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VARIABILITY OF SUBSURFACE DRIP IRRIGATION (SDI) TAPE PLACEMENT USING RTK-GPS GUIDED EQUIPMENT

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Abstract

Maintaining crop rows in subsurface drip irrigated (SDI) fields at precisely the same parallel distance to drip irrigation laterals, year after year, is very difficult. Crop row to drip lateral distance directly affects seed germination and plant development, particularly in areas of limited irrigation capacity. Newer SDI systems are installed with GPS guided tractors to improve positional accuracy. A 4.5-acre experimental SDI system was installed at the TAES research facility at Halfway in July 2005. The drip tape was plowed in at a depth of 13 inches from the level soil surface using a GPS guided tractor with RTK (Real Time Kinematic) correction. The software program ArcMap™ 9.0 (ESRI, Redlands, California) was used to create shape files (polylines) that provided input for tractor guidance during drip lateral installation. Following installation, tape laterals were excavated at 192 sites and UTM coordinates of the laterals were obtained to reference their locations using portable RTK-GPS equipment. Differences in desired and actual tape location followed a normal probability distribution with 60% of the tape laterals within one inch of their referenced locations, 88% within two inches, and 97% within three inches.

Introduction

Maintaining crop rows in subsurface drip irrigated (SDI) fields at precisely the same parallel distance to drip irrigation laterals, year after year, is very difficult. Crop row to drip lateral distance directly affects seed germination and plant development particularly in areas of low rain and limited irrigation capacity. Many new SDI systems are installed with GPS guided tractors to improve uniform, parallel spacing of drip laterals compared to non-GPS guided installations. Commercially available tractor guided systems are capable of sub-inch repeatability when using their RTK systems (John Deere Starfire™ RTK, Trimble® AgGPS® Autopilot™, Autofarm RTK Autosteer™). An evaluation by Ehrl, et al. (2004) of RTK based guidance systems resulted in an average deviation from the planned track of 1.0-inch, although maximum deviations reached 4.0 inches. Ehrl et al. (2004) also noted downhill drift and yaw causing maximum Cross Track Error (XTE) of 9.4 inches when their guided tractor was loaded while planting wheat. The guidance accuracy of a tractor restrained by a draft load such as when pulling a SDI chisel plow may be different from that of a tractor in a non-draft situation. Deviations in final drip tape location relative to desired location could be caused by errors in the tractor guidance system, unrestrained movement in the hitch between the tractor and the plow, variations in instantaneous side loading of the plow while installing tape laterals, and/or errors in referencing the final drip tape location. This paper describes measured differences between target drip tape locations and final locations determined by a portable RTK-GPS system and also compares these measurements to similar distances resulting from 1) a non-draft, RTK-GPS guided tractor and 2) a non-GPS guided SDI installation.

Methods and Materials

A SDI system was installed on a 4.5-acre field at the Texas Agricultural Experiment Station, Halfway, TX (3500-ft elev., 34^0 9’N, 101^0 56’ W). The field is located in a transitional soil changing from a Pullman clay loam (fine, mixed, thermic Torrertic Paleustolls) at high elevations to an Olton loam (fine, mixed, thermic Aridic Paleustolls) at lower elevations. Prior to SDI installation the field was surveyed using mobile GPS survey equipment. From this map, drip tape lateral positions and corresponding GPS tractor guidance files were created using ArcMap™ 9.0 (ESRI, Redlands, California) software. The resulting guidance files (shape files) were loaded into a Trimble AgGPS 214 system onboard a John Deere 7420 4WD tractor. The drip lateral installation plow was a three bar tool (4”x 4” w/full top mast, Bigham Brothers Inc. Manufacturing, Lubbock, TX) with two 30” parabolic shanks and 2-inch tape installation tubes. The shanks were positioned so that the centers of the tape outlets were equidistant ($\pm$ 0.25”) from the centerline of the plow. The plow was mounted on the tractor using a standard Category III three-point hitch (ASAE, 2001) with auxiliary sway blocks that eliminated all visible side-to-side hitch movement with the plow in draft position. Prior to drip tape installation, the field was tilled twice to a 15” depth with parabolic chisels on 20-inch spacing in opposing diagonal paths, each path 45 degrees from the eventual direction of the drip laterals. The field was disked and then smoothed with a field cultivator. The drip laterals were installed in an east-west direction

Figure 1. Installing drip tape with a RTK-GPS guided tractor at TAES Halfway, 2005.

Figure 2. Obtaining drip lateral locations with a portable RTK-GPS survey system, TAES Halfway, 2005.

with planned lateral spacings of either 60” or 80” with each drip lateral irrigating two 30-inch or two 40-inch crop rows, respectively (Fig. 1).

