DEVELOPMENT AND TESTING OF A VARIABLE DEPTH PEANUT DIGGER

A Thesis
Presented to
the Graduate School of
Clemson University

In Partial Fulfillment
of the Requirements for the Degree
Master of Science
Plant and Environmental Science

by
Andrew Warner
May 2015

Accepted by:
Kendall R. Kirk, Ph.D., Committee Co-Chair
Young J. Han, Ph.D., Committee Co-Chair
John D. Mueller PhD.
ABSTRACT

The variable depth peanut digger proved in year one that top link position and therefore digging angle is critical in each soil texture within a field. The conventional grower method of digger setup, of setting the top link for the high EC zone and digging the entire field, was proven to introduce higher mechanical yield losses than the optimum top link setting when crossing lower EC soil textures. The overall yield savings from use of a variable depth digger was statistically better than the conventional method in this study showing an approximate 89.6 kg ha\(^{-1}\) (80 lb ac\(^{-1}\)) yield savings or $47 ha\(^{-1}\) ($19 ac\(^{-1}\)). Additional observations were that the prototype soil draft force shanks did not warrant further study or development and that mechanical improvements to the depth gauge needed to be made to better allow the gauge to push through regularly encountered thick peanut canopies.

For year two of the variable depth digger study improvements were made to the depth gauge, and implementation of four depth control strategies were tested against one another: conventional grower method; depth-lock control; map-based variable depth control; and lower 3-point hitch arm control. Due to testing conditions, no statistical yield savings could be found when comparing the tested methods to the conventional grower method of top link setting, although the function of the depth gauge was improved and reliable. The depth-lock control logic maintained a difference in digger blade average elevation of 0.23 cm (0.09 in.) across the tested 378 m (1,240 ft) strip trial, which crossed all soil EC zones tested in the study. This was a tighter control than the extension-lock control logic, which showed a difference in digger blade average elevation of 1.2 cm
(0.47 in.) in the same strip trial test.

The variable depth digger proved in the dry soil conditions of year one to reduce mechanical digging losses and demonstrated in year two with the depth-lock control that it is able to maintain a prescribed blade elevation across a test field making this a feasible option when compared to the conventional grower method. An important outcome of this study was that more research is needed to better determine the effects of soil moisture on blade depth and yield losses.
DEDICATION

I dedicate my thesis work to my family, my amazing girlfriend Mollie Harrison who has been here from day one, and the US Army which has given me this awesome opportunity to attend one of the top universities in the nation and prove what I could do. I would also like to recognize and dedicate this thesis work too three exceptional individuals for their endless efforts to make this degree possible. Mr. Danny Jones you constantly told me I had more potential than just staying in Greenwood, SC, and cutting grass for a living and that I needed attend college. SGT Anthony Kious you pushed me to my breaking point both mentally and physically on many occasions through good times and bad, but you also taught me a lot along the way and made me into the leader I am today. Dr. Kendall Kirk you offered me the opportunity to work with you on this project knowing I did not have all the background knowledge I needed to complete this project. You work tirelessly to insure that we completed the project and that I understood the material and research. I cannot thank these three individuals enough for their efforts because without them this degree would not have been possible.
ACKNOWLEDGEMENTS

I wish to thank my committee members who were more than generous with their
talent and their valuable time. A special thanks to Dr. Kendall Kirk, my committee
Co-Chair, for the countless hours he spent teaching me what I needed to know to have a
successful project, and for his help with revising the drafts of all papers for
this project. Thank you Dr. Young Han for agreeing to be my committee co-chair along
with Dr. Kirk, Dr. John Mueller thank you for joining my committee on very short notice,
and Mr. Hunter Massey thank you for staying with the project and serving as a non-
committee member after the issues during the GS2 approval process.

Thanks are due to Dr. Scott Monfort and Mr. James Thomas of the Edisto
Research and Education Center. Dr. Scott Monfort thank you for your endless support,
knowledge, and efforts in ensuring grants were properly presented to the South Carolina
Peanut Board. Mr. James Thomas thank you for your wealth of knowledge, for initially
coming up with the idea of a variable depth peanut digger, and for all the hard work you
put into insuring the fields, were planted well maintained, and set up for the studies.

Thanks are also due to the South Carolina Peanut Board, which supplied the bulk
of the funding for this project, to Amadas Industries, who provided technical support, and
to the many individuals who assisted in data acquisition and analysis: Will Anderson,
Ethan Barnette, Ashley Bonnette, Hunter Bruce, Jay Chapman, Thomas Chapman, James
Cole, Daniel Compton, Kaminer Counts, John Covington, Alan Craig, William Creech,
Nathan Downer, James Fleming, Hollens Free, Benjamin Fogle, Richard Hallman, Justin
Hiers, Jess Johnson, Jacob Koch, Justin Long, Matthew McCaskill, Reid Miller, Trent
Miller, Guy Ramsey, Baylor Ronemus, Coleman Ruff, Zachary Senn, Logan Simon, Cameron Wells, Charlie Westbrook, Kemp Wilson, and Coral Zadrozny.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>TITLE PAGE</td>
<td>i</td>
</tr>
<tr>
<td>ABSTRACT</td>
<td>ii</td>
</tr>
<tr>
<td>DEDICATION</td>
<td>iv</td>
</tr>
<tr>
<td>ACKNOWLEDGEMENTS</td>
<td>v</td>
</tr>
<tr>
<td>LIST OF TABLES</td>
<td>ix</td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
<td>xi</td>
</tr>
<tr>
<td>CHAPTER 1. INTRODUCTION TO THE STUDY</td>
<td>1</td>
</tr>
<tr>
<td>Objectives</td>
<td>2</td>
</tr>
<tr>
<td>References</td>
<td>3</td>
</tr>
<tr>
<td>CHAPTER 2. IMPORTANCE OF PROPER TOP LINK SETTING FOR PEANUT DIGGING LOSS REDUCTION</td>
<td>4</td>
</tr>
<tr>
<td>Abstract</td>
<td>4</td>
</tr>
<tr>
<td>Introduction</td>
<td>5</td>
</tr>
<tr>
<td>Materials and Methods</td>
<td>8</td>
</tr>
<tr>
<td>Results and Discussion</td>
<td>11</td>
</tr>
<tr>
<td>Conclusions</td>
<td>14</td>
</tr>
<tr>
<td>CHAPTER 3. VARIABLE DEPTH DIGGER DESIGN AND TESTING</td>
<td>18</td>
</tr>
<tr>
<td>Abstract</td>
<td>18</td>
</tr>
<tr>
<td>Introduction</td>
<td>19</td>
</tr>
<tr>
<td>Materials and Methods</td>
<td>22</td>
</tr>
<tr>
<td>Results and Discussion</td>
<td>26</td>
</tr>
<tr>
<td>Conclusions</td>
<td>30</td>
</tr>
<tr>
<td>CHAPTER 4. Variable Depth Peanut Digger Digging Loss Analysis</td>
<td>33</td>
</tr>
<tr>
<td>Abstract</td>
<td>33</td>
</tr>
<tr>
<td>Introduction</td>
<td>34</td>
</tr>
<tr>
<td>Materials and Methods</td>
<td>36</td>
</tr>
<tr>
<td>Results and Discussion</td>
<td>39</td>
</tr>
<tr>
<td>Conclusions</td>
<td>44</td>
</tr>
<tr>
<td>CHAPTER 5. DESIGN AND TESTING OF A DEPTH GAUGE CONTROLLER FOR PEANUT DIGGING ANGLE ADJUSTMENT</td>
<td>47</td>
</tr>
<tr>
<td>Abstract</td>
<td>47</td>
</tr>
</tbody>
</table>
# TABLE OF CONTENTS (continued)

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction</td>
<td>48</td>
</tr>
<tr>
<td>Method and Materials</td>
<td>51</td>
</tr>
<tr>
<td>Results and Discussion</td>
<td>58</td>
</tr>
<tr>
<td>Conclusion</td>
<td>65</td>
</tr>
<tr>
<td>CHAPTER 6. PEANUT DIGGING LOSS ANALYSIS FOR FOUR DIFFERENT DEPTH</td>
<td>68</td>
</tr>
<tr>
<td>CONTROL METHODS</td>
<td></td>
</tr>
<tr>
<td>Abstract</td>
<td>68</td>
</tr>
<tr>
<td>Introduction</td>
<td>69</td>
</tr>
<tr>
<td>Materials and Methods</td>
<td>73</td>
</tr>
<tr>
<td>Results and Discussion</td>
<td>81</td>
</tr>
<tr>
<td>Conclusion</td>
<td>88</td>
</tr>
<tr>
<td>CHAPTER 7. CONCLUSION OF THE STUDY</td>
<td>92</td>
</tr>
</tbody>
</table>
LIST OF TABLES

Table 2.1. Recoverable yield, as the sum of mechanical digging losses and combined yield, for each soil texture zone across imposed digging angles.................................................. 12

Table 2.2. Mechanical digging losses, as the sum of above ground and below ground losses, for each soil texture zone across imposed digging angles.......................... 12

Table 2.3. Mechanical digging losses, as percent of recoverable yield, for each soil texture zone across imposed digging angles.......................... 13

Table 3.1. Top link cylinder extension, as a percentage of full extension, for each of the digger settings, or digging blade angles used in this study ......................... 23

Table 3.2. Sand, silt, and clay contents in the top 10 cm (4 in) of soil across EC-defined soil texture zones................................................................. 27

Table 3.3. Top link hydraulic pressure for each digger setting in the medium EC and high EC zones................................................................. 28

Table 3.4. Digging blade depth in each digger setting and each zone, as indicated by blade depth gauge................................................................. 28

Table 3.5. Front soil draft force in each digger setting and each zone................................................................. 29

Table 4.1. Mechanical digging losses, as the sum of above ground and below ground losses, for each soil texture zone across imposed digging angles.................. 40

Table 5.1. Sand, silt, and clay contents in the top 10 cm (4 in) of soil across EC-defined soil texture zones................................................................. 53

Table 5.2. Average digging elevations as indicated by the depth gauge. Negative elevations indicate distance below ground surface .................................. 62

Table 6.1. Recoverable yield, as the sum of mechanical digging losses and combined yield, for each treatment within each soil texture zone.......................... 81

Table 6.2. Average mechanical digging losses for 2014 study, calculated in lb ac⁻¹ d.b., for each of the treatments used in this study............................................. 83

Table 6.3. Mechanical digging losses, as percent of recoverable yield, for each soil texture zone across imposed digging treatment................................................. 83

Table 6.4. Average indicated blade elevation per treatment as a function of depth gauge reading ................................................................................. 85
LIST OF TABLES (CONTINUED)

Table 6.5. Average soil volumetric moisture content for treatments within each soil EC zone ................................................................. 87

Table 6.6. Top link cylinder extension for 2014 study, as a percentage of full extension, for each of the digger settings, and digger blade depth used in this study ........................................................................................................... 87

Table 6.7. Average over-mature and diseased pods digging losses for 2014 study, calculated in lb ac\(^{-1}\) d.b., for each of the treatments used in this study ............. 88
LIST OF FIGURES

Figure 2.1. Illustration depicting various top link settings for a given soil type: (a) represents proper top link adjustment with the blade operating about one inch below pods; (b) represents digging too deep as a result of the top link being too short creating an excessive digging angle; and (c) represents digging too shallow as a result of the top link being too long creating an insufficient digging angle (adapted from Bader, 2012) ................................................... 7

Figure 2.2. Soil texture zone delineation as a function of EC mapping and test plot locations within the zones ................................................... 9

Figure 2.3. Digging loss sampling, showing excavated test area and soil sieve in operation ................................................... 11

Figure 3.1. Schematic used for hydraulic top link control (a) and physical mounting of a hydraulic top link, linear potentiometer, and valve block (b) ........................................ 24

Figure 3.2. Instrumented shanks used for soil draft force sensing at the front of the digger, behind the center coulter (a) and at the rear of digger, adjacent to the conveyor chain (b) ............................................ 25

Figure 3.3. The blade depth gauge trailed from the frame at the left side of the digger, free to pivot from the digger frame. The upper end was attached to a rotary potentiometer indicating angular position relative to the digger frame and the lower end engaged the s ................................................... 26

Figure 4.1. Digging loss sampling, showing excavated test area and soil sieve in operation ................................................... 39

Figure 4.2. Mechanical digging losses as a function of indicated blade depth in the low EC texture zone. Error bars represent ± ½ LSD ........................................ 42

Figure 4.3. Mechanical digging losses as a function of soil draft force at the front load shank, behind the center coulter. Error bars represent ± ½ LSD within soil texture zones ................................................... 43

Figure 4.4. Mechanical digging losses as a function of top link hydraulic pressure. Error bars represent ± ½ LSD within soil texture zones ................................................... 44

Figure 5.1. (a) Schematic used for hydraulic top link control (b) physical mounting of hydraulic top link, linear potentiometer, and valve block ........................................ 55
Figure 5.2. (a) The blade depth gauge was designed to move up or down with the terrain. Spring tension and the weight of the depth gauge allowed it to stay in contact with the ground. As the depth gauge moved up and down going through the field it moves a rotary potentiometer shaft, which was calibrated to indicate blade elevation relative to the ground surface. (b) The hydraulic top link would reactively adjust according to the depth gauge reading and the prescribed digging elevation. ................................................................. 57

