor in order to place the implement on the centerline. In our study, both implements (planter, inverter) were mounted to the tractor with a 3-point hitch which limited the effectiveness of the Trueguide™ system.

2.2. Planting and Harvest

Peanuts were planted using strip tillage. Tillage and planting were done as a single operation. The Georgia-06G peanut cultivar was used during both years. Peanuts were inverted (Figure 4) and allowed to dry for two to three days before harvest. During the 2010 harvest, the "middle" pass of each strip within each treatment was harvested individually. The two "outside" passes in each strip were considered buffer passes and not harvested individually. The peanuts harvested from the middle pass were emptied by the harvester into a peanut wagon mounted on four load scales and the mass of peanuts recorded (Figure 5). During 2011, all three passes in each strip were harvested individually and their yield recorded individually. The measured mass of peanuts was corrected for foreign material content and moisture content using grading data from the United States Department of Agriculture grading office at the buying point to which the cooperating farmer sold his peanuts.

Figure 4. Inverting peanuts with a 4-row KMC (Kelley Manufacturing Company, Tifton, GA, USA) peanut inverter pulled by the University of Georgia (UGA) tractor equipped with a Trimble® AgGPS Autopilot™ auto-steer system.

Figure 5. Peanut harvester emptying a load of peanuts into a peanut wagon (left) and load scales used to record weight of peanuts harvested from a pass (right). A load scale is located under each wheel of the wagon.

2.3. Data Analysis

The experimental design was entered into the Farm Works™ software which was used to measure and verify strip length and area. In addition, the strips were grouped into low, medium, and high curvature rows. Curvature was estimated by using the radius of curvature formula [10]

$$r = \frac{(c/2)^2 + h^2}{2h} \tag{1}$$

where:

r = the radius of curvature in units of length
c = the length of the chord, and
h = the height

These variables are illustrated in Figure 6. The formula was applied to the middle pass of each strip using a 150 m (500 ft) arc length as shown in Figure 6. The Farm Works™ software was used to superimpose the arc over the strip. The chord (*c*) was snapped to the endpoints of the arc and its length measured. The height line (*h*) was then placed at the midpoint of the chord at a right angle and its length to the arc measured. Using English units, the measurements were entered into Equation (1) and the radius of curvature (*r*) calculated—the smaller the calculated radius of curvature, the higher the curvature of the strip. Strips with a radius of curvature of less than 400 ft were designated as high curvature, those between 400 ft and 1000 ft as medium curvature, and those above 1000 ft as low curvature. The 2010 field contained only medium and high curvature strips (Figure 7) while the 2011 field contained low, medium, and high curvature strips (Figure 8).

Figure 6. Screenshot from the The Farm Works™ software showing how the radius of curvature analysis was conducted. We superimposed an arc of 121 m (500 ft) over the center of each strip. The chord (c) was snapped to the endpoints of the arc and its length measured. The height line (h) was then placed at the midpoint of the chord at a right angle and its length measured. The measurements were entered into the formula on the right and the radius of curvature (r) calculated—the smaller the calculated radius of curvature, the higher the curvature of the strip.

