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Peanut Digging Loss Analysis for Four Different Depth Control Methods

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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. A proper top link position prescription was determined for each of the three zones and these three extension-lock prescriptions were applied across each of the three EC zones. Three additional depth-lock treatments 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 three 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.*

Keywords. *Peanut, digger, yield loss, precision agriculture, harvest.*

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 al., 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. 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.

Methods and Materials

Field Testing

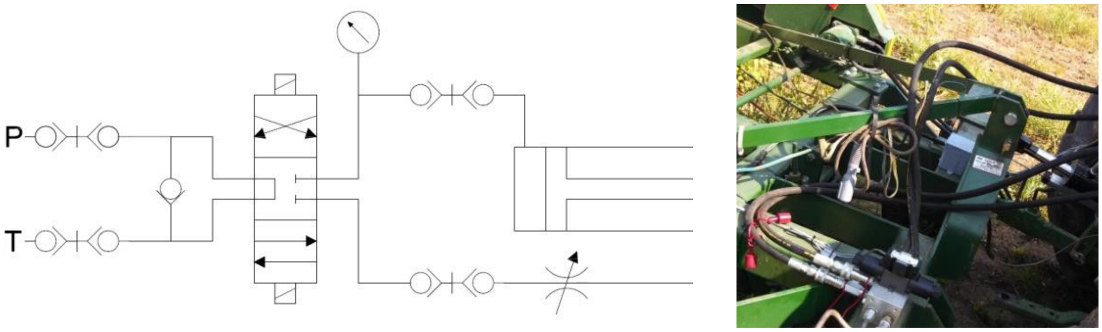
The digger test was conducted at Clemson University's Edisto Research and Education Center in Blackville, SC. The field used was approximately 6.9 ha (17 ac) with all soils being classified as either a sand or a loamy sand. The plots in the study were 29.3 m (96 ft) long with row spacing at 97 cm (38 in.). Plots were dug with a KMC two row, 3-point hitch mounted digger/shaker/inverter (Kelley Manufacturing Co., Tifton, Ga.) and a John Deere 7330 equipped with Trimble RTK AutoPilot^{TM} (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, 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 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 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}.



(a) (b)

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

Extension-Lock Treatments

Based on 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 2) was fabricated from an 81 cm (32 in.) length of 2.5 cm (1 in.) diameter steel round stock and approximately 1 ft^2 of 16 ga. steel 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 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 ±0.91cm (±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 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.


(a) (b)

Figure 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 mechanical linkage. (b) Calibration of the depth gauge for linear measurement of blade elevation.

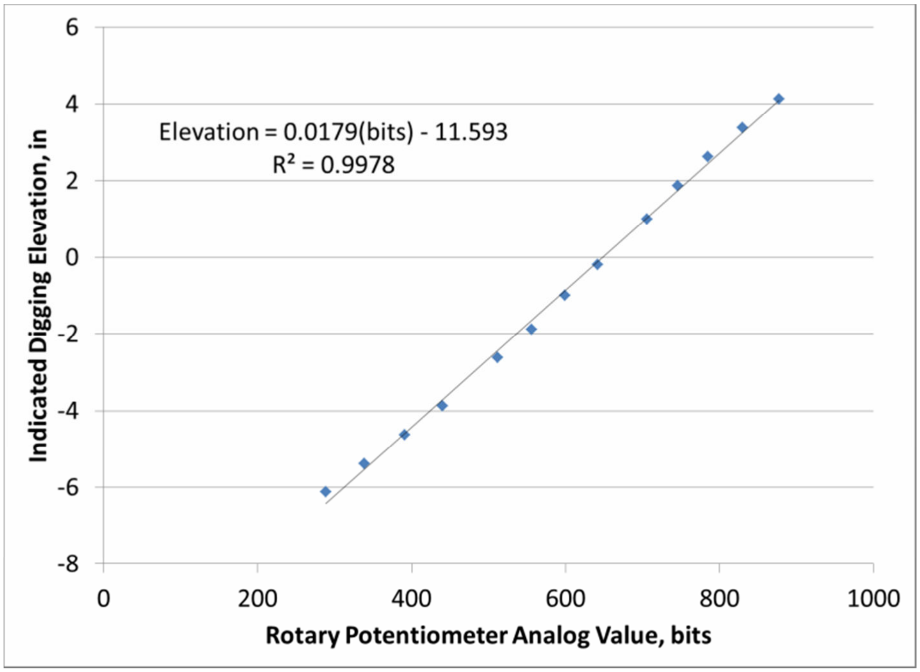
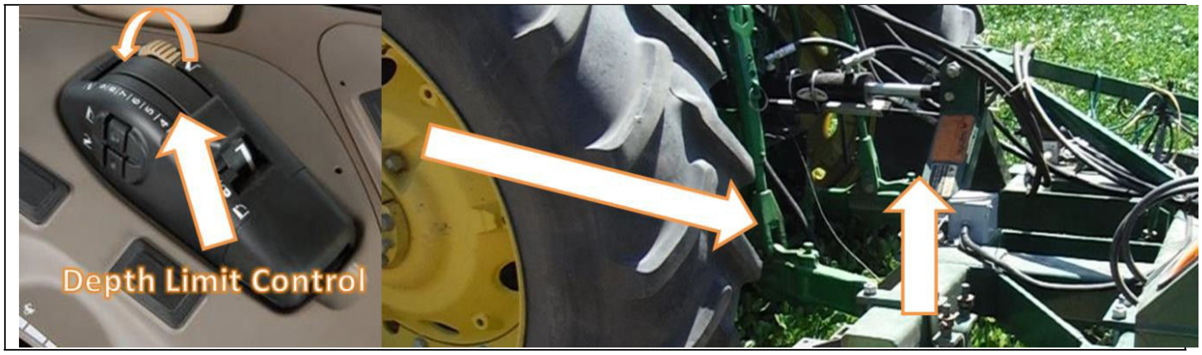