Figure 5.3. Data and linear regression relating indicated blade elevation to rotary potentiometer value. ........................................................................................................ 57

Figure 5.4. 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................................................................. 60

Figure 5.5. 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................................................................. 61

Figure 5.6. The direction of travel of digging was in one direction for the entire study. The down hill and up hill 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. .......... 61

Figure 5.7. Digger blade elevation as a function of soil EC in the plot trials for the DepthLock-Proper and Ext.Lock-MediumEC treatments. ................................. 64

Figure 6.1. (a) Schematic used for hydraulic top link control (b) physical mounting of hydraulic top link, linear potentiometer, and valve block................................. 76

Figure 6.2(a) The blade depth gauge trailed from the frame at the left side of the digger, and spring tension was provided to maintain contact with the ground. The rotary potentiometer was connected to the upper portion of the................. 78

Figure 6.3. Data and linear regression relating indicated blade elevation to rotary potentiometer value. ............................................................................................ 78
Figure 6.4. The depth limit control (a) used to adjust for the control-arm treatments. Two clicks were used for the depth limit in the medium EC zone, and four clicks were used in the low EC zone to raise the depth limit of the 3-point hitch lower control arms (b)......................................................... 79

Figure 6.5(a) Collecting above ground yield losses prior to combining and (b) collecting below ground digging losses by use of a mechanical sieve. After combining, but before collection of below ground digging losses for each plot a leaf blower was used to carefully blow away debris and losses generated by combine................................................................. 81
CHAPTER 1. INTRODUCTION TO THE STUDY

The method in which peanuts were harvested changed in the 1950s from the stack-pole system to the conventional windrow production method (Wright & Steele, 1979). The windrow method better allows for the mechanical harvest of the crop from the field. In the late 1960s with the creation of a new means of inverting peanuts Brown Manufacturing Corporation created the model for the modern day peanut digger (Lilley, 1967). Since its development there have been very few major developments in peanut digger design. This presents an excellent opportunity for research and development, considering that most yield loss occurs during the inversion process of the peanuts (Bader et al., 2012).

Mechanical digging losses are known to be greatly influenced by soil texture and blade digging angle, which is controlled by top link setting. For example, a low EC soil is easier to penetrate resulting in a setup with shallower required blade angles as compared to heavier textured soils, which require more aggressive digging angles in order to achieve the same digging depth. In-field soil texture differences, which are common in the Southeastern coastal plain where peanuts are typically grown, would require operators to regularly adjust the top link positions within a field to match top link setting for the soil texture. The timeliness of this is impractical and it is not a cost effective practice when it comes to digging peanuts. So, to combat this most growers set the top link to a more aggressive blade angle so the digger blade will be positioned adequately below the pods in the heaviest land. This aggressive digging angle results in greater digging losses in the lighter soil textures a less aggressive digging angle would have been appropriate.
However, there currently exists no commercially available, practical means of adjusting the top link for each soil texture within a field.

In efforts to address this problem and to reduce mechanical digging losses that occur during the inversion process of peanut harvest, Clemson University worked with Amadas Industries on developing a variable depth peanut digger. The variable depth peanut digger was developed as a remote sensing and control platform to automatically adjust a hydraulic top link of a 3-point hitch as a function of operator prescribed settings.

**Objectives**

The objectives for this study were to:

- Develop a system capable of controlling digger top link settings.
- Evaluate various remote, sensor-based feedback devices.
- Develop a method of collecting mechanical yield losses within the test plots.
- Characterize yield losses incurred as mechanical-related or maturity- and disease-related.
- Analyze mechanical digging losses as a function of top link position, digging depth, and soil electrical conductivity to determine most effective means of digging.
- Characterize soil moisture data at the time of digging.
- Evaluate the performance of several digging depth control methods.
References


CHAPTER 2. IMPORTANCE OF PROPER TOP LINK SETTING FOR PEANUT DIGGING LOSS REDUCTION

Abstract

The digging and inversion process has the potential to cause the most yield loss during peanut harvest. Even if the grower produces high yields from proper care and management of his crop it can quickly be lost due to improper settings of the peanut digger. Although all losses cannot be prevented during the process a high percentage of yield losses are generally avoidable. Proper setting of the peanut digging angle for the soil texture encountered is among the most important factors in optimizing yield losses during the inversion process. It is common practice for producers to set the peanut digger for the high EC soil texture in the field. This is in part due to the difficulty of adjusting the top link every time the soil texture changes within a field, as well as the misconception that it is better to dig more aggressively. Tests conducted at the Clemson University Edisto Research and Education Center demonstrated that improper top link settings across soil textures within a field led to higher digging losses. Digging losses ranged from 3.3 to 10.9% of potential yield in the low EC soil texture, 5.8 to 15.7% in the medium EC, and 12.3 to 24.1% in the High EC soil texture. The data indicated that there was an optimum top link setting for each soil texture, with increased losses at both shallower and deeper depths. Average recoverable yield was statistically less in the low EC texture zone (4,457 lb ac\(^{-1}\)) than in the medium EC (5,149 lb ac\(^{-1}\)) and High EC (4,891 lb ac\(^{-1}\)) texture zones. Over-mature and diseased digging losses were greatest for the high EC, but not statistically different from those for the low EC and medium EC.
zones.

Introduction

It has been documented that most peanut harvest losses occur during the digging or also known as the inversion process (Bader, 2012). Pod losses generally result from weakened peg strength caused by disease and/or over-maturity (Chapin and Thomas, 2005; Grichar and Boswell, 1987; Thomas et al., 1983; Troeger et al., 1976), or mechanical actions of the digger, dislodging pods from plants. As a result, time of digging and proper digger settings is critical to reduce peanut yield loss. Invariably, some loss will be experienced due to the wide range of maturity existing across the pod profile in a given field. To harvest a field at the optimum time, some pods are over-mature and loss of these is generally unavoidable. Soil friability impacts pod losses profoundly (Grichar and Boswell, 1987). Even with favorable soil conditions and proper digger setup, 450 kg ha\(^{-1}\) (400 lb ac\(^{-1}\)) are common digging losses. A digging loss study in Virginia varieties conducted by Clemson University demonstrated average digging losses ranging from 650 to 1,350 kg ha\(^{-1}\) (580 to 1,200 lb ac\(^{-1}\)) dry weight, equating to about 9 to 22% of the total production with proper digger settings (Kirk et al., 2013).

Soil texture, which can be highly variable throughout fields in the southeastern coastal plains, can substantially impact proper top link adjustment for peanut digging angle. To reduce yield losses created from improper digging angle, the operator must stop and change the length of the top link for the digger. To save time in adjustments, some peanut growers set the digger blade depth to best match the finest/ heaviest soil texture within a field. However, this method of digger set up creates problems in coarser soil
Proper depth adjustment results in blades cutting the taproot about an inch below the pods (Figure 2.1a). Even if proper top link adjustment is established for a given area, travel within a field across various soil textures will result in variable digging depths. The digger blade experiences less resistance in coarser textured soils, allowing it to move to a greater depth at a given top link adjustment than the depth to which it would travel in a finer texture soil. Conversely, finer texture soils provide greater resistance to blade travel than coarser soils, which cause the blade to travel to a shallower depth for a given top link position.

If the top link is too short (Figure 2.1b), the taproot will cut too deep and excessive soil builds up on blades causing losses by pushing the plants forward before the taproot is severed. In cases where the blade is extremely deep, the taproot is not sheared and instead ripped from the ground. Further losses occur as pods ride over soil mounded on the blades. If the top link is too long (Figure 2.1c), the peanuts will be dug too shallow, shearing some pods and leaving others in the soil. So, if the top link is properly set up (Figure 2.1a) for a medium EC soil, relative to the textures present in a given field, movement into a coarser soil will result in the condition shown in Figure 2.1b and movement into a finer texture soil will result in the condition shown in Figure 2.1c, both conditions will contribute to greater harvest losses.

Because the majority of profits or losses in peanut production can be attributed to digging decisions (Monfort, 2013), thorough knowledge of digging performance and diligent regulation across a range of conditions and situations is critical to peanut
Figure 2.1. Illustration depicting various top link settings for a given soil type: (a) represents proper top link adjustment with the blade operating about one inch below pods; (b) represents digging too deep as a result of the top link being too short creating an excessive digging angle; and (c) represents digging too shallow as a result of the top link being too long creating an insufficient digging angle (adapted from Bader, 2012).

Objectives

The objectives of this project were to: quantify recoverable yield across three soil...
texture zones, quantify digging losses across different top link settings in three soil texture zones, and quantify over-mature and diseased digging losses across three soil texture zones.

**Materials and Methods**

Digging tests were conducted at Clemson University’s Edisto Research and Education Center in Blackville, SC. The field used was approximately 2.7 ha (6.7 ac) with a substantial amount of soil texture variability, from 88 to 98% sand content, 0 to 8.5% silt content, and 0 to 6% clay content. The plots in the study were 12 m (40 ft) long with row spacing at 97 cm (38 in.) and planted with Champs, a Virginia peanut variety. Plots were dug with a KMC two-row, three-point hitch mounted digger/shaker/inverter (Kelley Manufacturing Co., Tifton, Ga.) and a John Deere 7330 equipped with Trimble RTK AutoPilot™ (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 Extension (Clemson University) 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, vines were not wrapping around shanks, and that blade angle and depth were set properly.

Soil EC mapping using a Veris 3100 (Veris Technologies Inc., Salina, Kans.) was used to spatially delineate three soil texture zones: low EC, medium EC zone, and high EC zone. The three zones were defined using an EC contour map (Figure 2.2) constructed in Farm Works Software (Trimble Navigation Limited, Sunnyvale, Cal.). To verify the
validity of the use of EC data for delineation of soil texture zones within the digging depth of influence, soil samples were collected from the top 10 cm (4 in) at the time of digging (Warner et al., 2014).

Figure 2.2. Soil texture zone delineation as a function of EC mapping and test plot locations within the zones.

The digger was set up for the proper digging blade angle within each of the three soil texture zones, providing a low EC setting, a medium EC setting, and a 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 blade angle settings were applied as digging treatments across each of the soil texture zones, giving nine treatments. An additional “too shallow” setting was applied in the low EC zone and a “too deep” setting was applied in the High
EC zone, give a total of 11 treatments across the 3 soil texture zones (Table 2.1. Recoverable yield, as the sum of mechanical digging losses and combined yield, for each soil texture zone across imposed digging angles.). Six replicates were provided for each treatment and 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.

Digging loss data collection occurred five to six days after digging. To distinguish digging losses from combining losses, the windrow from each two-row plot in the study was gently lifted with pitchforks to a trailer, which carried the windrows to a stationary combine. The windrows were manually fed into the combine header and the entire yield from each plot was bagged and weighed. A sample for moisture analysis of approximately 1 kg (2 lb) was collected and weighed. Samples were oven dried using ASABE S401.2 conventional oven method (ASABE, 2010).

A 0.6 m (2 ft) long by 2 row test area was randomly defined along the length of each plot. Above ground digging losses were collected and weighed from this area, independently quantifying sound pod losses from over-mature and diseased pod losses. Over-mature and diseased pods were not considered to be “mechanical” digging losses because of their high propensity to be lost during harvest due to weak peg strength regardless of digger setup. Each test area was then excavated to a depth of 4 inches and the excavated soil was mechanically sieved (Figure 2.3) to collect the below ground losses. Below ground losses were weighed, once again distinguishing between sound, over-mature, and diseased pods. “Mechanically caused digging losses”, or sound above
and below ground losses were oven dried using ASABE S401.2 conventional oven method (ASABE, 2010). All losses reported in the results section are “mechanical digging losses” or sound losses on a dry weight basis.

Figure 2.3. Digging loss sampling, showing excavated test area and soil sieve in operation.

Results and Discussion

Recoverable yield for each plot was taken to be the weight collected from the stationary combine in addition to the digging losses considered to be mechanical digging losses, or those that were not over-mature or diseased. As the data in Table 2.1. Recoverable yield, as the sum of mechanical digging losses and combined yield, for each soil texture zone across imposed digging angles. demonstrate, there were no differences in recoverable yield within any soil texture across digging angle treatments; results of Fisher’s LSD tests indicated in the table were conducted within, and not across soil texture zones. When comparing average recoverable yield across soil texture zones as presented in the last row of Table 2.1. Recoverable yield, as the sum of mechanical digging losses and combined yield, for each soil texture zone across imposed digging
angles., the medium EC Zone and High EC zone recoverable yields were statistically the same, and both were greater than the low EC texture yield.

Table 2.1. Recoverable yield, as the sum of mechanical digging losses and combined yield, for each soil texture zone across imposed digging angles.