The actual locations of the installed drip laterals were determined by excavating drip tape with shovels or mechanical ditcher. UTM coordinates of the exposed laterals were determined using a mobile Trimble AgGPS 214 system mounted on a 4 wheel all terrain vehicle (Fig. 2). The base station used for tractor guidance during lateral installation and for lateral referencing was permanently installed approximately 4 miles from the SDI installation site. The field antenna used to determine tape locations was mounted on a rod with survey-grade leveling bubble. To obtain drip lateral locations, operators would place the lower end of the rod in the center of a drip tape, “level” the rod using the centering bubble, and capture GPS reference data at that point. Fig. 3 shows the spatial distribution of 192 points determined by this method relative to SDI treatment plots.

The shape file containing the locations of the 192 drip lateral points was imported into ArcMap^{TM} 9.0. The perpendicular distance between these points and the lines describing the planned drip lateral locations (defined from the original tractor guidance paths) were measured within ± 0.01 ft using the ArcMap^{TM} measurement tool (Fig. 4). The frequency distribution of these distances was determined and graphed.

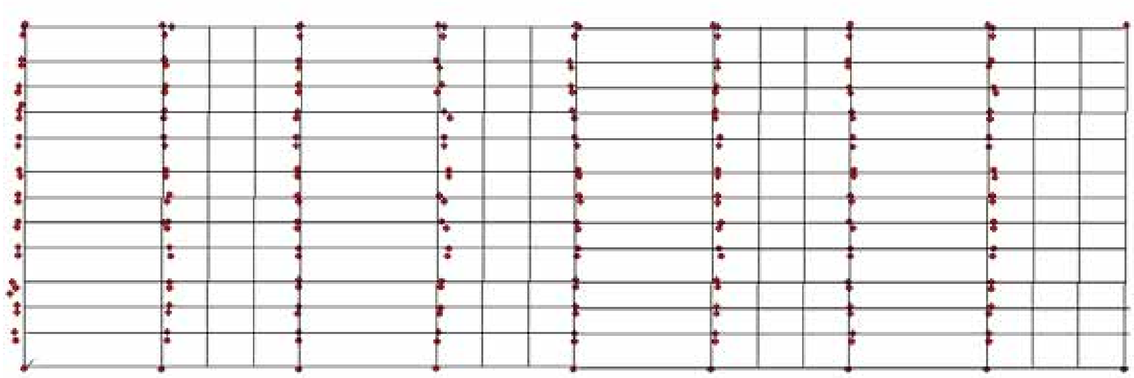

Figure 3. Field map of SDI plot boundaries and 192 drip lateral excavation sites, TAES Halfway, 2005.

