2950 Niles Road, St. Joseph, MI 49085-9659, USA
269.429.0300 fax 269.429.3852 hq@asabe.org www.asabe.org

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Variable Depth Peanut Digger: Part I - Design and Testing

Andrew C. Warner[1], Kendall R. Kirk[2], James S. Thomas[2], W. Scott Monfort[2], J. Warren White[3], Stanley A. Brantley[3], Joel S. Peele[3], Hunter F. Massey[1], Young J. Han[1], J. Daniel Compton[1]

[1] Agricultural Mechanization & Business; Clemson University; Clemson, S.C.
[2] Edisto Research & Education Center; Clemson University; Blackville, S.C.
[3] Amadas Industries, Inc.; Suffolk, Va.

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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 the digger blade angle, can be prescribed as a function of soil electrical 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.*

Keywords. *Peanut, precision agriculture, digger, soil texture, management zones, site-specific.*

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 be mobile. 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 electrical 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. 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. While the sensing system used for this variable depth subsoiler is dissimilar from the variable depth peanut digger described here, the control mechanism is similar, directing hydraulic fluid flow to a cylinder that controls implement depth.

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; sandy 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 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. 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 6 ha (15 ac) with a substantial amount of soil texture variability, from 0 to 75% sand content, 5 to 85% silt content, and 0 to 50% 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^{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 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: sand, medium, and clay. 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.

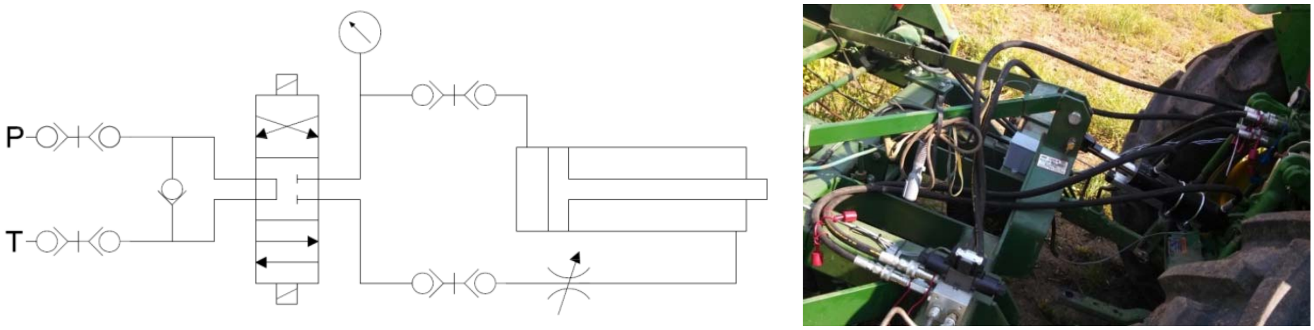
The digger was set up for the proper digging blade angle within each of the three soil texture zones, providing a sand setting, a medium setting, and a clay setting. Assessment of proper blade angle and depth was performed as described in Kirk et al. (2013). Once the proper blade angle was determined 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 sand zone and a "too deep" setting was applied in the clay zone, give a total of 11 treatments across the 3 soil texture zones (table 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 (α=0.05). Analysis of variance was not performed across data from different soil texture zones.

Table 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.

Digger	Sand Zone			Medium Zone			Clay Zone		
Setting	% Ext.		SD	% Ext.		SD	% Ext.		SD
Too Shallow	79.8	a	0.56	-		-	-		-
Sand	75.5	b	0.40	75.2	a	0.14	75.1	a	0.52
Medium	69.9	c	0.50	70.1	b	0.41	70.6	b	0.34
Clay	55.8	d	0.11	56.0	c	0.26	56.1	c	0.19
Too Deep	-		-	-		-	46.6	d	1.98

Digger Setup

A model 9-5152 8x20x4 cm (3x8x1.5 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 (fig. 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.



(a) (b)

Figure 1. Schematic used for hydraulic top link control (a) and physical mounting of 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 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.

(a) (b)

Figure 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 the digger, adjacent to the conveyor chain (b).

A blade depth gauge (fig. 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. 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 roughly in-line with the frogs supporting the digger blade.

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 development 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 sand, medium, and clay texture zones, successively. Clay content was only significantly different between the medium and clay texture zones, being higher in the clay texture zone.

Table 2. Sand, silt, and clay contents in the top 10 cm (4 in) of soil across EC-defined soil texture zones.

	Sand Content			Silt Content			Clay Content		
EC Zone	%		SD	%		SD	%		SD
Sand	51	a	17	31	a	16	18	a,b	11
Medium	36	b	14	47	b	12	17	a	10
Clay	17	c	14	58	c	15	25	b	13

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). Top link hydraulic pressure data were not available for the sand 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 clay and medium texture 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.

Table 3. Top link hydraulic pressure for each digger setting in the medium and clay texture zones.

Digger	Medium Texture			Clay Texture		
Setting	P, psi		SD	P, psi		SD
Sand	241	a	86	259	a	155
Medium	450	b	155	471	b	94
Clay	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 sand texture zone, incrementally increasing in depth with increasing blade angle (table 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 sand texture zones with full closure in the medium and clay texture zones, explaining why the best relationship between blade depth indication and digger setting was observed in the sand 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 4. Digging blade depth in each digger setting and each zone, as indicated by blade depth gauge.

Digger	Sand Zone			Medium Zone			Clay Zone		
Setting	D, in		SD	D, in		SD	D, in		SD
Too Shallow	0.6	a	0.5	-		-	-		-
Sand	2.5	b	0.7	3.3	a	0.4	3.5	a	0.5
Medium	3.3	c	0.3	4.3	b	0.4	3.6	a,b	0.7
Clay	3.9	c	0.5	4.2	b	0.7	4.1	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 clay texture 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 5. Front soil draft force in each digger setting and each zone.

Digger	Sand Zone			Medium Zone			Clay Zone	
Setting	F, lb		SD	F, lb		SD	F, lb	SD
Too Shallow	13	a	4	-		-	-	-
Sand	27	a,b	15	44	a	23	36	13
Medium	43	b,c	29	64	a,b	18	60	16
Clay	53	c	9	84	b	18	93	21
Too Deep	-		-	-		-	58	21

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 the 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 sand texture zone than in the medium and clay texture 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 angles but still allows the operator the ability to adjust top link extension prescriptions as necessary to compensate for variables such as soil moisture, plant health, and cultural practices.

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.

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