<table>
<thead>
<tr>
<th>Digger Setting</th>
<th>Low EC Zone</th>
<th>Medium EC Zone</th>
<th>High EC Zone</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>lb ac⁻¹, d.b.</td>
<td>SD</td>
<td>lb ac⁻¹, d.b.</td>
</tr>
<tr>
<td>Too Shallow</td>
<td>4,547 a</td>
<td>1,327</td>
<td>-</td>
</tr>
<tr>
<td>Low EC</td>
<td>4,563 a</td>
<td>910</td>
<td>4,902 a</td>
</tr>
<tr>
<td>Medium EC</td>
<td>4,192 a</td>
<td>704</td>
<td>5,436 a</td>
</tr>
<tr>
<td>High EC</td>
<td>4,527 a</td>
<td>1,041</td>
<td>5,109 a</td>
</tr>
<tr>
<td>Too Deep</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Average, All Plots 4,457 965 5,149 540 4,891

Digging loss results indicated that digger-related yield losses were substantially affected by soil texture and digging depth, supporting the need for adjustment of digging angle across soil textures (Table 2.2 and Table 2.3). The greatest digging losses were experienced in the high EC zone, while the low EC texture zone sustained the lowest yield losses. The data within the low EC and high EC zones demonstrate numerically that an optimum digging blade angle exists, above and below which digging losses increase, with statistical significance of this evidence in the low EC zone. It can be speculated that an optimum digging blade angle also existed for the medium EC, although the greatest prescribed angle in this study did not achieve enough depth to generate values demonstrating this. The data do not statistically support the premise that digging too deep is worse than digging too shallow.

Table 2.2. Mechanical digging losses, as the sum of above ground and below ground losses, for each soil texture zone across imposed digging angles.
When considering only treatments where digging losses were minimal for each soil texture zone, the losses in the low EC (155 kg ha\(^{-1}\), 138 lb ac\(^{-1}\), d.b.) and medium EC (330 kg ha\(^{-1}\), 294 lb ac\(^{-1}\), d.b.) texture zones were not statistically different and less than the losses in the High EC zone (674 kg ha\(^{-1}\), 601 lb ac\(^{-1}\), d.b.). It should be noted that the top link adjustment thought to be best for the low EC and medium EC zones did not produce the least digging losses in those zones, suggesting that our prescriptions for optimal settings were too shallow and/or that the test plots for digger setup were not representative of the plots used for yield loss testing.

These results demonstrate that absence of digging angle adjustment throughout a field with texture variability could substantially increase digging losses from those at the optimum angle for each texture zone. The data demonstrate that minimum digging losses for the test field were 386 kg ha\(^{-1}\) (344 lb ac\(^{-1}\), d.b.) if the optimum digging angle was set for each of the three soil texture zones. As a worst case scenario, had the operator set the
digging angle up for the low EC texture zone and provided no top link adjustment throughout the field, losses would have more than doubled to 808 kg ha\(^{-1}\) (720 lb ac\(^{-1}\), d.b.). If the digging angle was set at the medium EC setting for the entire field, losses would have been 531 kg ha\(^{-1}\) (474 lb ac\(^{-1}\)). In the more likely event that the operator set the digging angle up for the finest soil texture in this field without additional adjustment in the field, digging losses would have been 490 kg ha\(^{-1}\) (437 lb ac\(^{-1}\), d.b.), or 104 kg ha\(^{-1}\) (93 lb ac\(^{-1}\), d.b.) greater than optimum.

Over-mature and diseased losses were treated as one category during sampling, so the quantities for each of the two cannot be distinguished. When considering only the optimal digging angle treatments within each soil texture zone, or those digging angles that produced the least mechanical digging losses, mean over-mature and diseased losses were 67 kg ha\(^{-1}\) (60 lb ac\(^{-1}\), d.b.) in the low EC texture zone, 64 kg ha\(^{-1}\) (57 lb ac\(^{-1}\), d.b.) in the medium EC zone, and 146 kg ha\(^{-1}\) (130 lb ac\(^{-1}\), d.b.) in the high EC zone. These data were collected and presented in order to consider quantified recommendations for varying digging timing across soil texture zones, such as to dig zones on different days if practical. There were no statistical differences between any of these means, however the greater numerical value of diseased and over-mature losses for the high EC zone is suggestive that a more detailed investigation should be conducted in this area.

**Conclusions**

The results of this study support the need to adjust top link position and therefore digging angle in fields with high soil texture variability. The data demonstrated that there was an optimum top link position as a function of soil texture zone, whereby greater or
lesser digging angle increased digging losses. For the settings tested in this study, additional digging losses from digging too shallow were found to be similar to digging losses for digging too deep.

As a percentage of recoverable yields, average digging losses for the tested digger settings ranged from 3.3 to 10.9% in the low EC texture zone, 5.8 to 15.7% in the medium EC zone, and 12.3 to 24.1% in the high EC zone. As indicated, if this field were dug entirely at the High EC setting with no adjustment, digging losses in excess of minimal would have been 104 kg ha\(^{-1}\) (93 lb ac\(^{-1}\), d.b.). At a conservatively assumed peanut value of $441 mt\(^{-1}\) ($400 ton\(^{-1}\)), this additional loss equates to $47 ha\(^{-1}\) ($19 ac\(^{-1}\)). It must be recognized that soil texture variability exhibits different extremes in different fields; the field used for this study exhibited a relatively high degree of variability.

The data indicated that over-mature and diseased losses in the high EC zone numerically, but not statistically, exceeded those from the medium EC and low EC texture zones. This may be an indication that variable digging times across textures within a field would be beneficial. However, in many cases this will not be practical due to the logistics of getting the digging and combining equipment moved between fields and because the management zone orientation may not align with the row orientation. While studies have been conducted to evaluate proper time for digging, none encountered in the literature have specifically addressed temporally variable zone management. Better understanding of proper digging time as a function of soil texture may improve decision making ability in determining when to dig, even if not practical to dig at different times within a field.
Future work should be directed at evaluating the digging loss impacts of top link adjustment in fields that exhibit different degrees of soil texture variability. A common practice growers sometimes employ to dig to a shallower depth for a given top link setting is to lift the three point hitch arms on-the-go in areas of the field with low EC soils. Research to quantify digging losses should be directed at this method of blade depth control, in contrast to the top link adjustment employed in this study, which changes the digging angle to impose a change in blade depth.

Acknowledgements

Thanks is due to the South Carolina Peanut Board, which supplied the bulk of the funding for this project, to Amadas Industries, who provided technical support, and to the many individuals who assisted in data acquisition and analysis: Will Anderson, Ashley Bonnette, Hunter Bruce, Jay Chapman, James Cole, Daniel Compton, Nathan Downer, James Fleming, Justin Hiers, Justin Long, Matthew McCaskill, Trent Miller, Baylor Ronemus, Zachary Senn, Charlie Westbrook, and Coral Zadrozny.

References


CHAPTER 3. VARIABLE DEPTH DIGGER DESIGN AND TESTING

Abstract

A variable depth control peanut digger was developed as an automated system to control the three point hitch top link position on a 2-row KMC peanut digger, aimed at reducing peanut digging losses across a variety of soil textures. Investigation was performed to determine if top link position, and therefore digger blade angle, can be prescribed as a function of soil electro conductivity (EC) prescription maps, relating to soil texture, or on-the-go sensor-based feedback control. Sensors included for evaluation of on-the-go depth control included: (1) load cells fixed to ripper shanks for direct measurement of soil draft force; (2) a pressure transducer mounted to a hydraulic top link for measurement of digger reactant force; and (3) a rotary potentiometer mounted to a depth gauge for indication of blade depth. A linear potentiometer was included to indicate extension of the hydraulic top link. The measures of soil draft force were included to evaluate on-the-go indication of soil texture, because proper digger top link adjustment has been indicated to be dependent on soil texture. The hydraulic top link position was adjusted using a computer-operated directional control valve. EC mapping was used to divide a field into three texture zones, with each soil texture zone divided into 12 m (40 ft) long 2-row plots. Soil texture measurement, as indicated by hydrometer testing, demonstrated a good relationship with soil EC. On-the-go data from the front soil draft force sensing shank, top link pressure transducer, and blade depth gauge all correlated with digger setting, increasing in value with decreasing top link extension, with the top link pressure transducer statistically showing the most promise for use as a feedback-
based control sensor. The results indicated that soil EC maps coupled with on-the-go sensor-based adjustment is feasible for prescription of variable depth digger settings.

**Introduction**

Peanut harvest started to change in the 1950s from the stack-pole system to the conventional windrow production method (Wright & Steele, 1979). The windrow method was developed to allow for mechanization of peanut harvest versus the use of manual labor. The first three point hitch peanut digger, created by Brown Manufacturing Corporation in the 1960s, allowed for stationary peanut combines to mobilize. This increased the productivity and efficiency of the peanut harvest, bringing the machine to the windrow as compared to the laborious process of bringing the windrow to the machine. Most modern peanut diggers utilize a functionally similar design to the Brown digger. Aside from capitalizing on the benefits of RTK-based auto-steering for peanut digging, the authors found little literature documenting precision agriculture applications for peanut digging.

Soil electro-conductivity (EC) is currently used to identify soil texture zones (Khalilian et al., 2008; Oguri et al., 2009; Perry et al., 2007b) and mapped data are used as a guide for variable rate nematicide application in cotton (Ortiz et al., 2007; Perry et al., 2007a; Perry et al., 2006) and have also been used for variable rate fertilizer and lime management in peanut and other crops. Ongoing research has demonstrated a reliable and accurate peanut yield monitoring system is possible (Fravel et al., 2013; Porter et al., 2013) and based on implementation of yield data in other crops, will certainly help improve management zone classification in peanut. As competition for water resources
becomes more prevalent, variable rate irrigation technologies may also be economically advantageous for peanut production. Many of the precision agriculture technologies currently employed for peanut production were developed for other crops and adapted for use in peanuts, but no existing technology has been adapted to improve digger efficiency.

While not specific to peanuts or peanut digging, a Clemson University team developed a variable depth subsoiler that was capable of variably adjusting deep enough to break the hard pan, which would reduce fuel consumption and operation cost (Khalilian, 2002). This technology included a continuous strip of load cells attached to an experimental shank operating at a fixed depth that could sense the depth of the hard pan. The data provided could then be used to provide an on-the-go or map for variable subsoiler depth prescription.

Proper peanut digger set-up includes allowing the implement to ride freely with no tractor draft and adjusting the three-point hitch top link to change the blade angle as it enters the soil, with greater top link extension providing shallower digging angles. Proper depth adjustment results in blades cutting the taproot about an inch below the pods. If dug too shallow, the digger blade physically rips pods from plants. Soil builds up on blades when the digger is set too deep causing losses by pushing the plants forward before the blade cuts the taproot. Further losses occur when pods have to ride over soil mounded on the blades.

Soil texture greatly influences blade depth for a given angle; low EC soil is easier to penetrate resulting in a setup with shallower blade angles compared to heavier textured soils. In-field soil texture differences are common in the Southeastern coastal plain where
peanuts are typically grown. Since digging too shallow almost always results in higher digging losses, growers often have to use a more aggressive blade angle so the digger will be positioned adequately below the pods in the heaviest land. Improper top link adjustment for a given soil texture can result in an additional 560 kg ha\(^{-1}\) (500 lb ac\(^{-1}\)) yield loss (Warner et al., 2014). A limited number of growers have a hydraulically controlled top link, which can be adjusted on the go, but adjustment is usually delayed until a problem is visually detected. Since soil EC has been shown to be strongly correlated to soil texture and texture is a major factor in determining proper digger adjustment, an automated, variable-depth, map-based system using a soil EC map or real-time remote sensing as a guide could greatly enhance digging efficiency. In addition to increased yield resulting from reduced digging losses, fuel savings may be achieved through reduction in drawbar and pto power requirements in areas where shallower digging depths are prescribed.

Because the majority of profits or losses in peanut production can be attributed to digging decisions (Monfort, 2013), thorough knowledge of digging performance across a range of conditions and situations is critical to peanut production.

Objectives

The objectives of this project were to: develop of a variable depth peanut digger; evaluate various remote sensing technologies for use in blade angle prescription; and characterize the relationship between soil EC data and soil texture in the upper 10 cm (4 in.) of the soil profile, where the digger blade generally operates.
Materials and Methods

Field Testing

Digging tests were conducted at Clemson University’s Edisto Research and Education Center in Blackville, SC. The field used was approximately 2.7 ha (6.7 ac) with a substantial amount of soil texture variability, from 88 to 98% sand content, 0 to 8.5% silt content, and 0 to 6% clay content. The plots in the study were 12 m (40 ft) long with row spacing at 97 cm (38 in.). Plots were dug with a KMC two-row, three-point hitch mounted digger/shaker/inverter (Kelley Manufacturing Co., Tifton, Ga.) and a John Deere 7330 equipped with Trimble RTK AutoPilot™ (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 Extension (Clemson University) 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, vines were not wrapping around shanks, and that blade angle and depth were set properly.

Soil electro-conductivity mapping using a Veris 3100 (Veris Technologies Inc., Salina, Kans.) was used to spatially delineate three soil texture zones: low EC, medium EC, and high EC. The three zones were defined using an EC contour map constructed in Farm Works Software (Trimble Navigation Limited, Sunnyvale, Cal.). To verify the validity of the use of EC data for delineation of soil texture zones within the digging depth of influence, soil samples were collected from the top 10 cm (4 in.) at the time of digging. 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.