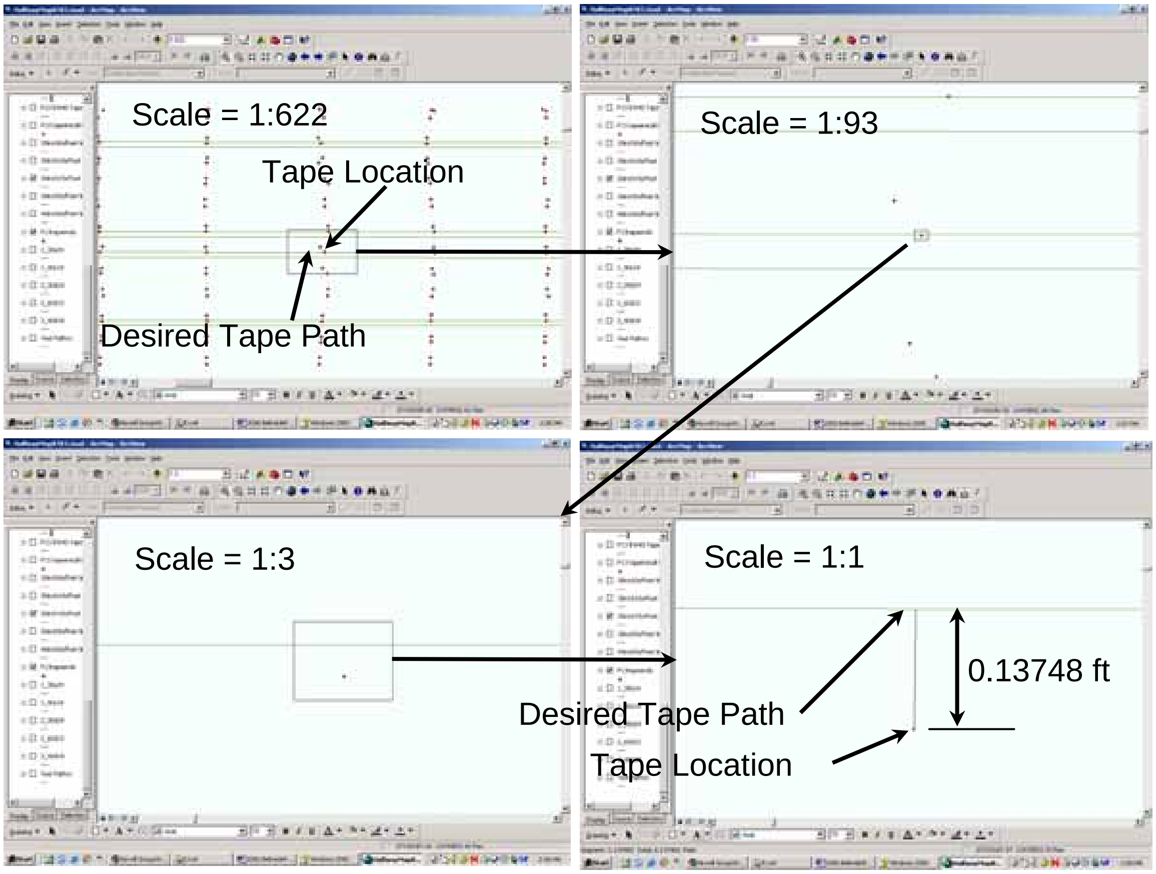

Figure 4. Four consecutive views of ArcMap™ screens showing increased magnification of a GPS referenced drip tape desired and actual locations and the measured difference.

Additional field data were obtained to better evaluate the occurrence of observed deviations from planned tracks during drip installation. The question was, how much of the observed deviations could be attributed to effects other than the tractor guidance system. The XTE of the tractor in a non-draft situation was determined by repeating the above procedure in the area south of the SDI installation site. Five paths were made, 700 ft long, in smooth, cultivated soil using a marker solidly placed in the center of the tractor. The actual locations of these paths were referenced by measuring the center of the path at 110 marked locations with the mobile Trimble GPS unit. Marked locations were surveyed twice by two equipment operators at different times and the two surveys compared to develop a sense for potential error in determining reference locations.

Results

Based on the measurement methods used, the average difference between the actual drip lateral locations at excavated sites and the desired lateral paths was 1.00 inch. Of the 192 exposed tape laterals, 52.1 percent were on the down slope or south side of the desired east-west pathway, 45.8 percent were on the north side, and 2.1 percent were within 0.01 inch of the desired location. Figure 5 graphically shows the frequency distribution of these differences. Sixty percent of the observations were within 1 inch of the desired pathway, 88% within 2 inches, and 97% with 3 inches. The maximum difference measured was 4 inches.

Some of the deviations of the SDI tape laterals from the planned location were due to inaccuracies in determining the reference location of the tapes, i.e. the operator and equipment error in the portable RTK-GPS system. The average difference in measurements of the 110 identical locations in the field by the two operators using the portable RTK-GPS system was 0.67 inches. Figure 6 provides the frequency distribution of these differences. This graph indicates that, with the equipment and methods used, one operator had a 78% chance of determining coordinates of a

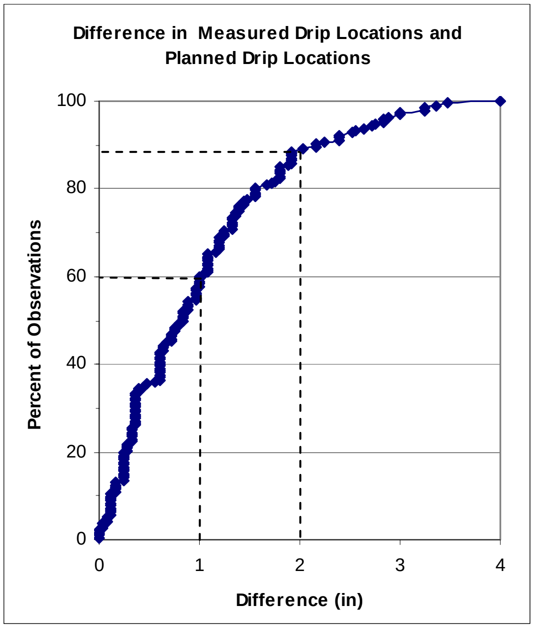

Figure 5. Probability distribution of deviations between measured and planned SDI locations following RTK-GPS guided tractor installation.