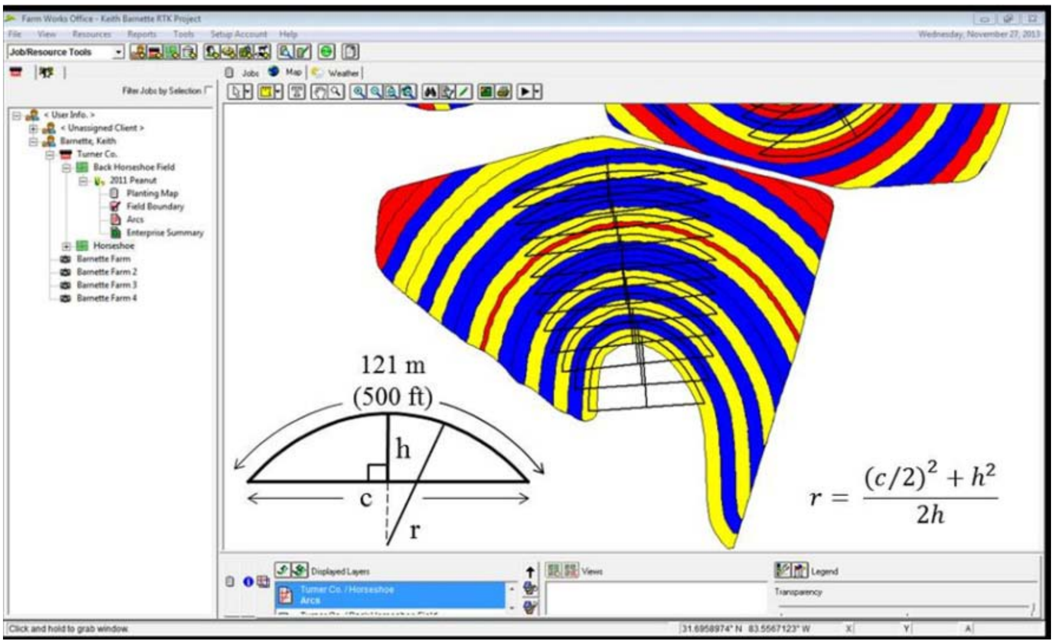


Figure 7. The 2010 field was divided into high and medium curvature areas.

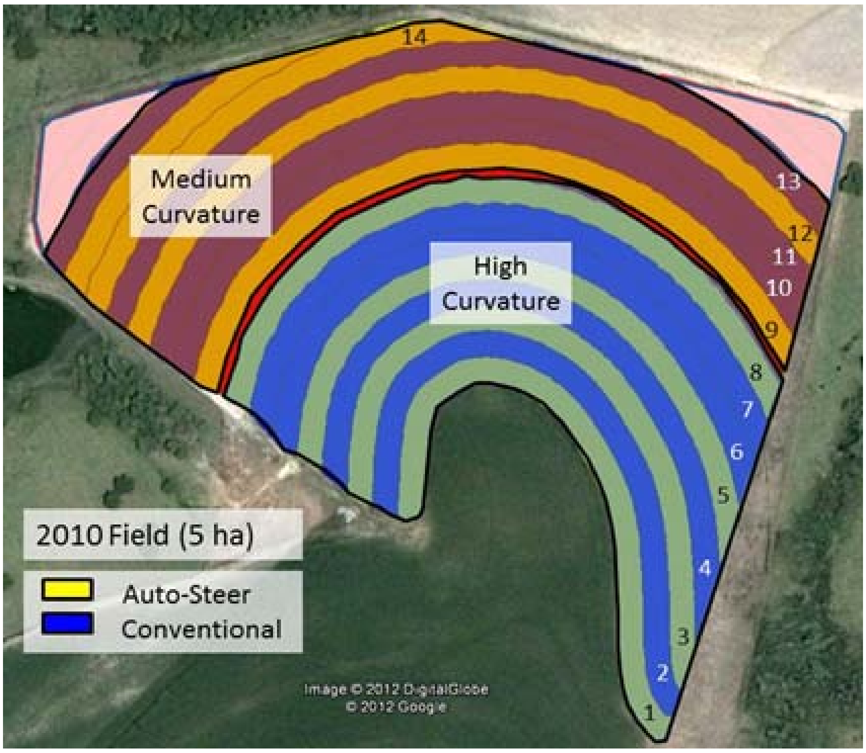
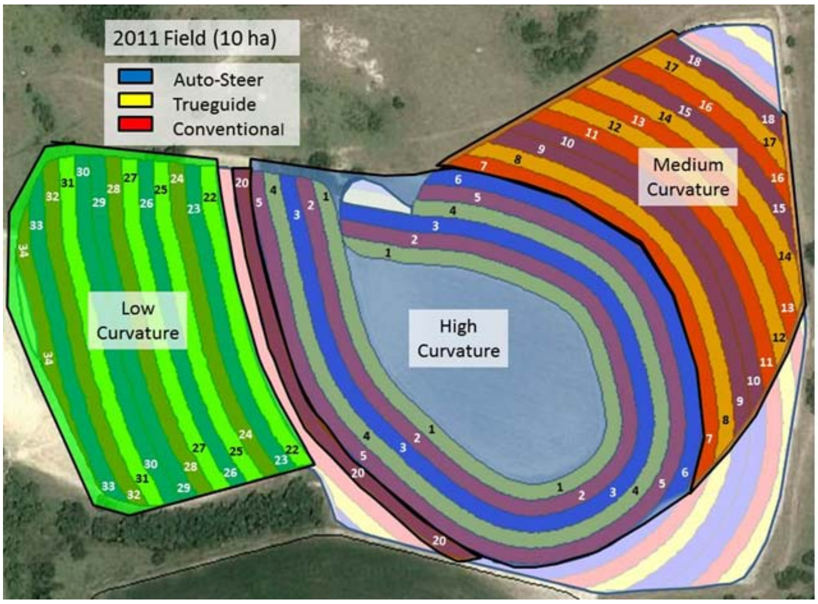


