Design and Testing of a Depth Gauge Controller for Peanut Digging Angle Adjustment

Andrew C. Warner¹, Kendall R. Kirk², James S. Thomas², J. Warren White³, Joel S. Peele³, John D. Mueller², Hunter F. Massey¹, Young J. Han¹

¹ Agricultural Mechanization & Business; Clemson University; Clemson, SC; awarne2@g.clemson.edu
² Edisto Research & Education Center; Clemson University; Blackville, SC; kirk2@clemson.edu
³ Amadas Industries, Inc.; Suffolk, VA

Written for presentation at the
2015 ASABE Annual International Meeting
Sponsored by ASABE
New Orleans, Louisiana
July 26 – 29, 2015

Abstract. A depth gauge was developed as an automated system to provide feedback for control of the 3-point hitch top link position on a 2-row KMC peanut digger, aimed at reducing peanut digging losses across a variety of soil textures. The goal of the depth gauge control is to maintain a prescribed digging elevation on the basis of on-the-go remote sensing, in contrast to the use of discrete top link prescriptions for EC map-based management zones to control top link position, a technology developed and tested by Clemson University and Amadas Industries in 2013. The basis for the depth gauge control is that the peanut pod zone occurs at a similar depth across soil textures, that any given top link position will result in digging elevation variability across soil textures within a field, and that digging too deep or too shallow results in increased digging losses. An investigation was performed to characterize the performance of the depth gauge across various soil textures and topographies within the same field. The hydraulic top link position was actuated using a computer-operated directional control valve; two logic functions were provided for top link control: (1) depth-lock control logic causing the top link to extend or retract as a function of the depth gauge value relative to a depth prescription, and (2) extension-lock control logic causing the top link to hold a prescribed extension length, effectively representing a conventional or fixed position top link. Using the depth-lock control logic during plot tests the depth gauge indicated a difference in average blade depth of 0.66 cm (0.26 in.) across soil textures. Using the extension-lock control logic in plot tests, the depth gauge indicated a difference in average blade depth of 1.88 cm (0.74 in.) across soil textures. In 378 m (1,240 ft) strip tests, differences in blade depth across soil textures were 0.23 cm (0.09 in.) for the depth-lock control logic and 1.2 cm (0.47 in.) for the extension-lock control logic. The degree of depth variability for the extension-lock control logic would likely have been higher in drier soil conditions. The results indicated that the depth gauge coupled with an adjustable top link is a feasible alternative to the EC map-based top link prescriptions, with the added benefit of continuously variable control capabilities.

Keywords. Peanut, digger, precision agriculture, site specific, harvest.

The authors are solely responsible for the content of this meeting presentation. The presentation does not necessarily reflect the official position of the American Society of Agricultural and Biological Engineers (ASABE), and its printing and distribution does not constitute an endorsement of views which may be expressed. Meeting presentations are not subject to the formal peer review process by ASABE editorial committees; therefore, they are not to be presented as refereed publications. Citation of this work should state that it is from an ASABE meeting paper. EXAMPLE: Author’s Last Name, Initials. 2015. Title of Presentation. ASABE Paper No. ---. St. Joseph, Mich.: ASABE. For information about securing permission to reprint or reproduce a meeting presentation, please contact ASABE at rutter@asabe.org or 269-932-7004 (2950 Niles Road, St. Joseph, MI 49085-9659 USA).
Introduction