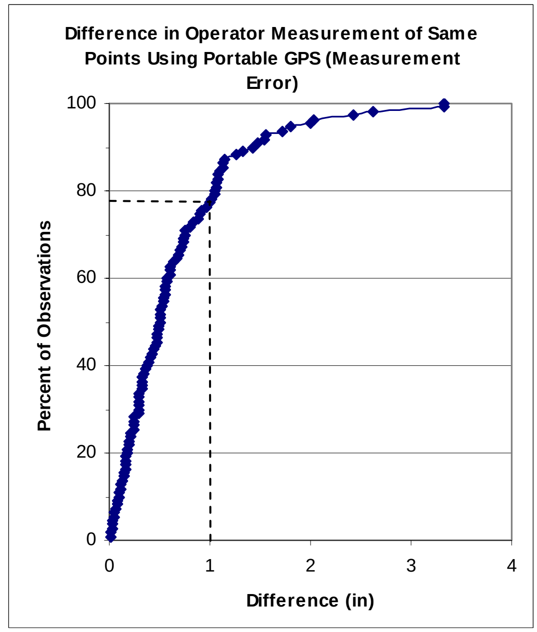

Figure 6. Probability distribution of deviations between two measurements of the same location using portable RTK-GPS survey equipment.

point in the field within one inch of the second operator. Variations in measurements are attributed to different ways that operators positioned the rod on a point, how the leveling bubble was read, and/or error in the GPS measurement system.

An additional percentage of the deviation between the measured and the desired lateral locations is attributed to the

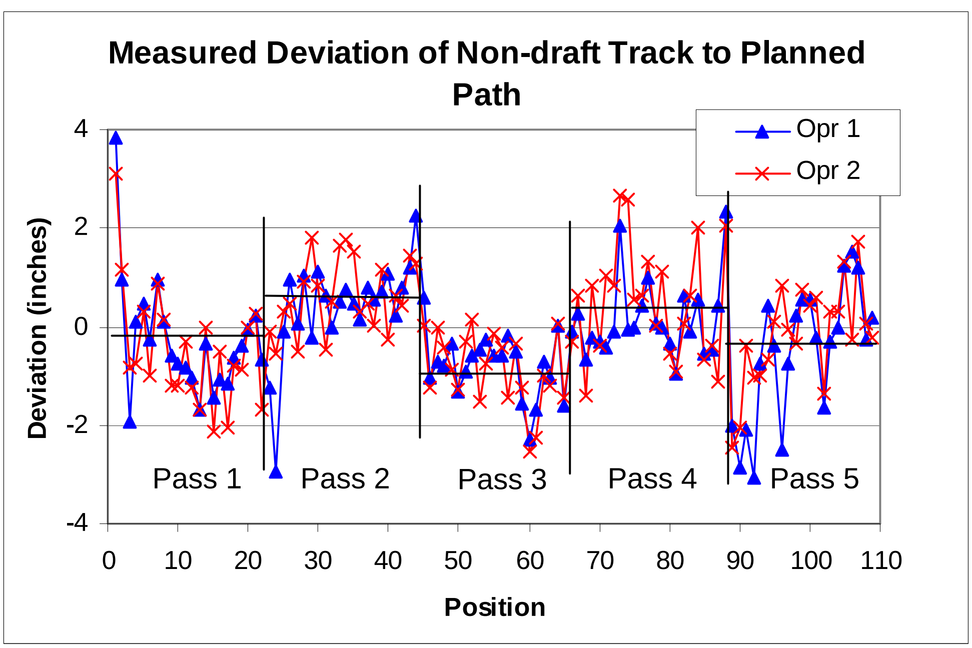

Figure 7. Measured deviations from the desired path of the centerline of a RTK-GPS guided tractor operated in a non-draft situation. Two sets of measurements were made with a portable GPS survey unit by separate operators at different times.

instantaneous side-to-side loading of the tractor and drip installation plow. Local differences in soil properties or conditions, slack in the hitching system between the tractor and the plow, and/or the effect of slight cross slopes could result in deviations in tape placement relative to the desired path. Differences in operator measured tractor path to the desired path without the drip installation tool (non-draft mode) are shown in Fig. 7. The frequency distribution of deviations from the desired path of measured locations in the non-draft field test is shown in Figure 8. The measured path locations were the average of the two operator measurements of each of the 110 locations along the five track passes.

Twenty-two observations were made in each of the five tractor passes represented in Fig. 7. Passes 1, 3 and 5 were made with the tractor moving from west to east, passes 2 and 4 were made moving from east to west. The average deviation of all west to east observations was 0.64 inches south of the desired path and the average deviation of all east to west observations was 0.42 inches north of the desire path. These offsets indicate a systematic error in either the marker used to define the tractor path or in the position of the tractor guidance antenna. Even with this offset included in the analysis, under non-draft conditions, 70% of the measured sites along the tractor path were within one inch of the desired locations (Fig. 8). This compares to only a 60% probability of a drip tape lateral being within one inch of the desired tape path as indicated earlier in Fig. 5. Although not greatly affected, the precision of drip lateral placement was measurably less than that of tractor paths in a non-draft situation.