Figure 8. The 2011 field was divided into high, medium, and low curvature areas. Strip 20 is included in the medium curvature area.



Data were analyzed two different ways: (1) they were grouped together by treatment and compared; and (2) they were grouped by curvature of the rows harvested and treatment and compared. To be consistent with 2010, only data from the middle pass in 2011 were used for comparisons. Treatments were compared statistically using the *t*-test. We used an alpha level of 0.05 for all statistical tests.

3. Results and Discussion

When all data were grouped together, auto-steer outperformed conventional by 579 kg/ha in 2010 and 493 kg/ha in 2011 (Table 1). Auto-steer outperformed conventional by an average of 536 and 488 kg/ha in high curvature and medium curvature rows, respectively (there were no low curvature rows in the 2010 field). In 2011, auto-steer outperformed conventional by 642 kg/ha in low curvature rows. The differences were statistically significant. Table 1 summarizes the comparison between conventional and auto-steer. These results indicate that there is no clear curvature effect on the performance of auto-steer. The curvature results were somewhat surprising at first because all involved with this project expected the opposite result. In retrospect, however, this result is logical. It was originally assumed that under low curvature conditions, a human operator would be able to follow the centerline well. In fact, the solid green peanut canopy encountered when inverting peanuts makes it difficult for the human operator to align the tractor with the planting centerline whereas the auto-steer system can place the tractor within 2.5 cm of the centerline.

Table 1. Comparison between the effect of conventional and auto-steer on peanut yield during the 2010 and 2011 studies.

Curvature	Treatment	2010 Average Yield (kg/ha)	2010 Difference [2] (kg/ha)	2010 Economic Gain [3] (USD)	2011 Average Yield (kg/ha)	2011 Difference [1] (kg/ha)	2011 Economic Gain [2] (USD)
All Rows [1]	Auto-Steer	5748	579	27,851	6187	493	37,540
	Conventional	5169			5694		
High Curvature	Auto-Steer	5804	338	16,274	6648	637	48,521
	Conventional	5466			6011		
Medium Curvature	Auto-Steer	5518	745	35,821	6269	491	37,372
	Conventional	4773			5778		
Low Curvature	Auto-Steer	N/A			6013	642	48,889
	Conventional	N/A			5371		

[1] Includes all rows regardless of curvature; [2] Difference = Auto-steer—Conventional; [3] Economic Gain is calculated using peanut prices of 660 USD/tonne in 2010 and 1045 USD/tonne in 2011.

3.1. Trueguide™ Compared to Auto-Steer and Conventional

The Trueguide™ system performed poorly under high curvature conditions yielding 146 kg/ha less than conventional and 783 kg/ha less than auto-steer. The difference in means between Trueguide™ and auto-steer was statistically significant. This was expected based on the observed performance of the system during planting and inverting. Because of the 3-point hitch, the AgGPS Autopilot™ automated steering system was unable to adjust the direction of travel of the tractor to place the implement over the centerline of the sharply curved rows—when the tractor's longitudinal axis changed direction so did the implement's. As a result, the system was constantly under-correcting or over-correcting without being able to properly adjust to the conditions.