Based on 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 a low EC setting, a medium EC setting, and a 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 blade angle settings were applied as digging treatments across each of the soil texture zones, giving nine treatments. An additional “too shallow” setting was applied in the low EC zone and a “too deep” setting was applied in the High EC zone, giving a total of 11 treatments across the 3 soil texture zones (Table 3.1). Six replicates were provided for each treatment and comparisons across treatments within each soil texture zone were performed using one-way ANOVA and Fisher’s LSD tests ($\alpha=0.05$). Analysis of variance was not performed across data from different soil texture zones.

Table 3.1. Top link cylinder extension, as a percentage of full extension, for each of the digger settings, or digging blade angles used in this study.

<table>
<thead>
<tr>
<th>Digger Setting</th>
<th>Low EC Zone</th>
<th>Medium EC Zone</th>
<th>High EC Zone</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>% Ext.</td>
<td>SD</td>
<td>% Ext.</td>
</tr>
<tr>
<td>Too Shallow</td>
<td>79.8 a 0.56</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Low EC</td>
<td>75.5 b 0.40</td>
<td>75.2 a 0.14</td>
<td></td>
</tr>
<tr>
<td>Medium EC</td>
<td>69.9 c 0.50</td>
<td>70.1 b 0.41</td>
<td></td>
</tr>
<tr>
<td>High EC</td>
<td>55.8 d 0.11</td>
<td>56.0 c 0.26</td>
<td></td>
</tr>
<tr>
<td>Too Deep</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Digger Setup

A model 9-5152 8x20x4 cm (3.0 x8.0 x1.5 in) double acting hydraulic top link (Surplus Center, Lincoln, Neb.) was provided for control of the blade angle, extension providing shallower angles and retraction providing deeper angles. 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 3.1). Solenoid switching was provided through digital outputs of a model 1018 interface kit (Phidgets Inc., Calgary, Alberta, Canada) and model 3051 dual relay board (Phidgets Inc., Calgary, Alberta, Canada). The cylinder was mounted so that the rod was facing the implement and a series TDH30 pressure transducer (Transducers Direct, Cincinnati, Ohio) was installed in line with the blind end, providing an indication of reactant force on the top link during digging. To provide indication of percent extension of the top link, a model 3582 linear potentiometer (Phidgets Inc., Calgary, Alberta, Canada) was attached to the cylinder.

Figure 3.1. Schematic used for hydraulic top link control (a) and physical mounting of a hydraulic top link, linear potentiometer, and valve block (b).

Soil draft force sensing was provided through instrumented ripper shanks (Part 120001, Tractor Supply Co., Brentwood, Tenn.) at two positions on the digger, one near the front and one near the rear of the implement as seen in Figure 3.2. The front shank was mounted directly behind the center coulter and the rear shank was mounted to the side of the conveyor chain. The upper end of each shank was mounted to a shaft
supported by flange bearings mounted on the digger frame, providing free pivoting of the shank. A chain and 4 kN (1,000 lb) load cell (Mustang Dynamometer, Twinsburg, Ohio) were attached to each shank and to the digger frame so that they were in tension during soil engagement. Tension in the chain attached to each shank was calibrated to soil draft force through placing known forces against the bottom ends of the shank, simulating draft.

![Figure 3.2. Instrumented shanks used for soil draft force sensing at the front of the digger, behind the center coulter (a) and at the rear of digger, adjacent to the conveyor chain (b).](image)

A blade depth gauge (Figure 3.3) was fabricated from a 51 cm (20 in.) length of 2.5 cm (1 in.) diameter steel round stock. The gauge trailed from the frame to the left side of the digger, roughly in-line with the frogs and was allowed to freely pivot as it rode along the ground surface. Gauge angle relative to the digger frame was indicated by a model 3583 rotary potentiometer (Phidgets Inc., Calgary, Alberta, Canada). Because the digger frame angle with the horizon changed as a function of top link extension position, a multiple regression equation was developed to calibrate blade depth as a function of top link extension and rotary potentiometer position.
Figure 3.3. The blade depth gauge trailed from the frame at the left side of the digger, free to pivot from the digger frame. The upper end was attached to a rotary potentiometer indicating angular position relative to the digger frame and the lower end engaged the soil.

Data acquisition of analog signals from the linear potentiometer indicating top link extension, hydraulic pressure transducer, and the rotary potentiometer on the blade depth gauge was conducted using a model 1018 interface kit (Phidgets Inc., Calgary, Alberta, Canada). For the soil draft force shanks, each load cell was wired to a separate circuit of a model 1046 bridge board (Phidgets Inc., Calgary, Alberta, Canada). Data acquisition software was developed in Visual Basic 2010 Express (Microsoft Corp., Redmond, Wash.); analog and bridge inputs were collected at a data rate of 10 Hz, logging the average of 10 readings each second. Spatial position was logged each second and provided by a model 1040 GPS (Phidgets Inc., Calgary, Alberta, Canada). The software developed included control functions for the hydraulic top link, allowing the operator to extend or retract to a specified percent extension.

**Results and Discussion**

Data from the soil texture analysis demonstrated correlations between soil texture...
zones, as defined by EC mapping, and both sand and silt content in the top 10 cm (4 in). This supports the use of soil EC mapping for definition of soil texture, and therefore digging management zones. Sand and silt contents were significantly different across each of the three EC-defined soil texture zones, with decreasing sand content and increasing silt content through the low EC zone, medium EC zone, and high EC zones, successively. Clay content was only significantly different between the medium EC and high EC zones, being higher in the high EC zone.

Table 3.2. Sand, silt, and clay contents in the top 10 cm (4 in) of soil across EC-defined soil texture zones.

<table>
<thead>
<tr>
<th>EC Zone</th>
<th>Sand Content</th>
<th>Silt Content</th>
<th>Clay Content</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>%</td>
<td>SD</td>
<td>%</td>
</tr>
<tr>
<td>Sand</td>
<td>95.1 a</td>
<td>2</td>
<td>3.1 a</td>
</tr>
<tr>
<td>Medium</td>
<td>93.4 b</td>
<td>2</td>
<td>4.9 b</td>
</tr>
<tr>
<td>Clay</td>
<td>91.6 c</td>
<td>2</td>
<td>5.8 c</td>
</tr>
</tbody>
</table>

The reactant force imparted on the top link during digging, as measured by the hydraulic pressure transducer used in this study was directly proportional to digging blade angle and significantly different across all treatments within each soil texture zone (Table 3.3). Top link hydraulic pressure data were not available for the low EC texture digging treatments due to a sensor malfunction during testing. While statistical analysis of comparisons across soil textures was not conducted, the values for top link pressure at each digger setting were similar between the high EC and medium EC zones. It can therefore be postulated from this data that top link pressure may not be a good indicator of soil texture, but that it could be a useful tool in feedback based control of the digger angle when coupled with a soil texture zone map.
Blade depth sensing was only effective in producing a rational relationship with digger setting in the low EC texture zone, incrementally increasing in depth with increasing blade angle (Table 3.4). At the time of digging, it was observed that the blade depth gauge was not consistently riding on top of the ground surface, as designed, when the canopy coverage was full; instead, it was being pushed up by the canopy, artificially reducing the blade depth indication. Canopy closure was consistently less than 80% in the low EC texture zones with full closure in the medium EC and high EC zones, explaining why the best relationship between blade depth indication and digger setting was observed in the low EC texture. If the blade depth gauge could be redesigned to push through the canopy, it could prove to be an effective on-the-go sensor for feedback-based control of top link position, independent of soil texture zone delineation.

Table 3.3. Top link hydraulic pressure for each digger setting in the medium EC and high EC zones.

| Digger Setting | Medium EC Zone | | | | High EC Zone |
|----------------|---------------|-----------|-----------|-----------|
|                | P, psi        | SD        | P, psi    | SD        |
| Low EC         | 241 a         | 86        | 259 a     | 155       |
| Medium EC      | 450 b         | 155       | 471 b     | 94        |
| High EC        | 730 c         | 128       | 666 C     | 54        |
| Too Deep       | -             | -         | 991 d     | 36        |

Blade depth sensing was only effective in producing a rational relationship with digger setting in the low EC texture zone, incrementally increasing in depth with increasing blade angle (Table 3.4). At the time of digging, it was observed that the blade depth gauge was not consistently riding on top of the ground surface, as designed, when the canopy coverage was full; instead, it was being pushed up by the canopy, artificially reducing the blade depth indication. Canopy closure was consistently less than 80% in the low EC texture zones with full closure in the medium EC and high EC zones, explaining why the best relationship between blade depth indication and digger setting was observed in the low EC texture. If the blade depth gauge could be redesigned to push through the canopy, it could prove to be an effective on-the-go sensor for feedback-based control of top link position, independent of soil texture zone delineation.

Table 3.4. Digging blade depth in each digger setting and each zone, as indicated by blade depth gauge.

| Digger Setting | Low EC Zone | | | | Medium EC Zone | | | | High EC Zone |
|----------------|-------------|-----------|-----------|-----------|---------------|-------------|-----------|
|                | D, in       | SD        | D, in     | SD        | D, in         | SD          | D, in     |
| Too Shallow    | 0.6 a       | 0.5       | -         | -         | -             | -           | -         |
| Low EC         | 2.5 b       | 0.7       | 3.3 a     | 0.4       | 3.4 a         | 0.5         |           |
| Medium EC      | 3.3 c       | 0.3       | 4.3 b     | 0.4       | 3.6 a,b       | 0.7         |           |
| High EC        | 3.9 c       | 0.5       | 4.2 b     | 0.7       | 4.7 b         | 0.4         |           |
| Too Deep       | -           | -         | -         | -         | 2.4 c         | 0.4         |           |

Draft force sensing at the front of the digger, behind the center coulter, increased
with increasing digging angle in all instances, except for the “too deep” setting in the high EC zone. The inconformity of this “too deep” setting is assumed to be a function of the geometry of the soil draft force shank, whereby it was perhaps being lifted from the soil surface at the most aggressive digging angle, reducing the load cell tension. Because of the mounting position of the front soil draft force shank, it moves deeper as the blade depth is increased, so it was expected that soil draft force would increase with increasing digging angles.

Table 3.5. Front soil draft force in each digger setting and each zone.

| Digger Setting | Low EC Zone | | High EC Zone | |
|----------------|-------------|----------|-------------|
|                | F, lb       | SD       | F, lb       | SD       |
| Too Shallow    | 13 a 4      |          | -           | -        |
| Low EC         | 27 a,b 15   | 44 a     | 23          | 36       |
| Medium EC      | 43 b,c 29   | 64 a,b   | 18          | 60       |
| High EC        | 53 c 9      | 84 b     | 18          | 93       |
| Too Deep       | -           | -        | -           | 58       |

While the numerical trend of front soil draft force generally followed this relationship and there were some statistical differences across digger settings, the differences across digger settings may not be sufficient to warrant its use for feedback-based control of digging angle. Looking within each digger setting and across soil texture zones, it can be observed that the soil draft force was consistently less in the low EC texture zone than in the medium and high EC zones. Although statistical comparisons were not conducted across zones, the differences here do not appear to be sufficient to justify its use in on-the-go indication of soil texture.

Data from the rear soil draft force shank is not presented here because the shank was lifted entirely above the soil surface for several of the most aggressive digging
angles. Adjustment to a point where it would not be lifted from the soil at the most aggressive digging angle would have been impractical because it would have required that the depth be excessive in the shallowest digging angles. The rear soil draft force shank as implemented here was not sufficient for use in predicting soil texture or for feedback-based control of top link position.

Conclusions

The relationships demonstrated between soil texture and soil EC indicated that EC mapping is acceptable for delineation of soil texture zones for typical peanut digging depths. Electrical control of a hydraulic top link proved to be an effective and practical method of on-the-go digging angle adjustment. The technology developed here allows the operator to manually set or prescribe the proper top link setting for each of his EC-defined soil texture zones. The top link setting for each texture zone is stored in the control computer as a linear potentiometer analog input. Using GPS position, the software can then be used to automatically adjust to the appropriate top link prescription, or linear potentiometer analog input, as a function of position and therefore current soil texture zone. A system such as this provides automated control of digging angle but still allows the operator the ability to adjust top link extension prescriptions as necessary.

With exception of the top link linear potentiometer, the top link pressure transducer showed the greatest potential for utility as an on-board feedback-based control of top link extension, when coupled with a map indicating soil texture zones. Although the depth gauge was not successful in predicting blade depth for peanuts where there was full canopy coverage, the researchers involved with this project believe that it has good
potential for use as an on-the-go basis for blade angle adjustment, if it can be redesigned to push through the crop canopy.

Future research should be conducted to determine the practicality and benefits of developing a continuously adjustable variable depth digger. Use of the un-contoured spatial EC data, along with operator-assigned top link extension prescriptions at the minimum and maximum EC values, and perhaps a mid-range EC top link extension prescription may allow for infinitely variable top link prescription. However, because soil EC mapping is a practice still not readily available to producers in all areas, an alternative to EC map-based prescriptions would be helpful. Continued work on identification of an on-the-go soil texture sensor might enable feedback-based adjustment from on-board sensors in the absence of EC mapping.