Figure 3. Data and linear regression relating indicated blade elevation relative to rotary potentiometer value.

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 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.).



(a) (b)

Figure 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 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 10 cm (4 in.) and the excavated soil was mechanically sieved to collect the below ground losses (Figure 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.

(a) (b)

Figure 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 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 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 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 1. Recoverable yield, as the sum of mechanical digging losses and combined yield, for each treatment within each soil texture zone.

Treatment	Low EC Zone			Medium EC Zone			High EC Zone		
	lb ac^{-1}, d.b.		SD	lb ac^{-1}, d.b.		SD	lb ac^{-1}, d.b.		SD
Ext.Lock-LowEC	3,589	a	795	4,058	a	324	4,401	a	192
Ext.Lock-MediumEC	3,872	a	712	4,225	a	456	4,270	a	249
Ext.Lock-HighEC	3,061	ab	187	4,413	a	158	4,451	a	294
DepthLock-Shallow	3,944	ab	924	4,245	a	226	4,308	a	293
DepthLock-Proper	3,643	ab	606	4,113	a	370	4,129	a	362
DepthLock-Deep	3,209	b	200	4,333	a	257	4,284	a	373
ControlArm	3,517	ab	741	4,200	a	359	-	-	-
Average, All Plots	3,548		595	4,227		307	4,307		294

The mechanical digging loss results, as seen in Tables 2 and 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 2) and percent (Table 3) bases were consistently lowest within each treatment in the low EC zone.

The data from Tables 2 and 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 2. Average mechanical digging losses as lb ac^{-1} d.b. within each EC zone.

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	366	a	102	305	a	110
Ext.Lock-MediumEC	129	ab	116	395	a	79.0	330	a	120
Ext.Lock-HighEC	52.4	b	24.6	396	a	163	291	a	130
DepthLock-Shallow	271	a	312	345	a	121	272	a	64.7
DepthLock-Proper	98.2	b	57.0	298	a	120	306	a	223
DepthLock-Deep	60.7	b	43.1	416	a	160	433	a	197
ControlArm	85.1	b	63.6	453	a	180	-	-	-

Table 3. Average mechanical digging losses as percent of recoverable yield within each EC zone.

Treatment	Low EC Zone			Medium EC Zone			High EC Zone		
	Loss % Rec.		SD	Loss % Rec.		SD	Loss % Rec.		SD
Ext.Lock-LowEC	2.07	b	1.19	9.09	a	2.62	6.86	a	2.27
Ext.Lock-MediumEC	3.00	ab	2.55	9.35	a	1.44	7.84	a	3.14
Ext.Lock-HighEC	1.70	b	0.76	9.00	a	3.80	6.45	a	2.67
DepthLock-Shallow	5.78	a	6.00	8.18	a	3.08	6.35	a	1.66
DepthLock-Proper	2.57	b	1.22	7.22	a	2.88	7.23	a	5.04
DepthLock-Deep	1.91	b	1.39	9.62	a	3.68	10.36	a	5.07
ControlArm	2.22	b	1.47	11.1	a	5.01	-	-	-

Average indicated blade elevation, as seen in Table 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 4. Average indicated blade elevations as a function of depth gauge reading within each EC zone.

	Low EC Zone			Medium EC Zone			High EC Zone		
Treatments	Avg. Elev. (in.)		SD	Avg. Elev. (in.)		SD	Avg. Elev. (in.)		SD
Ext.Lock-LowEC	-0.49	a	0.38	-0.64	ab	0.18	-0.55	ab	0.19
Ext.Lock-MediumEC	-1.31	b	0.46	-1.01	c	0.15	-0.89	c	0.19
Ext.Lock-HighEC	-1.61	b	0.08	-1.57	e	0.09	-1.33	d	0.36
DepthLock-Shallow	-0.50	a	0.13	-0.46	a	0.08	-0.41	a	0.20
DepthLock-Proper	-0.74	a	0.36	-0.68	b	0.09	-0.70	ab	0.10
DepthLock-Deep	-0.72	a	0.15	-0.98	c	0.08	-0.78	bc	0.09
ControlArm	-0.73	a	0.12	-1.33	d	0.38	-	-	-

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 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. 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% (1.52 cm 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% (4.57 cm 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 5. Average soil volumetric moisture content for treatments within each soil EC zone.

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

Table 6. Top link cylinder extension as a percentage of full extension within each soil EC zone.

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

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 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 7. Average over-mature and diseased pods digging losses as lb ac^{-1} d.b. within each EC zone.

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

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.

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