Very few improvements have been made to peanut digger since the development of the modern peanut digger made by the Brown Manufacturing Corporation in the late 1960’s (Lilley, 1967). Considering that most yield losses in peanut harvest happen during the inversion process or the digging of the peanuts (Bader et al., 2012), peanut digger technology creates great opportunities for development. Mechanical digger-related yield losses, excluding those caused by weakened peg strength from over-maturity or disease issues, are caused by improper top link setting for the soil texture, dull digging blades, row center deviation, or improper conveyor chain speed, with a primary cause being improper top link setting for the soil texture. However, in most cases peanut growers will set their digger top link for the proper position in the heaviest soil texture within a field and dig the entire field, with the belief that it is better to dig too deep than to dig too shallow. The effect of such an approach is to dig too deep in all but the heaviest soil textures in the field. A study on the importance of proper top link settings conducted at the Edisto Research and Education Center demonstrated that this current grower method of setting the top link can lead to excessive yield losses within lighter soil textures (Kirk et al., 2014). In efforts to reduce yield losses caused by improper top link setting, a variable depth digger was developed by Clemson University and Amadas Industries. The first version of the variable depth digger used a map-based system to adjust the top link to proper position per soil texture zone. This saved an average yield, in a field of with three distinct soil textures, of approximately 90 kg ha\(^{-1}\) d.b. (80 lb ac\(^{-1}\) d.b.) or roughly $47 ha\(^{-1}\) ($19 ac\(^{-1}\)) in yield recovery (Warner et al., 2014). This map-based control method required soil texture mapping prior to digging in order to develop zone-based top link prescriptions. Many growers do not have these soil maps or access to soil maps with enough detail to run the system. In an effort to make the variable depth digger technology more accessible and easier to implement, the study presented here was conceived, where a depth-lock control logic would adjust top link position as a function of blade depth instead of as a function of soil EC or management zones. The fundamental basis for the use of the depth-lock control logic was based on the observation that peanut pod zones, regardless of soil EC or texture zone, tend to grow to generally the same depth in the soil.

As a result, the taproot for the peanuts should be cut at approximately to same depth below the ground surface based. The depth-lock control logic is designed to sense depth of the digger blade relative to the ground surface, with the ability to adjust a hydraulic top link to seek to maintain an operator-prescribed depth, the adjustment of the top link resulting in relative maintenance of blade depth regardless of soil texture. A companion study (Warner et al., 2015) evaluated digging losses for the depth-lock control logic as compared to other depth control methods with favorable results, suggesting that the depth-lock control logic may help in reducing mechanical digging losses encountered from improper top link setting across soil textures. The depth-lock method would provide an added benefit to the grower when compared to the map-based, or extension-lock, control logic by not requiring the grower to produce a soil EC or zone based digger prescription map for the field prior to digging.

Precision agricultural applications for peanut have been researched, but very few have been commercially implemented. Many of the precision agriculture technologies that are being used or have been researched for peanut production were developed for other crops and have been adopted for use in peanuts. Research on peanut yield monitoring systems, similar to systems used in cotton and grains, has shown reliable and accurate data collection is possible (Fravel et al., 2013; Porter et al., 2013; Free et al., 2014), although a commercially available peanut yield monitor is not yet available. Soil EC or electrical conductivity mapping has been demonstrated to be useful in delineating soil texture zones within a field (Khalilian et al., 2008; Oguri et al., 2009; Perry et al., 2007). The data collected from soil EC can be used to create zones for prescription of variable rate input applications that can be applied in peanuts and other crops. Aside from implementation of RTK guidance and auto-steer for reduction in digging losses from row center deviation (Ortiz et al., 2013) and availability of an in-cab conveyor chain speed monitor (Amadas Industries, 2011), there are no commercially available precision agriculture technologies that have been adapted to improve peanut digger efficiency.

Soil texture change across a given field has been proven to have a dramatic influence on proper top link position (Warner et al., 2014). With in-field soil texture differences being very common in the Southeastern Coastal Plain where peanuts are typically grown it would be beneficial for growers to adjust digger settings throughout the field to match the soil texture encountered. Using existing technologies, however, growers can only make these adjustments manually based on visual observation. It is impractical for a grower to manually screw a conventional top link in or out as different soil textures are encountered. Currently, growers use a more aggressive blade angle and top link position so the digger blades will cut the tap root below the pods in the heaviest soils within the field. The variable depth digger demonstrated an additional 313 kg ha\(^{-1}\) (279 lb ac\(^{-1}\)) yield loss in the lighter texture soil when using the current grower method of top link adjustment (Warner et al.,...
Because the majority of profits or losses in peanut production can be attributed to digging decisions (Monfort, 2013), knowledge of digging performance across a range of soil textures, conditions, and situations is critical to peanut production. The objectives of this project were too develop a depth-lock control system capable of automatically adjusting top link position to meet a prescribed digging elevation and to compare the performance of the extension-lock control logic with that of the depth-lock control logic.