Acknowledgements

Thanks is due to the South Carolina Peanut Board, which supplied the bulk of the funding for this project, to Amadas Industries, who provided technical support, and to the many individuals who assisted in data acquisition and analysis: Will Anderson, Ashley Bonnette, Hunter Bruce, Jay Chapman, James Cole, Nathan Downer, James Fleming, Justin Hiers, Justin Long, Matthew McCaskill, Trent Miller, Baylor Ronemus, Zachary Senn, Charlie Westbrook, and Coral Zadrozny.

References


CHAPTER 4. VARIABLE DEPTH PEANUT DIGGER DIGGING LOSS ANALYSIS

Abstract

A variable depth peanut digger was developed for use in assessing the ability to reduce digging losses as a function of digging blade angle and on-board remote sensing. Soil electrical conductivity (EC) data were used to divide a field into three zones, ranging from low EC to high EC. A computer controlled hydraulic top link was provided for adjustment of top link extension and therefore digging angle. The optimal top link position was determined for each of the three zones by visual observation of the windrow and these three top link positions were applied in six replications across all three zones. Additional top link positions were conducted in the High EC and low EC soil zones, operating shallower than optimal in the low EC texture zone and deeper than recommended in the high EC zone. Average digging losses (dry basis) ranged from 156 to 556 kg ha\(^{-1}\) (138 to 496 lb ac\(^{-1}\)) in the low EC texture zone, 330 to 854 kg ha\(^{-1}\) (294 to 761 lb ac\(^{-1}\)) in the medium EC zone, and 674 to 1190 kg ha\(^{-1}\) (601 to 1,061 lb ac\(^{-1}\)) in the high EC zone. Within each texture zone, the optimum indicated soil draft force, as indicated by a load shank positioned behind the center coulter, increased from coarse to fine soil textures. Hydraulic top link pressure indicated potential for use as an on-the-go feedback-based control for optimizing digging depth, with minimized digging losses occurring in the same range of pressure across two soil textures. A digging blade depth gauge was effective in on-the-go indication of blade depth and demonstrated potential for on-the-go digging angle prescription, but only where incomplete canopy coverage existed. The system, as developed demonstrated the potential for $47 ha\(^{-1}\) ($19 ac\(^{-1}\)) in
yield loss savings with an estimated break-even payoff acreage of 109 ha (269 ac).

**Introduction**

Applications of precision agriculture or variable rate technologies often result in increased production efficiencies, reduced inputs (energy, nutrient, chemical, etc.), and increased crop yields. Relative to the major grain crops and cotton, there have not been as many developments of precision agriculture applications specifically for peanut production. Therefore there are great opportunities for developments in this area. Implementation of RTK, auto-steering technologies have significantly reduced peanut harvest losses, profitability and efficiency of peanut production caused by off-centered steering. One study indicated 186 kg ha\(^{-1}\) (166 lb ac\(^{-1}\)) yield loss for every 20 mm (0.79 in) deviation from row center (Ortiz et al., 2013).

Peanut digger research carried out at N.C. State University involved the development of a variable speed conveyor chain that adjusted to match the speed of the tractor, helping to reduce yield losses (Roberson, 2008). In this research the conveyor chain speed was synchronized with the tractor ground speed using variable rate sprayer technology and hydraulic controls. The overall goal was to reduce pods being ripped from the vines or shed due to bunching from speed of the chain being faster or slower, respectively, than the tractor speed. This improvement has yet to be added to commercially available peanut diggers, although Amadas Industries offers a cab-mounted speed indicator, providing a visual output of conveyor chain speed in mph (Amadas Industries, Inc., 2011).

Most peanut yield losses occur during the digging, or inversion process (Bader,
Generally, pod losses occur as a result of either weakened peg strength caused by disease and/or over-maturity (Chapin and Thomas, 2005; Grichar and Boswell, 1987; Thomas et al., 1983; Troeger et al., 1976), or physical actions of the digger which dislodge pods from plants. This makes time of digging and proper digger settings critical to reduce yield loss during the peanut harvest. Some loss is expected since a wide range of maturity exists across the pod profile. In order to harvest at the optimum time some pods are over-mature and loss of these is generally taken to be unavoidable. Soil conditions (friability) impact pod losses profoundly (Grichar and Boswell, 1987).

Digging losses of 450 kg ha\(^{-1}\) (400 lb ac\(^{-1}\)) are not uncommon using the current digger design even when soil conditions are favorable. A twin row vs. single row digging loss study in a Virginia variety conducted by Clemson University demonstrated average digging losses ranging from 650 to 1,350 kg ha\(^{-1}\) (580 to 1,200 lb ac\(^{-1}\)) dry weight, or about 9 to 22% of the total production for optimum digger top link setting (Kirk et al., 2013).

Proper digging angle is known to be dependent on soil texture, which can be highly variable throughout a field, especially in southeastern coastal plains soils where many peanuts in the U.S. are grown. To reduce yield losses created from improper digging angle, the operator must stop and change the length of the top link for the digger. In order to save time in adjustments, some peanut growers use the method of setting the digger blade depth to best match the finest or heaviest soil texture within field. However, this method of digger set up creates problems in coarser soil textures found within the field. Proper depth adjustment results in blades cutting the taproot about an inch below
the pods. If peanuts are dug too deep, excessive soil builds up on blades causing losses by pushing the plants forward before the blade cuts the taproot. Even further losses can occur when pods have to ride over soil mounded on the blades.

Because the majority of profits or losses in peanut production can be attributed to digging decisions (Monfort, 2013), thorough knowledge of digging performance across a range of conditions and situations is critical to peanut production.

Objectives

The objectives of this project were to: quantify digging losses across different digging angles in three soil texture zones and evaluate various remote sensing technologies for use in digging angle prescription for minimization of digging losses.

Materials and Methods

Digging tests were conducted at Clemson University’s Edisto Research and Education Center in Blackville, SC. The field used was approximately 2.7 ha (6.7 ac) with a substantial amount of soil texture variability, from 88 to 98% sand content, 0 to 8.5% silt content, and 0 to 6% clay content. The plots in the study were 12 m (40 ft) long with row spacing at 97 cm (38 in.). Plots were dug with a KMC two-row, three-point hitch mounted digger/shaker/inverter (Kelley Manufacturing Co., Tifton, Ga.) and a John Deere 7330 equipped with Trimble RTK AutoPilot™ (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 Extension (Clemson University) 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, vines were not wrapping around shanks, and that blade angle and depth were set properly.

Soil EC mapping using a Veris 3100 (Veris Technologies Inc., Salina, Kans.) was used to spatially delineate three soil texture zones: low EC, medium EC, and high EC zones. The three zones were defined using an EC contour map constructed in Farm Works Software (Trimble Navigation Limited, Sunnyvale, Cal.). To verify the validity of the use of EC data for delineation of soil texture zones within the digging depth of influence, soil samples were collected from the top 10 cm (4 in.) at the time of digging. 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 digger was set up for the proper digging blade angle within each of the three soil texture zones, providing a low EC setting, a medium EC setting, and a 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 blade angle settings were applied as digging treatments across each of the soil texture zones, giving nine treatments. An additional “too shallow” setting was applied in the low EC zone and a “too deep” setting was applied in the High EC zone, give a total of 11 treatments across the 3 soil texture zones (Table 4.1). Six replicates were provided for each treatment and comparisons across treatments within each soil texture zone were performed using one-way ANOVA and Fisher’s LSD tests ($\alpha=0.05$). Analysis of variance was not performed across data from different soil texture zones.
As described in Warner et al. (2014), the digger was equipped with a solenoid-controlled hydraulic top link, a linear potentiometer indicating extension length of the hydraulic top link, a hydraulic pressure transducer indicating digger reactant force on the top link, two soil draft force shanks, a digging blade depth gauge, and a data acquisition system collecting data at 10 Hz.

Digging loss data collection occurred five to six days after digging. To distinguish digging losses from combining losses, the windrow from each two-row plot in the study was gently lifted with pitchforks to a trailer, which carried the windrows to a stationary combine. The windrows were manually fed into the combine header and the entire yield from each plot was bagged and weighed. A sample for moisture analysis of approximately 1 kg (2.2 lb) was collected and weighed. Samples were oven dried using ASABE S401.2 conventional oven method (ASABE 2012).

A 0.6 m (2 ft) long by 2 row test area was randomly defined along the length of each plot. Above ground digging losses were collected and weighed from this area, independently quantifying sound pod losses from over-mature and diseased pod losses. Over-mature and diseased pods were not considered to be “mechanical” digging losses because of their high propensity to be lost during harvest due to weak peg strength regardless of digger setup. Each test area was then excavated to a depth of 4 inches and the excavated soil was mechanically sieved (Figure 4.1) to collect the below ground losses. Below ground losses were weighed, once again distinguishing between sound, over-mature, and diseased pods. “Mechanical”, or sound above and below ground losses were oven dried using ASABE S401.2 conventional oven method (ASABE 2012). All
losses reported in the results section are “mechanical” or sound losses on a dry weight basis.

![Figure 4.1. Digging loss sampling, showing excavated test area and soil sieve in operation.](image)

**Results and Discussion**

Digging loss results indicated that digger-related yield losses are substantially affected by soil texture and digging depth, supporting the need for a variable digging angle prescribed as a function of soil texture (Table 4.1). The greatest digging losses were experienced in the High EC texture soil, while the low EC texture soil sustained the lowest yield losses. The data within the low EC and high EC zones demonstrate numerically that an optimum digging blade angle exists, above and below which digging losses increase, with statistical significance of this evidence in the low EC zone. It can be speculated that an optimum digging blade angle also existed for the medium EC, although the greatest prescribed angle in this study did not achieve enough depth to generate values demonstrating this.
Table 4.1. Mechanical digging losses, as the sum of above ground and below ground losses, for each soil texture zone across imposed digging angles.

<table>
<thead>
<tr>
<th>Digger Setting</th>
<th>Low EC Zone</th>
<th>Medium EC Zone</th>
<th>High EC Zone</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>lb ac⁻¹, d.b.</td>
<td>SD</td>
<td>lb ac⁻¹, d.b.</td>
</tr>
<tr>
<td>Too Shallow</td>
<td>496 a</td>
<td>197</td>
<td>-</td>
</tr>
<tr>
<td>Low EC</td>
<td>338 a,b</td>
<td>222</td>
<td>761 a</td>
</tr>
<tr>
<td>Medium EC</td>
<td>138 b</td>
<td>59</td>
<td>518 a,b</td>
</tr>
<tr>
<td>High EC</td>
<td>417 a</td>
<td>293</td>
<td>294 b</td>
</tr>
<tr>
<td>Too Deep</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

These results demonstrate that absence of digging angle adjustment throughout a field with texture variability could substantially increase digging losses from those at the optimum angle. The data demonstrate that minimum digging losses for the test field were 386 kg ha⁻¹ (344 lb ac⁻¹, d.b.) if the optimum digging angle was set for each of the three soil texture zones. As a worst case scenario, had the operator set the digging angle up for the low EC texture zone and provided no top link adjustment throughout the field, losses would have more than doubled to 808 kg ha⁻¹ (720 lb ac⁻¹, d.b.).

In the more likely event that the operator set the digging angle up for the finest soil texture in this field without additional adjustment in the field, digging losses would have been 490 kg ha⁻¹ (437 lb ac⁻¹, d.b.), or 104 kg ha⁻¹ (93 lb ac⁻¹) greater than optimum. At a conservatively assumed peanut value of $441 mt⁻¹ ($400 ton⁻¹), savings indicated in this study from implementation of variable depth digger technology could realistically equate to $47 ha⁻¹ ($19 ac⁻¹). Using a conservatively estimated retail cost for variable depth digger technology of $5000, if made commercially available, the break-even payoff acreage for investment in the technology would be 109 ha (269 ac). It must be recognized that soil texture variability exhibits different extremes in different fields; the field used for this study exhibited a relatively high degree of variability. While digging loss savings
from implementation of variable depth digger technology should be expected in most instances, the magnitude of savings will differ with the magnitude of soil variability.

As demonstrated in Figure 4.2, the numerically optimum digging depth in the low EC texture zone occurred at the digging angle setting prescribed for the medium EC zone. As indicated by the blade depth gauge, the blade depth for this optimum depth was 8.4 ± 0.8 cm (3.3 ± 0.3 in). While losses at this setting can be said to be significantly less than those at the too shallow and High EC settings, they are not statistically different from losses at the low EC setting, which demonstrated an indicated blade depth of 6.4 ± 1.8 cm (2.5 ± 0.3 in). Relationships between digging losses and blade depth for the medium EC and high EC zones could not be developed for this study due to the problems associated with the blade depth gauge in full canopy coverage, discussed in Warner et al. (2014). If the blade depth gauge can be redesigned to work across all levels of canopy coverage, the data for the low EC texture zone indicate that the blade depth gauge can be a viable prescription basis for on-the-go variable control. Furthermore, if the optimum digging blade depth is similar across soil textures, then EC and texture management zones would not be required for variable digging angle prescription.
Figure 4.2. Mechanical digging losses as a function of indicated blade depth in the low EC texture zone. Error bars represent ± ½ LSD.