In contrast, under low curvature conditions, the Trueguide™ system was able to outperform conventional and auto-steer by 896 kg/ha and 255 kg/ha, respectively. The difference in means between Trueguide™ and conventional was statistically significant. This is likely because even with the 3-point hitch, the less demanding terrain (low curvature and lower slope) allowed the system to better place the implement over the centerline. Although the Trueguide™ system shows impressive benefits under low-curvature, low-slope conditions, it cannot be used to its maximum potential when the implement is mounted to the tractor rather than towed by the tractor.

3.2. Effect of Auto-Steer on Digging Losses

As mentioned earlier, digging losses in peanuts may range from 15% to 30% of the crop's potential yield. When peanuts are grown with strip tillage on finer-textured, less friable soils as was done in this study, digging losses may approach the upper end of this range. For example [11] measured digging losses of 26% in strip tillage peanuts planted and inverted without auto-steer at a location in southern Georgia with similar soils. Assuming similar digging losses for the overall average conventional yields measured in this study (5169 and 5694 kg/ha for 2010 and 2011, respectively—Table 1), then the potential yields for 2010 and 2011 would be 6985 and 7694 kg/ha, respectively. At 26%, the theoretical digging losses would then be 1816 kg/ha in 2010 and 2000 kg/ha in 2011. By using auto-steer, digging losses were reduced by 579 kg/ha (32%) in 2010 and 493 kg/ha (25%) in 2011. In other words, estimated digging losses for all curvatures combined were reduced to 18% in 2010 and 20% in 2011. Digging losses were further reduced in the medium and low curvatures when using the Trueguide™ system in 2011.

3.3. Economic Returns from Using Auto-Steer

Table 1 also includes the economic benefit resulting from applying the measured yield gains to the average area planted to peanuts each year by the cooperating farmer (73 ha). Using the yield gain resulting from auto-steer under all curvature conditions (579 kg/ha in 2010 and 493 kg/ha in 2011), the farmer would have realized an economic gain of USD 27,851 in 2010 and USD 37,540 in 2011. The large difference in economic return between 2010 and 2011 is caused by the large difference in peanut prices between the two years. In 2010, the crop market value for peanuts was approximately 660 USD/tonne while in 2011 the crop market value was approximately 1045 USD/tonne. Considering that installation of an RTK tower-based auto-steer system on a tractor costs between USD 22,000 and USD 25,000 (depending on the manufacturer) and requires an annual RTK correction subscription of between USD 800 and USD 1000, investing in an auto-steer system is a good economic decision as the system can easily pay for itself in a short time period. It should be noted that these results include only the economic benefits resulting from reduced yield losses and do not include other economic benefits of using auto-steer such as reduced expenses from fuel savings or indirect yield increases resulting from timely planting of larger areas, *etc*. Few studies have addressed the economic returns gained by using auto-steer but [12] showed that auto-steer becomes more profitable as farm size increases.

4. Conclusions

The experiment reported here conclusively shows that using RTK-based auto-steer to plant and invert peanuts results in substantial yield gains and associated economic returns by reducing digging losses. Auto-steer performs effectively under a variety of terrain conditions and its performance does not appear to be affected by curvature. When added to the other efficiency gains resulting from consistently using auto-steer for farm operations such as spraying, tillage, *etc*., investing in auto-steer appears to be a sound investment for many farmers. Because of this, peanut industry observers report that auto-steer is quickly becoming an essential tool for farmers in the southeastern USA who include peanuts in their crop rotation [8].

Acknowledgments

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Author Contributions

George Vellidis and Brenda Ortiz were co-project leaders of this research project. John Beasley contributed to the grant proposal, experimental design, and data analysis. Rodney Hill, Herman Henry, and Heather Brannen contributed to the data collection and data analysis.

Conflicts of Interest

The authors declare no conflict of interest.

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