**Methods and Materials**

**Field Testing**

The digger test was conducted at Clemson University's Edisto Research and Education Center in Blackville, SC. The field used was approximately 6.9 ha (17 ac) with all soil textures within the field being classified as either sand or loamy sand. The plots in the study were 29.3 m (96 ft) long with row spacing at 97 cm (38 in.). Plots were dug with a KMC two row, 3-point hitch mounted digger/shaker/inverter (Kelley Manufacturing Co., Tifton, Ga.) and a John Deere 7330 equipped with Trimble RTK AutoPilotTM (Trimble Navigation Limited, Sunnyvale, Cal.) following the same path from planting to minimize digging losses from row center deviation. Tillage was conventional and cultural practices and pest control followed Clemson University Extension recommendations. The digger blade was mounted so that the bevel was down. Care was taken to ensure that blades were not dull; conveyor speed was properly matched to ground speed, personnel walked beside digger to ensure vines bunching under the prototype depth gauge were not encountered, and that blade angle and therefore depth for each treatment were set properly.

Soil electrical conductivity mapping using a Veris 3100 (Veris Technologies Inc., Salina, Kans.) was used to identify three different soil texture zones within the field. The three zones were defined using a contour map of the shallow EC (0-30 cm, 0-12 in.) constructed in Farm Works Software (Trimble Navigation Limited, Sunnyvale, Cal.). Corresponding to general digging depth, soil samples were collected from the top 10 cm (4 in.), of each plot. Hydrometer tests were conducted on the samples using the procedures outlined by Huluka and Miller (2010) to quantify the relative fractions of sand, silt, and clay. The average sand, silt, and clay contents, respectively, were: 96.1%, 1.7%, and 2.2% in the low EC zone; 92.2%, 5.5%, and 2.3% in the medium EC zone; and 87.6%, 8.3%, and 4.1% in the high EC (Table 1). Soil volumetric moisture content was taken at the time of digging using a model 10HS large volume soil moisture sensor (Decagon Devices Inc., Pullman, Wash.). Average volumetric soil moisture contents were 3.2% in the low EC zone, 5.7% in the medium EC zone, and 5.9% in the high EC zone.

<table>
<thead>
<tr>
<th>EC Zone</th>
<th>Sand Content</th>
<th>Silt Content</th>
<th>Clay Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low EC</td>
<td>96.1 a 2</td>
<td>1.7 a 2</td>
<td>2.2 a 1</td>
</tr>
<tr>
<td>Medium EC</td>
<td>92.2 b 2</td>
<td>5.5 b 1</td>
<td>2.3 a 1</td>
</tr>
<tr>
<td>High EC</td>
<td>87.6 c 2</td>
<td>8.3 b 2</td>
<td>4.1 b 1</td>
</tr>
</tbody>
</table>

A total of 20 plot treatments were applied as further described below: nine extension-lock treatments, nine depth-lock treatments, and two control-arm treatments. Six replicates of each treatment were provided and spatially arranged as plots in completely randomized designs within each soil texture zone. Travel direction was easterly and the same for all plots. Plots with heavy weed pressure or planting skips were excluded from the study. Comparisons across treatments within each soil texture zone were performed using one-way ANOVA and Fisher’s LSD tests (α=0.05). Analysis of variance was not performed across data from different soil texture zones, since soil texture was spatially organized and could not be randomized. In addition to the plot treatments, two strip treatments were provided using the depth-lock proper setting and the extension-lock medium EC setting. Strips covered the entire length of the field and traversed all three EC zones. Two replicates of each strip treatment were provided, giving four adjacent strips. The strip treatments are further described below.

**Digger Setup**

The digger was equipped with a solenoid-controlled hydraulic top link, a linear potentiometer indicating extension length of the hydraulic top link, a rotary potentiometer indicating position of a digging blade depth gauge, and a data acquisition system collecting data at 10 Hz through a model 1018 interface kit (Phidgets Inc., Calgary, Alberta, Canada). Data acquisition software was developed in Visual Basic 2010 Express.
The software developed included control functions for the hydraulic top link.