Figure 4.3 shows mechanical digging losses as a function of the front soil draft force, from the instrumented shank mounted on the front of the digger behind the center coulter. It is reiterated that the mounting position of the front soil draft force shank caused the shank to change depth with the digging blade, increasing indicated force at greater depths. For clarity and due to problems with the geometry of the load shank mounting configuration discussed in Warner et al. (2014), the point associated with the too deep setting in the high EC zone is not included here. The data suggest that the soil draft force associated with the optimum digging loss setting increases from coarse to fine texture soils. While this trend is suggestive that soil draft force sensing could be useful as a prescriptive tool, the high degree of variability observed in soil draft force sensing within each treatment would make on-the-go, continuously variable adjustment on the basis of soil draft force coarse and imprecise.
Figure 4.3. Mechanical digging losses as a function of soil draft force at the front load shank, behind the center coulter. Error bars represent ±½ LSD within soil texture zones.

The reactant force imparted on the top link during digging, as measured by the hydraulic pressure transducer, produced less variable data within each treatment than the soil draft force sensing (Figure 4.4), with statistical differences between each treatment within each soil texture. As discussed in Warner et al. (2014), a sensor malfunction resulted in loss of top link pressure data for the low EC soil texture. The data show that the top link pressure at the optimum digging angle was not statistically different between the medium EC and high EC zones. This is in contrast to the relationship demonstrated between soil draft force at optimum digging angle and soil texture, increasing from low EC to high EC textures. While further study must be conducted to confirm or refute, this suggests that an optimum top link pressure may be definable for a given machine and field condition, which is universally applicable across all soil textures for that field and machine. This would allow on-the-go continuously variable digging angle adjustment in
the absence of an EC map or knowledge of soil texture.

![Figure 4.4. Mechanical digging losses as a function of top link hydraulic pressure. Error bars represent ± ½ LSD within soil texture zones.](image)

Conclusions

A variable depth peanut digger was developed and tested to evaluate several digging angle prescription methodologies relative to digging losses incurred. Proof of concept was demonstrated in the developed system, which allows the operator to prescribe a top link extension length for each of three soil texture zones. A map-based control system was developed with the ability to adjust top link length to the prescriptions, according to GPS position and therefore soil texture zone.

Among the sensing technologies developed and tested for on-the-go, feedback-based prescription, the blade depth gauge and top link pressure showed the most potential for suitability. Both of these sensing technologies demonstrated potential to be employed in the absence of EC and soil texture management zone development, although further
study is required to confirm. Soil draft force sensing demonstrated too much variability across reps within treatments to be a stable feedback basis for digging angle prescription.

Future work should be directed at reducing variability in digging loss data by sampling larger test areas or multiple test areas per plot. Redesign of the blade depth gauge is required to allow the gauge to ride along the soil surface regardless of canopy effects. Testing in different fields with various degrees of soil texture variability should be conducted in order to evaluate the repeatability of the results presented here.

Acknowledgements

Thanks is due to the South Carolina Peanut Board, which supplied the bulk of the funding for this project, to Amadas Industries, who provided technical support, and to the many individuals who assisted in data acquisition and analysis: Will Anderson, Ashley Bonnette, Hunter Bruce, Jay Chapman, James Cole, Daniel Compton, Nathan Downer, James Fleming, Justin Hiers, Justin Long, Matthew McCaskill, Trent Miller, Baylor Ronemus, Zachary Senn, Charlie Westbrook, and Coral Zadrozny.

References


CHAPTER 5. DESIGN AND TESTING OF A DEPTH GAUGE CONTROLLER FOR PEANUT DIGGING ANGLE ADJUSTMENT

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.

**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., 2014).

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.

Method 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 AutoPilot™ (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 5.1). 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 5.1. Sand, silt, and clay contents in the top 10 cm (4 in) of soil across EC-defined soil texture zones.

<table>
<thead>
<tr>
<th>EC Zone</th>
<th>Sand Content</th>
<th>Silt Content</th>
<th>Clay Content</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>%</td>
<td>%</td>
<td>%</td>
</tr>
<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 ($\alpha=0.05$). 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 (Microsoft Corp., Redmond, Wash.). 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 5.1). 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 5.1. (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 5.2) was fabricated from an 81 cm (32 in.) length of 2.5 cm (1 in.) diameter steel round stock and approximately 1 ft² 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 5.2b) as necessary to attempt to stay within ±0.091 cm (±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 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 5.3). 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.
Figure 5.2. (a) The blade depth gauge was designed to move up or down with the terrain. Spring tension and the weight of the depth gauge allowed it to stay in contact with the ground. As the depth gauge moved up and down going through the field it moves a rotary potentiometer shaft, which was calibrated to indicate blade elevation relative to the ground surface. (b) The hydraulic top link would reactively adjust according to the depth gauge reading and the prescribed digging elevation.

Figure 5.3. Data and linear regression relating indicated blade elevation to rotary potentiometer value.

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 5.4 shows blade elevation and top link position as a function of distance travelled through two of the plots in the study. The data in Figure 5.4a and Figure 5.4b 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 5.5). In Figure 5.4a, 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 5.4a 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 5.4 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 5.4) to
those of the extension-lock treatment (Figure 5.5), the depth-lock treatment maintained a
more constant depth across the plot. In the extension-lock plot (Figure 5.5), 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 5.5), showed a flat trend line
confirming that the top link successfully maintained the prescribed position across the
plot. The indicated blade elevation (Figure 5.5), 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 5.4. 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 5.6 better illustrates the differences in
terrain features found in the field studied.
Figure 5.4. 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 5.5. 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 down hill and up hill 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 5.2. 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 5.2 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 5.2. 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></th>
<th>Medium EC Zone</th>
<th></th>
<th>High EC Zone</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Avg. Depth</td>
<td>SD</td>
<td>Avg. Depth</td>
<td>SD</td>
<td>Avg. Depth</td>
<td>SD</td>
</tr>
<tr>
<td></td>
<td>(in)</td>
<td></td>
<td>(in)</td>
<td></td>
<td>(in)</td>
<td></td>
</tr>
<tr>
<td>DepthLock-Deep</td>
<td>-0.72</td>
<td>a 0.15</td>
<td>-0.98</td>
<td>c 0.08</td>
<td>-0.78</td>
<td>bc 0.09</td>
</tr>
<tr>
<td>Ext.Lock-LowEC</td>
<td>-0.59</td>
<td>a 0.38</td>
<td>-0.64</td>
<td>ab 0.18</td>
<td>-0.55</td>
<td>ab 0.19</td>
</tr>
</tbody>
</table>
The plot trial data in Figure 5.6 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 5.7. Digger blade elevation as a function of soil EC in the plot trials for the DepthLock-Proper and Ext.Lock-MediumEC treatments.

Figure 5.7 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 (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 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.
References


CHAPTER 6. PEANUT DIGGING LOSS ANALYSIS FOR FOUR DIFFERENT DEPTH CONTROL METHODS

Abstract.

A variable depth peanut digger was used in assessing the ability to reduce digging losses as a function of digging blade angle and feedback-based control from on-the-go remote sensing. Soil electrical conductivity (EC) data was used to divide a field into three soil texture zones, ranging from light to a heavier soil texture. A computer controlled hydraulic top link was provided for adjustment of top link extension and therefore digging angle. A proper top link position prescription was determined for each of the three zones by visual observation of the windrow and these three extension-lock prescriptions were applied across each of the three EC zones. Three additional depth-lock treatments at blade elevations of 0.66 cm (0.26 in.) (shallow), 0.05 cm (0.02 in.) (proper), and -0.53 cm (-0.21 in.) (deep) were applied across all three zones using an experimental feedback-based, depth-lock control. Two additional control-arm treatments were applied in the low and medium EC zones using the lower control arms of the three point hitch to control proper digging depth. In the low EC zone, average mechanical digging losses were 87.9 kg ha\(^{-1}\) d.b. (78.5 lb ac\(^{-1}\) d.b.) for the proper extension-lock prescription, 110 kg ha\(^{-1}\) d.b. (98.2 lb ac\(^{-1}\) d.b.) for the proper depth-lock prescription, and 95.3 kg ha\(^{-1}\) d.b. (85.1 lb ac\(^{-1}\) d.b.) for the control-arm prescription, with no statistical differences between these three treatments. In the medium EC zone, average mechanical digging losses (dry-basis) were 442.4 kg ha\(^{-1}\) d.b. (395 lb ac\(^{-1}\) d.b.) for the proper extension-lock prescription, 333.8 kg ha\(^{-1}\) d.b. (298 lb ac\(^{-1}\) d.b.) for the proper depth-lock prescription, and 507.4 kg
ha\(^{-1}\) d.b (453 lb ac\(^{-1}\) d.b.) for the control-arm prescription, with no statistical differences between these three treatments. In the high EC zone, average mechanical digging losses (dry-basis) were 325.9 kg ha\(^{-1}\) d.b. (291 lb ac\(^{-1}\) d.b.) for the proper extension-lock prescription and 342.7 kg ha\(^{-1}\) d.b. (306 lb ac\(^{-1}\) d.b.) for the proper depth-lock prescription, with no statistical differences between these two treatments. Within each treatment digging losses generally increased as a function of soil EC, and decreased as a function of sand content. The data indicated no statistical differences in digging losses between proper prescriptions of the four depth control methods within soil texture zones, suggesting that depth-lock and lower control arm control of digging blade depth may be acceptable alternatives to the conventional method of top link adjustment.

**Introduction**

Peanut harvesting machinery has experienced few if any commercial applications of precision agriculture technologies. Most precision agriculture technologies have been made commercially available for major row crops such as corn, soybean, wheat, and cotton; although research has been conducted in implementing yield monitor systems for peanut (Free et al., 2014). Peanut digger technology has seen little to no major developments since the 1960’s with the development of the modern day digger (Lilley et al., 1967). Peanut or specialty crop machinery presents great opportunities in the realm of precision agriculture.

Applications of precision agricultural technologies are assumed, by most, to result in an increase in yield or possibly reduced inputs required. Implementation of RTK, auto-
steering technologies have significantly reduced harvest losses and increased profitability of peanut production. One study indicated 186 kg ha\(^{-1}\) d.b. (166 lb ac\(^{-1}\) d.b.) yield loss for every 20 mm (0.79 in.) deviation from row center (Ortiz et al., 2013). A recent peanut digging study conducted by NC State University involved the development of a variable speed conveyor chain that adjusted the speed of the chain to match the travel tractor. This was implemented in efforts to reduce yield losses (Roberson, 2008). In this research the conveyor chain speed was adjusted by using a variable rate sprayer technology and hydraulic controls. The overall goal was to reduce pods being ripped from the vines from speed of the chain going too fast or disturbance from bunching due to it moving too slow in comparison to the tractor speed. This improvement has yet to become commercially available on peanut diggers, although Amadas Industries offers a cab-mounted speed indicator, providing a visual output of conveyor chain speed in mph (Amadas Industries, Inc., 2011).

In 2013, Clemson University developed a patent pending variable depth digger technology which used a map based system to actuate a hydraulic top link and therefore adjust the pitch of a digger to correct top link setting per soil texture (Warner et al., 2014). This development proved in dry soil conditions (0.000 - 0.024 cm\(^3\) cm\(^{-3}\)) to save approximately $47 ha\(^{-1}\) ($19 ac\(^{-1}\)) in yield recovery as compared to conventional top link adjustment methods and a projected average payoff period of approximately one year or 101.2 ha\(^{-1}\) (250 ac\(^{-1}\)) (Warner et. 2014b). However, this system required use of a soil texture zone map, and also required operators to prescribe a proper top link setting for each zone in each field. These requirements created barriers to ease of use and application
of the technology. In an effort to make this technology more accessible and simplified, Clemson University researchers in collaboration with Amadas Industries engineers devised a depth gauge for on-the-go feedback-based control, discussed here. Aside from the research conducted by the authors with the variable depth digger, the benefits of RTK-based auto-steering (Ortiz et al., 2013), and effect of conveyor chain speed, no literature documentation was found in the application of precision agriculture technologies to peanut diggers. Most peanut losses occur during the digging, or inversion process (Bader, 2012). In most cases pod losses occur as a result of either weakened peg strength caused by disease and/or over-maturity (Chapin and Thomas, 2005; Grichar and Boswell, 1987; Thomas et al., 1983; Troeger et al., 1976), or physical actions of the digger which dislodge pods from plants (Kirk et al., 2014). This makes the timing of digging and proper digger settings critical to reduce yield loss during the peanut harvest. Some yield losses are expected due to the range of maturity across the pod profile. In order to harvest at the optimum time 70% or more, depending on the variety, of the peanuts pods after blasting should a dark brown or black coloration to help insure the peanuts will grade and yield well at the buy point (Chapin and Thomas et al., 2005). With doing this some pods are over-mature and loss of these is generally accepted to be unavoidable. Soil conditions (friability) impact pod losses profoundly (Grichar and Boswell, 1987). Digging losses of 450 kg ha\(^{-1}\) d.b. (400 lb ac\(^{-1}\) d.b.) are not uncommon using the current digger design even when soil conditions are favorable. A twin row vs. single row digging loss study in a Virginia varieties conducted by Clemson University demonstrated average digging losses ranging from 650 to 1,350 kg ha\(^{-1}\) d.b. (580 to 1,200
lb ac\(^{-1}\) d.b.) dry weight, or about 9 to 22\% of the total production for proper digger depth settings (Kirk et al., 2013).