Although placement of drip tape laterals may never be within a ± 1.0-inch standard 100% of the time, the use of RTK guidance systems for drip tape installation provides a vast improvement compared to installations without RTK-GPS guidance. Figure 9 shows the frequency distribution of deviations of measured tape locations from straight lines representing desired tape paths. The tape was installed using a non-guided tractor in 30-inch bedded rows in a 16-acre field at TAES, Halfway. Prior to tape installation, crop rows were created using a traditional row marker system with sequential tractor paths overlapping the previous path to “insure” parallel, straight rows. Crop beds appeared straight and uniform at the time of the SDI installation. However, 50% of the 100 measured lateral sites were greater than 3 inches from their expected locations and over 10% of the laterals were greater than 8 inches from the appropriate locations. Offset errors are compounded over time as “row drift” from one crop season to the next occurs. Obviously, RTK-GPS guidance provides much greater precision in drip placement than even the most carefully installed non-guided methods.

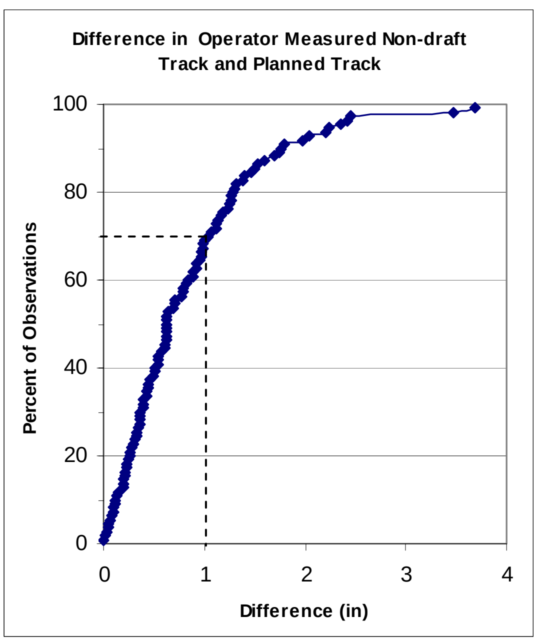

Figure 8. Probability distribution of deviations between measured and planned non-draft tractor paths.

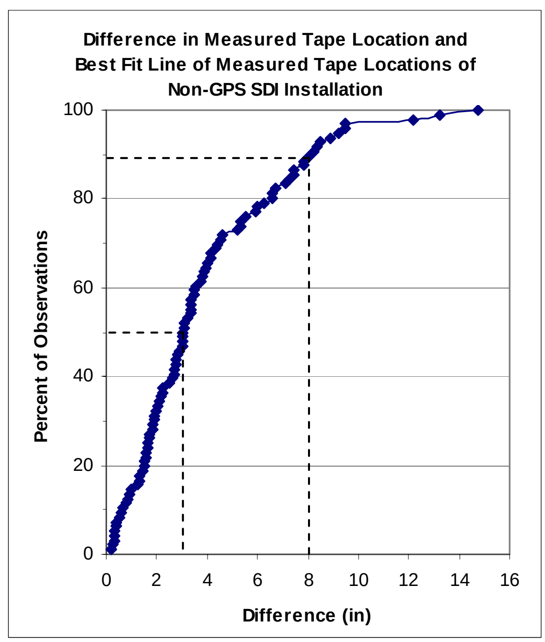

Figure 9. Probability distribution of deviations between measured and desired drip tape locations in a non-guided SDI installation.

Conclusions

Differences in desired and actual (referenced) tape lateral locations were as follows: 60% of the laterals were within one inch of their planned locations, 88% were within two inches, and 97% were within three inches. Installing SDI with RTK-GPS guidance increased the probability of actual tape lateral positions being within one inch of target tape locations from 18%, without GPS guidance, to over 60%, with guidance. RTK-GPS guidance further showed 99.9% probability of being within 4 inches of the target location compared to off target errors up to 14 inches without guidance. Adding a draft load to a guided tractor slightly reduced the probability of being with one inch of target locations from 70%, without load, to 60%, with load. The lack of better repeatability of the RTK-GPS system in these evaluations can be partially attributed to inaccuracies in determining reference positions as well as potential misalignment due to tractor/plow hitching and non-uniform draft loads.

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