A model 9-5152 8x20x4 cm (3x8x1.5 in.) double acting hydraulic top link (Surplus Center, Lincoln, Neb.) was used to provide control of the blade angle, extension providing shallower digging depths and retraction providing deeper digging depths. A three-position, 4-way DC solenoid valve (D03S-2C-12D-35, Hyvair Corp., Magnolia, Texas) was used to actuate the hydraulic top link (Figure 1). Solenoid switching was provided through digital outputs of the model 1018 interface kit and a model 3051 dual relay board (Phidgets Inc., Calgary, Alberta, Canada). A model WFC-400 hydraulic flow control valve (Prince Manufacturing Corporation, North Sioux City, S.D.) was added to the blind end of the cylinder to control the extension rate. The use of the tractor's hydraulic flow control was used to control the retraction rate of the cylinder. The flow control valves were set so that cylinder extension and cylinder retraction rates were equal at 0.36 in sec\(^{-1}\).

![Figure 1](image)

**Figure 1.** (a) Schematic used for hydraulic top link control (b) physical mounting of hydraulic top link, linear potentiometer, and valve block.

**Extension-Lock Treatments**

Based on visual observation of the windrow at the time of digging, the digger was set up for the proper digging blade angle within each of the three soil texture zones, providing cylinder extension lengths for a proper low EC setting, a proper medium EC setting, and a proper high EC setting. Assessment of proper blade angle and depth was performed as described in Kirk et al. (2013). Once the proper blade angle was determined for each of the three soil texture zones, all three of these top link extension lengths were applied as extension-lock digging treatments across each of the three soil texture zones, providing nine treatments. The software was programmed so that the cylinder extension would automatically adjust as necessary to stay within ±1% of the prescribed cylinder extension for any given treatment, percent provided as percent of stroke length.

**Depth-Lock Treatments**

A blade depth gauge (Figure 2) was fabricated from an 81 cm (32 in.) length of 2.5 cm (1 in.) diameter steel round stock and approximately 1 ft\(^2\) of 16 ga. Steel plate, which was provided to stiffen the assembly, provide down force, and keep the mechanical linkage out of the peanut vines. The gauge trailed from the frame to the left side of the digger, roughly in-line with the rear of the blade so it was allowed to freely pivot as it trailed along the ground surface. A mechanical linkage was fabricated to connect the depth gauge to a model AT333680 rotary potentiometer (Deere & Company, Moline, Ill.) mounted to the underside of the digger frame. Indicated blade elevation relative to the depth gauge invert elevation was calibrated and indicated by rotary position of the potentiometer. The software was programmed so that the top link would automatically adjust (Figure 2b) as necessary to attempt to stay within ±0.091cm (±0.036 in.) of the prescribed blade elevation, relative to the ground surface, for any given treatment. Spring tension force using a C-277 Century Spring (Century Spring Corp., Los Angeles, Cal.) was applied to assist the depth gauge in maintaining contact with the ground through thick peanut vines and rough field conditions. The spring was positioned to limit excessive down-force to reduce the tendency for the depth gauge would to push downwards through bare, loose soil. The indicated blade elevation was calibrated using a linear regression model as a function of rotary potentiometer position (Figure 3). Based on visual observation of the windrows across soil textures, a Depth-Lock Proper setting was prescribed at a blade elevation of 0.05 cm (0.02 in.) and an additional two treatments were applied as Depth-Lock Shallow at a blade elevation of 0.58 cm (0.23 in.) above the Depth-Lock Proper setting, and Depth-Lock Deep at blade elevation of 0.58 cm (0.23 in.) below the Depth-Lock Proper setting.
Strip-Trial Evaluation of Depth-Lock and Extension-Lock Control Logic

The strip trials were conducted with the depth-lock proper setting and the extension-lock medium EC setting to assess the effects on digging elevation when crossing soil EC zones. Two replications were provided for each treatment, with strips arranged across the 378 m (1,240 ft) length of the field; all replications crossed all three soil EC zones. The direction of travel was in both directions across the field to simulate the typical manner performed by a grower. The replications of each treatment were conducted in both directions of travel, easterly and westerly. As in the plot treatment, the digger blade elevation was indicated by the calibrated depth gauge output. Assessment of the relationship between blade elevation and soil EC was provided by contouring the soil EC in Farm Works Software (Trimble Navigation Limited, Sunnyvale, Calif.). Spatial position was provided by a model 1040 GPS (Phidgets Inc., Calgary, Alberta, Canada), which allowed the blade elevations to be averaged with each soil EC contour. The average soil EC values were then compared to the average digging blade elevations.