Proper digging angle was proven to be dependent on soil texture (Warner et al., 2014b), which can be highly variable throughout a field, especially in southeastern coastal plains soils where many peanuts in the U.S. are grown. In order to minimize yield losses created from improper digging angle, the length of the top link should be adjusted as a function of soil texture. The conventional method of top link adjustment is to set it for the proper digging depth in the heaviest soil texture in a field. However, this can result in digging too deep in the lighter soil textures. Proper depth adjustment results in blades cutting the taproot about an inch below the pods. If peanuts are dug too deep, excessive soil builds up on blades causing losses by pushing the plants forward before the blade cuts the taproot. A study conducted at the Edisto Research and Education Center demonstrated a 312.5 kg ha\(^{-1}\) d.b. (279 lb ac\(^{-1}\) d.b.) recovery savings as compared to the conventional method by adjusting to the proper digger setting in the lighter soil textures (Warner et al., 2014b). Some operators already compensate for soil texture by manual control of a hydraulic top link or by lifting the lower 3-point hitch control arms as lighter soils are encountered. However, such manual adjustments are hardly precise and they are generally only based on on-the-go visual observation from the tractor cab.

The majority of yield losses in peanut production can be attributed to digging decisions (Monfort, 2013); thorough knowledge of digging performance across a range of conditions and situations is critical to peanut production.
Objectives

The objectives of this study were to compare digger related yield losses for four different methods of digging depth control: conventional, fixed top link setting for the heaviest soil in a field; map-based extension-lock top link adjustment (as described in Warner, 2014b); depth-lock control based on feedback from a depth gauge; and 3-point hitch control arm adjustment.

Materials and Methods

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 soils being classified as either a sand or a 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 (Kelle y 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 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, Calif.). 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 zone. Soil volumetric moisture content was taken at the time of digging using the Decagon 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.

A total of 20 digging treatments were applied as described below: nine extension-lock treatments, nine depth-lock treatments, and two control-arm treatments. Six replicates of each treatment were provided and arranged as plots in completely randomized designs within each soil texture zone. 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.

**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 (Microsoft Corp., Redmond, Wash.). 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 6.1). 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 6.1. (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 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 soil texture zones. 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 6.2) was fabricated from an 81 cm (32 in.) length of 2.5 cm (1 in.) diameter steel round stock and approximately 1 ft² of 16 ga. steel sheets, 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 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 (Figure 6.2b) and indicated by rotary position
of the potentiometer. The software was programmed so that the top link would
automatically adjust as necessary to attempt to stay within ±0.91 cm (±0.036 in.) of the
prescribed blade elevation 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 so that the depth
gauge would not 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 6.3). Based on visual observation of the windrows, a DepthLock- Proper
setting was prescribed at a blade elevation of 0.05 cm (0.02 in.) and an additional two
treatments were applied as DepthLock-Shallow at a blade elevation of 0.58 cm (0.23 in.)
above the DepthLock- Proper setting, and DepthLock-Deep at blade elevation of 0.58 cm
(0.23 in.) below the DepthLock- Proper setting.
Figure 6.2(a) The blade depth gauge trailed from the frame at the left side of the digger, and spring tension was provided to maintain contact with the ground. The rotary potentiometer was connected to the upper portion of the

![Figure 6.2(a)](image)

Figure 6.3. Data and linear regression relating indicated blade elevation to rotary potentiometer value.

**Control-Arm Treatments**

The control-arm treatments were included to evaluate digging losses for a scenario where an operator sets the top link at the shortest length for the heaviest soil
texture in a field and lifts up on the 3-point hitch lower control arms as lighter soil is encountered. This type of control method does not require a hydraulic top link, although automated control must have the capability of accessing the vehicle controls. Control-arm treatments were only applied in the low and medium EC zones. In each of these two zones, the depth limit control knob (Figure 6.4a) for the 3-point hitch was adjusted (reduced) incrementally to prescribe a proper depth limit for that EC zone, coupled with the proper top link extension length for the high EC zone. As in the other types of treatments, proper depth limit was determined by visual observation of the windrow. Reduction of the depth limit on the 3-point hitch caused the digger to dig less aggressively in the lighter soil textures. In the low EC zone four rotary clicks were applied, which produced an average digging depth of -1.9 cm (-0.73 in.), and in the medium EC zone two rotary clicks were applied creating an average digging depth of -3.4 cm (-1.33 in.).

![Figure 6.4](image)

Figure 6.4. The depth limit control (a) used to adjust for the control-arm treatments. Two clicks were used for the depth limit in the medium EC zone, and four clicks were used in the low EC zone to raise the depth limit of the 3-point hitch lower control arms (b).

Digging Loss Collection

Digging loss data collection occurred six days after digging. A 1.2 m (4 ft) long
by 2 row sample area was defined at a travel distance of 18.3 m (60 ft) into each plot to allow sufficient time for the automated controls to stabilize. To distinguish digging losses from combining losses, a 1.8 m (6 ft) section of windrow above the sample area was gently lifted with a custom built windrow lifter. This allowed individuals to collect above ground digging losses from the defined sample area prior to combining (Figure 6.5a). Once above ground losses were collected a research plot combine (Kirk et al., 2012) was used to harvest peanuts, record yield weight, and collect combine samples from each plot. Prior to excavation, combine discharge and possible combining losses were removed from the test areas using a leaf blower. Once each test area was clear of debris, it was excavated to a depth of approximately 10cm (4 in.) and the excavated soil was mechanically sieved to collect the below ground losses (Figure 6.5b). Above and below ground digging losses as well as 500 g samples from the combine were oven-dried using ASABE S401.2 conventional oven method (ASABE 2012). Over-mature and diseased pods were dried and weighed separately from the other digging losses, as they were not considered to be mechanical digging losses because of their high propensity to be lost during harvest regardless of digger setup due to weak peg strength.
Figure 6.5(a) Collecting above ground yield losses prior to combining and (b) collecting below ground digging losses by use of a mechanical sieve. After combining, but before collection of below ground digging losses for each plot a leaf blower was used to carefully blow away debris and losses generated by combine.

**Results and Discussion**

Recoverable yield losses were defined as the sum of combine yield for the plot and mechanical digging losses for the sample area, excluding over-mature and diseased digging losses. The data in Table 6.1 show that only one treatment in one EC zone demonstrated a statistical difference in recoverable yield as compared to that of the other treatments; letters indicating results of Fisher’s LSD tests in Table 6.1 and the following tables were conducted within, and not across soil texture zones. Average recoverable yield across treatments within each soil texture zone as presented in the last row of Table 6.1 show that the average recoverable yield for the medium EC and high EC zones were 761 and 850 kg ha\(^{-1}\) d.b. (679 and 759 lb ac\(^{-1}\) d.b.) higher than that in the low EC zone.

Table 6.1. Recoverable yield, as the sum of mechanical digging losses and combined yield, for each treatment within each soil texture zone.

<table>
<thead>
<tr>
<th></th>
<th>Low EC Zone</th>
<th>Medium EC Zone</th>
<th>High EC Zone</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

81
The mechanical digging loss results, as seen in Table 6.2 and Table 6.3, showed only statistical differences between treatments in the low EC zone implying that all treatments within the medium EC and high EC zones performed the same, statistically. Although treatments cannot be statistically compared across soil EC zones due to the nature of the plot design, mechanical digging losses on lb ac\(^{-1}\) (Table 6.2) and percent (Table 6.3) bases were consistently lowest within each treatment in the low EC zone.

The data from Table 6.2 and Table 6.3 can be summarized by grouping them into depth control methods, where the digging losses for the proper setting for each method within each EC zone are averaged. Such a summary provides a numerical indication of expected full field digging losses for each depth control method. Application of the feedback based depth-lock control method numerically performed the best and is represented by using digging losses from the DepthLock-Proper treatment within each EC zone, giving average digging losses of 262 kg ha\(^{-1}\) (234 lb ac\(^{-1}\)) or 5.7%. The conventional depth control method where an operator sets the top link to the proper position for the heaviest soil texture produced the second lowest mechanical digging losses. In this scenario the Ext.Lock-High EC treatment is used in each EC zone, giving average digging losses of 277 kg ha\(^{-1}\) (247 lb ac\(^{-1}\)) or 5.7% of the recoverable yield. If
using the map-based control system as described in Warner et al., 2014b, digging losses for the proper Extension-Lock setting in each soil texture zone can be applied, giving average digging losses of 286 kg ha\(^{-1}\) (255 lb ac\(^{-1}\)) or 6.0%. The map-based control system produced the third best mechanical digging losses. Finally, the highest, or worst, mechanical digging losses were exhibited if the 3-point hitch control arm method was applied, use of digging losses from the control arm treatments in the low and medium EC zones with the Ext.Lock-HighEC treatment in the high EC zone give average digging losses of 309 kg ha\(^{-1}\) (276 lb ac\(^{-1}\)) or 6.6%. It should be noted that the differences in digging losses between these four modes of control were not statistically significant, with a total difference between the best and worst mode of only 47 kg ha\(^{-1}\) (42 lb ac\(^{-1}\)), which would equate to $20.76 ha\(^{-1}\) ($8.40 ac\(^{-1}\)) if considering a peanut value of $362.87 metric ton\(^{-1}\) ($400 ton\(^{-1}\)).

Table 6.2. Average mechanical digging losses for 2014 study, calculated in lb ac\(^{-1}\) d.b., for each of the treatments used in this study.

| Treatment          | Low EC Zone | | Medium EC Zone | | High EC Zone | |
|--------------------|-------------|--|----------------||--|----------------||--|----------------||--|----------------||--|
|                    | Loss lb ac\(^{-1}\) d.b. | SD | Loss lb ac\(^{-1}\) d.b. | SD | Loss lb ac\(^{-1}\) d.b. | SD |
| Ext.Lock-LowEC     | 78.5 b 50.7 | a 102 | 366 a 102 | a | 305 a 110 | a |
| Ext.Lock-MediumEC  | 129 b 116 | a 395 | 395 a 79.0 | a | 330 a 120 | a |
| Ext.Lock-HighEC    | 52.4 b 24.6 | a 345 | 345 a 121 | a | 291 a 130 | a |
| DepthLock-Shallow  | 271 a 312 | a 298 | 298 a 120 | a | 272 a 64.7 | a |
| DepthLock-Proper   | 98.2 b 57.0 | a 416 | 416 a 160 | a | 306 a 223 | a |
| DepthLock-Deep     | 60.7 b 43.1 | a 453 | 453 a 180 | a | 433 a 197 | a |
| ControlArm         | 85.1 b 63.6 | a 453 | 453 a 180 | a | - a - | - |

Table 6.3. Mechanical digging losses, as percent of recoverable yield, for each soil texture zone across imposed digging treatment.

| Treatment | Low EC Zone | | Medium EC Zone | | High EC Zone | |
|-----------|-------------|--|----------------||--|----------------||--|----------------||--|----------------||--|
| Loss % Rec. | SD | Loss % Rec. | SD | Loss % Rec. | SD |
| Ext.Lock-LowEC | | | | | | |
| Ext.Lock-MediumEC | | | | | | |
| Ext.Lock-HighEC | | | | | | |
| DepthLock-Shallow | | | | | | |
| DepthLock-Proper | | | | | | |
| DepthLock-Deep | | | | | | |
| ControlArm | | | | | | |
Average indicated blade elevation, as seen in Table 6.4, demonstrated that blade elevation for Extension-Lock treatments within EC zones consistently decreased with increasing digging angle or aggressiveness. Indicated blade elevation for the proper Extension-Lock settings numerically decreased as a function of soil EC, which may be supportive of differences in required blade depths across soil textures, although it cannot be said whether or not these blade elevations were statistically different from one another and there was a lack of statistical differences in digging losses between these treatments within each zone. It is important to recognize here that indicated blade elevation could be affected by canopy thickness, in that excessive canopy thickness along the path of the blade depth gauge would generally cause the blade to lift above the soil surface artificially decreasing the perceived blade elevation, or making it appear to be deeper than it really was. Down force on the depth gauge through mass and spring force along with a small contact area was provided to increase the down pressure of the gauge, in an attempt to reduce this canopy effect.