Results and Discussion

Figure 4 shows blade elevation and top link position as a function of distance travelled through two of the plots in the study. The data in Figures 4a and 4b were representative of trends found within many depth-lock control and extension-lock control logic treatments. The location of the plots shown was in the high EC zone in a
shallow valley within the field, which is not uncommon in peanut fields (Figure 5). In Figure 4a, the blade elevation trend line demonstrates a relatively flat appearance with a change in blade elevation of 0.017 cm m\(^{-1}\) (0.002 in. ft\(^{-1}\)) traveled indicating that the digger held a fairly consistent depth across the field. The digging elevation in Figure 4a tended to get a little deeper towards the end of the plot tested. This is likely due to the slow hydraulic response time demonstrated for actuation of the hydraulic top link for extension relative to that for retraction. The hydraulic flow rate was measured and set under no-load conditions, and when draft from the digger assisted retraction of the cylinder, the target depth was exceeded, requiring a greater length of cylinder extension time to compensate. This phenomenon is demonstrated in the cylinder extension data of Figure 4 by the steep downward slopes on retraction and the shallow upward slopes on extension. In short, correcting to a shallower depth required more time than did correcting to a deeper depth. This issue could likely be addressed through incorporation of pressure compensated flow controls.

When comparing blade elevations of the depth-lock treatment (Figure 4) to those of the extension-lock treatment (Figure 5), the depth-lock treatment maintained a more constant depth across the plot. In the extension-lock plot (Figure 5), the top link extension was set for the extension-lock high EC setting, or the proper cylinder extension for the high soil EC zone. The top link extension (Figure 5), showed a flat trend line confirming that the top link successfully maintained the prescribed position across the plot. The indicated blade elevation (Figure 5), showed a relatively dramatic decrease in digging elevation across the 29.3 m (96 ft) plot, with a change in depth of 0.083 cm m\(^{-1}\) (0.010 in. ft\(^{-1}\)), or about five times that for the depth-lock treatment in Figure 4. This increase of digging depth across the plot could have been due to the change in terrain within the field or likely local soil texture and moisture differences across the plot. The extent of digging elevation change within a plot tended to vary depending on the degree variability change in soil EC and terrain changes within the plot which would cause the tractor or implement to pitch up or down. Figure 6 better illustrates the differences in terrain features found in the field studied.

![Figure 4](image_url)

Figure 4. These data were chosen to represent the depth-lock treatments (plots had full canopy coverage, requiring the depth gauge to ride on top of the vines). This is from plot 373 and represents the DepthLock-Proper setting in a high soil EC.
Figure 5. These data were chosen to represent the extension-lock treatments (plots had full canopy coverage, requiring the depth gauge to ride on top of the vines). This is from plot 331 and represents the Ext.Lock-Medium setting in a high soil EC.

Figure 5.6. The direction of travel of digging was in one direction for the entire study. The downhill and uphill passes affected digger depth for the extension-lock treatments and had less overall effects on the depth-lock treatments, which compensated for the pitch changes on the implement used in this field.

In the plot study, all the depth-lock control logic treatments maintained a maximum average digging elevation difference of 0.48 cm (0.26 in.) across all soil EC zones; as seen in Table 2. The extension-lock control logic treatments across all soil EC zones produced a maximum average digging elevation difference of 1.07 cm (0.42 in.). The values indicate blade elevation relative to the ground surface, with negative values representing indicated blade depth below ground. The results indicate that the depth-lock control logic was able to maintain a more consistent digging elevation when crossing soil EC zones than the extension-lock method tested, which in essence represents a conventional, or fixed top link position. Based on proper top link settings from a similar 2013 study (Warner et al., 2014), it is expected that the maximum average digging elevation difference across EC zones would be greater in soil with higher moisture content. The 2013 study demonstrated that there was an optimum digging depth for each texture, both above and below which would increase digging losses. If pods grow at similar depths across soil textures, then the data in Table 2 implies that the depth-lock control logic method can be an acceptable method of reducing yield losses across a field, especially in fields that may not be completely flat or have different terrain features affecting digging elevation as a function of the tractor or implement position.
Table 2. Average digging elevations as indicated by the depth gauge. Negative elevations indicate distance below ground surface.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Low EC Zone</th>
<th>Med EC Zone</th>
<th>High EC Zone</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Avg. Depth (in)</td>
<td>SD</td>
<td>Avg. Depth (in)</td>
</tr>
<tr>
<td>DepthLock-Shallow</td>
<td>-0.50 a</td>
<td>0.13</td>
<td>-0.46 a</td>
</tr>
<tr>
<td>DepthLock-Proper</td>
<td>-0.74 a</td>
<td>0.36</td>
<td>-0.68 b</td>
</tr>
<tr>
<td>DepthLock-Deep</td>
<td>-0.72 a</td>
<td>0.15</td>
<td>-0.98 c</td>
</tr>
<tr>
<td>Ext.Lock-LowEC</td>
<td>-0.59 a</td>
<td>0.38</td>
<td>-0.64 ab</td>
</tr>
</tbody>
</table>

The plot trial data in Figure 6 shows a comparison of blade elevation as a function of EC for the depth-lock proper treatment and the extension-lock medium EC treatment. While both treatments demonstrated that the digging depth got shallower as heavier soils (higher ECs) were encountered, the results show that the depth-lock proper control method was able to maintain a more consistent digging elevation across all soil EC zones. The slopes from the linear regressions suggest that the depth-lock control logic was almost three times as effective in maintaining depth as a function of EC, as compared to the extension-lock control logic. For the extension-lock medium EC treatments the digger blade was being forced upwards in higher soil ECs. Without the implement being able to compensate for the depth change this could lead to additional mechanical losses within the field.

Figure 7 shows the average digging blade elevation as a function of soil EC for both the extension-lock medium EC setting and the depth-lock proper method over the 378 m (1,240 ft) strip trial. The change in digging blade elevation for extension-lock medium EC setting across all soil EC zones tested, as indicated by regression model, can be approximated as 1.2 cm (0.47 in.) from blade elevations of -3.25 cm (-1.28 in.) to -2.6 cm (-0.81 in.). The change in digging blade elevation for depth-lock proper setting across all soil EC zones tested, as approximated by the regression model, was 0.23 cm (0.09 in.) from blade elevations of -1.47 cm (-0.58 in.) to -1.24 cm (-0.49 in.). This data further demonstrates that the depth-lock control logic better maintained a consistent digging blade elevation when crossing different soil EC zones within the field tested, as compared to the extension-lock control logic.
Conclusion

Digger data analysis indicated that the depth-lock control logic better maintained a constant blade depth than the extension-lock control logic with the added benefit of continuously variable top link extension capabilities. In the plot trials, the depth-lock control logic showed a maximum of only -0.48 cm (-0.26 in.) change in average depth within any given treatment while crossing all soil textures tested in this study. The depth-lock control logic treatments demonstrated a lower overall change in blade elevation as a function of soil EC when compared to the extension-lock control logic treatments in both plot and strip trials, meaning the depth-lock control logic method did better overall during this study of maintaining a constant digging depth. The depth-lock control logic accomplished this while going through varying peanut canopy thicknesses, up and down hill situations and across varying soil textures, justifying that the depth-lock control logic is a feasible means of peanut digging blade depth control and could be a better alternative to the extension-lock control logic, which is representative of a conventional fixed top link. Further improvements should be considered for depth gauge such as the addition of a wheel, which may result in a more robust assembly for field applications.

Acknowledgments

Thanks is due to the South Carolina Peanut Board, which supplied the bulk of the funding for this project, to the Clemson University Creative Inquiry Initiative, to Amadas Industries, who provided technical support, and to the many individuals who assisted in data acquisition and analysis: Guy Ramsey, Justin Hiers, Ethan Barnette, Thomas Chapman, Kaminer Counts, John Covington, Alan Craig, William Creech, Benjamin Fogle, Jess Johnson, Jacob Koch, Coleman Ruff, Logan Simon, Cameron Wells, Kemp Wilson, and Coral Zadrozny.

References