Blade elevation for Depth-Lock treatments within EC zones generally decreased with blade increasing blade depth prescription. These data demonstrate and support proper function of the blade depth gauge. When comparing blade elevations for proper settings in the Extension-Lock treatments to those in the Depth-Lock treatments, they
were only statistically similar in the low EC zone. Blade elevation for the proper Depth-Lock treatment in the medium EC zone was 0.3 in shallower than that for the proper Extension-Lock treatment and blade elevation for the proper Depth-Lock treatment in the high EC zone was 0.6 in shallower than that for the proper Extension-Lock treatment. These data indicate that the blade elevations for the proper Depth-Lock settings in the medium EC and high EC zones were not the same as those for the proper Extension-Lock settings in those zones. However, due to the lack of statistical differences in digging losses between proper Depth-Lock and proper Extension-Lock settings in these zones it is not possible to conclusively say which blade elevation was better in terms of reducing digging losses. The significant differences in blade depths coupled with insignificant differences in digging losses is suggestive that there exists a range of blade depths over which digging losses can be statistically minimized.

Across EC zones and within each Extension-Lock treatment and each Depth-Lock treatment, it was generally demonstrated that blade elevation increased, or got shallower, with increasing EC. However, the range of change in average blade elevation for the Extension-Lock treatments was consistently larger (at about 0.76 cm or 0.3 in.) than that for the Depth-Lock treatments (at about 0.25 cm or 0.1 in.). While the lack of statistical differences in digging losses in this study neither support nor refute that maintenance of a nearly constant blade depth is superior to lack thereof, these data indicate that the feedback-based depth gauge control was successful in reducing differences in depth across soil textures as compared to fixed top link control.

Table 6.4. Average indicated blade elevation per treatment as a function of depth gauge
The general lack of statistical differences in mechanical digging losses found between treatments within each soil EC zone, in contrast to the data from the 2013 study (Warner et al., 2014b) is presumed to have been due to the higher volumetric moisture contents in the upper 10 cm (4 in.) of the soil profile (Table 6.5) in 2014. Soil moisture contents, by EC zone were approximately two to three times higher in 2014 as compared to those in 2013. While the tests were conducted in different fields across the two years, both fields demonstrated similar soil textures.

The higher soil moisture content resulted in relatively small differences in prescribed proper Extension-Lock settings across soil EC zones, as seen in Table 6.6. While the top link position in this study did show statistical differences across the Extension-Lock treatments, the total range of prescribed proper top link extension was only separated by 6.7% (1.52cm or 0.6 in.) of cylinder stroke length across the three EC zones. This can be compared to that of the drier 2013 test where the range of prescribed proper top link extension across three EC zones was 22.5% (4.57cm or 1.8 in). This relative lack of differences in proper top link prescriptions across EC zones for the 2014 study indicates that the field conditions did not exhibit or support a great need for or
benefit derived from variable top link position across soil textures. While this 2014 study does not conclusively indicate that soil moisture was the cause for this lack of variable top link position need, comparisons of conditions for the 2013 and 2014 study are suggestive that soil moisture was the culprit. The generally demonstrated lack of need for variable top link position in 2014 is possibly why little mechanical digging loss differences were found between treatments within soil EC zones.

Table 6.5. Average soil volumetric moisture content for treatments within each soil EC zone.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Low EC Zone</th>
<th></th>
<th>Medium EC Zone</th>
<th></th>
<th>High EC Zone</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Soil MC (%vol)</td>
<td>SD</td>
<td>Soil MC (%vol)</td>
<td>SD</td>
<td>Soil MC (%vol)</td>
<td>SD</td>
</tr>
<tr>
<td>Ext. Lock-LowEC</td>
<td>2.7</td>
<td>a 0.006</td>
<td>5.7</td>
<td>a 0.012</td>
<td>5.3</td>
<td>b 0.004</td>
</tr>
<tr>
<td>Ext. Lock-MediumEC</td>
<td>3.3</td>
<td>a 0.008</td>
<td>5.7</td>
<td>a 0.007</td>
<td>6.5</td>
<td>a 0.002</td>
</tr>
<tr>
<td>Ext. Lock-HighEC</td>
<td>3.1</td>
<td>a 0.012</td>
<td>5.1</td>
<td>a 0.007</td>
<td>5.6</td>
<td>ab 0.000</td>
</tr>
<tr>
<td>DepthLock-Shallow</td>
<td>3.5</td>
<td>a 0.009</td>
<td>6.2</td>
<td>a 0.010</td>
<td>5.9</td>
<td>ab 0.009</td>
</tr>
<tr>
<td>DepthLock-Proper</td>
<td>3.0</td>
<td>a 0.011</td>
<td>5.6</td>
<td>a 0.011</td>
<td>5.6</td>
<td>ab 0.010</td>
</tr>
<tr>
<td>DepthLock-Deep</td>
<td>3.5</td>
<td>a 0.019</td>
<td>5.6</td>
<td>a 0.006</td>
<td>6.4</td>
<td>ab 0.008</td>
</tr>
<tr>
<td>ControlArm</td>
<td>3.2</td>
<td>a 0.009</td>
<td>5.7</td>
<td>a 0.011</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 6.6. Top link cylinder extension for 2014 study, as a percentage of full extension, for each of the digger settings, and digger blade depth used in this study.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Low EC Zone</th>
<th></th>
<th>Medium EC Zone</th>
<th></th>
<th>High EC Zone</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>% Extension</td>
<td>SD</td>
<td>% Extension</td>
<td>SD</td>
<td>% Extension</td>
<td>SD</td>
</tr>
<tr>
<td>Ext. Lock-LowEC</td>
<td>88</td>
<td>a 0.000</td>
<td>87.5</td>
<td>b 0.008</td>
<td>87.7</td>
<td>b 0.004</td>
</tr>
<tr>
<td>Ext. Lock-MediumEC</td>
<td>84.7</td>
<td>d 0.007</td>
<td>85.0</td>
<td>d 0.005</td>
<td>84.9</td>
<td>d 0.002</td>
</tr>
<tr>
<td>Ext. Lock-HighEC</td>
<td>81.8</td>
<td>e 0.002</td>
<td>82.0</td>
<td>e 0.000</td>
<td>82.0</td>
<td>e 0.000</td>
</tr>
<tr>
<td>DepthLock-Shallow</td>
<td>88.5</td>
<td>a 0.010</td>
<td>88.7</td>
<td>a 0.006</td>
<td>88.8</td>
<td>a 0.009</td>
</tr>
<tr>
<td>DepthLock-Proper</td>
<td>86.6</td>
<td>b 0.006</td>
<td>86.4</td>
<td>c 0.005</td>
<td>86.9</td>
<td>b 0.010</td>
</tr>
<tr>
<td>DepthLock-Deep</td>
<td>85.7</td>
<td>bc 0.020</td>
<td>85.1</td>
<td>d 0.009</td>
<td>85.9</td>
<td>c 0.008</td>
</tr>
<tr>
<td>ControlArm</td>
<td>85.0</td>
<td>cd 0.004</td>
<td>82.2</td>
<td>e 0.004</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Over-mature and diseased pods for each plot were grouped together into one category with no differentiation made between the two. The data from Table 6.7 suggests a relatively low maturity rate in the low EC zone and relatively high over-maturity and/or
diseased pod rate in the medium EC and high EC zones by the extreme differences in over-mature and disease pod digging losses. The delay in maturity for the low EC zone could have assisted in the plant being able to hold onto the pods during the inversion process allowing for a 433 to 635 kg ha\(^{-1}\) d.b. (387 to 567 lb ac\(^{-1}\) d.b.) reduction in over-mature and diseased pod digging losses as compared to the medium EC and high EC zones. While recoverable yield was also lowest in the low EC zone, over-mature and diseased digging losses there were proportionately much less than the recoverable yield as compared to the other zones. This finding demonstrates a need for sampling for maturity and therefore time of digging to be determined by a composite sample across soil EC zones versus the use of undirected random sampling within a given field.

Table 6.7. Average over-mature and diseased pods digging losses for 2014 study, calculated in lb ac\(^{-1}\) d.b., for each of the treatments used in this study.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Low EC Zone</th>
<th>Medium EC Zone</th>
<th>High EC Zone</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>OMD lb ac(^{-1})</td>
<td>SD</td>
<td>OMD lb ac(^{-1})</td>
</tr>
<tr>
<td>Ext. Lock-LowEC</td>
<td>60.3 ab 33.5</td>
<td>793 a 293</td>
<td>501 ab 197</td>
</tr>
<tr>
<td>Ext. Lock-MediumEC</td>
<td>128 ab 83.8</td>
<td>716 a 221</td>
<td>581 ab 414</td>
</tr>
<tr>
<td>Ext. Lock-HighEC</td>
<td>48.5 b 35.9</td>
<td>687 a 277</td>
<td>331 b 195</td>
</tr>
<tr>
<td>DepthLock-Shallow</td>
<td>167 a 151</td>
<td>574 a 130</td>
<td>480 ab 89.5</td>
</tr>
<tr>
<td>DepthLock-Proper</td>
<td>148 ab 146</td>
<td>529 a 228</td>
<td>378 ab 214</td>
</tr>
<tr>
<td>DepthLock-Deep</td>
<td>59.8 ab 46.1</td>
<td>525 a 171</td>
<td>637 a 282</td>
</tr>
<tr>
<td>ControlArm</td>
<td>73.1 ab 56.0</td>
<td>831 a 448</td>
<td>- - -</td>
</tr>
<tr>
<td>Average, All Plots</td>
<td>97.8 78.9</td>
<td>665 253</td>
<td>485 232</td>
</tr>
</tbody>
</table>

Conclusion

While the depth-lock control method numerically produced the lowest overall mechanical digging losses, overall the digger performed statistically the same as the conventional grower method for all four modes of top link and depth control tested: conventional, map-based, depth-lock, and 3-point hitch control arm adjustment. It is
believed that soil moisture played a role in decreasing the range of proper top link settings across soil textures. With only 6.7% cylinder extension difference between the low EC and high EC soil texture for the proper Extension-Lock settings, the digging loss results proved to be statistically the same for each of the four modes of control within each soil EC zone. The findings in this study, especially when compared to the findings from Warner et al. (2014b), suggest that more testing and research should be conducted on how soil moisture affects digger top link setting and mechanical digging losses.

The extreme range of maturity- and disease-related losses found within the low EC zone and the medium EC to high EC zone could certainly have had an effect on the overall recoverable yield. This is due to the fact that the less mature pods’ pegs are held more tightly to the plant allowing the pod to better stay attached to the plants during the inversion process. This disparity between over-mature and diseased losses across EC zones demonstrates the importance of guided sampling for determination of digging date so that a representative composite can be obtained.

The depth gauge for use in feedback-based control of the top link position was effective in stabilizing blade depth across soil textures as compared to conventional, fixed top link settings. However, the lack of statistical significance in the digging loss results neither support nor refute that sensor-based, fixed depth digging is superior to conventional digger setup. Both the depth lock control system and the control arm system seem to be feasible options for variable depth control and top link control considering there was no statistical difference when compared to the extension lock system or the conventional grower method. However, further testing of both systems across varying
soil moisture conditions, soil EC zones, and pod maturity ranges need to be conducted before this can be confirmed.

Acknowledgments

Thanks is due to the South Carolina Peanut Board, which supplied the bulk of the funding for this project, 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

CHAPTER 7. CONCLUSION OF THE STUDY

Overall the variable depth digger performed well and has proven to be a feasible alternative to the conventional grower method of digger setup. In year one of the study the variable depth digger demonstrated the importance of top link position for different soil texture zones within a field. This study showed that in dry soil conditions at the time of digging, adjustment to a proper top link setting for each soil EC zone was critical and capable of producing an approximate $47 \text{ ha}^{-1}$ ($19 \text{ ac}^{-1}$) yield savings. Observations from year one indicated that among the remote sensing technologies tested, the depth gauge had the most potential for use as a feedback-based control sensor, although further improvements needed to be made to improve the performance and reliability of the depth gauge.

In year two of the study mechanical improvements were made to the depth gauge, coupled with development of the depth-lock control logic. The extension-lock control logic was also developed, which was similar, but an improvement to the top link control from year one study. The extension-lock control logic only allowed the top link to move ±1% cylinder extension once locked in position. The depth-lock control logic would adjust the top link to seek to achieve a prescribed digging depth as a function of indicated blade elevation output readings from the depth gauge. The 29.3 m (96 ft) plot trials showed no statistical differences in yield savings in year two of the study; this is thought to have been due to increased soil moisture in the test field, which resulted in only a 6.7% difference in top link extension across all tested soil EC zones. However, the depth-lock control logic in long strip trials showed a greater ability to maintain digging depth when
compared to the extension-lock control logic. The depth-lock control logic maintained a difference in average indicated blade elevation of 0.23 cm (0.09 in.) across 378 m (1,240 ft) strips of different soil EC zones and terrain features. In adjacent strips, the extension-lock treatments showed a 1.2 cm (0.47 in.) change in average indicated blade elevation across the strips. No yield data or soil moisture data was collected for the strip trial, so no yield savings statistics could be determined.

The variable depth digger has proven in dry soil conditions to have the potential to reduce mechanical digging losses and with the depth-lock control lock it demonstrated capability of maintaining a prescribed blade elevation across the test field. The general outcome of this research was that the variable depth peanut digger is a feasible alternative to the conventional grower method of digger setup. More research is needed to better determine the effects of soil moisture on blade depth and yield losses. Improvements to the depth gauge are still needed to improve its robustness in an agricultural field setting.