Development of a Digital Analysis System to Evaluate Peanut Maturity

B.C. Colvin*, D.L. Rowland, J.A. Ferrell, and W.H. Faircloth[1]

ABSTRACT

The profile color class method developed by Williams and Drexler in 1981 for the prediction of peanut harvest has proven to be a relative description of peanut maturity and is currently used by growers. However, the method requires the subjective visual classification of pods based on the development of color in the mesocarp layer of the hull which naturally introduces variability and possible error in maturity prediction based solely on observer bias. A Digital Image Model (DIM) was developed to eliminate subjectivity in pod color classification. The DIM is a method in which a scanned image of pod mesocarp colors is analyzed using a color definition algorithm. The final output of the DIM is a ratio of pixel color classes. To develop the DIM, replicated plots were established in Florida in 2010 and 2011 and sequentially harvested starting at 120 days after planting (DAP) and then progressing at wk intervals through 155 DAP. At harvest, yield and grade were evaluated for each plot and pod samples were collected for color classification by a single observer using the current profile board method. These same pod samples were then imaged and analyzed with the DIM method. The percentage of black and brown pods (mature pods) classified by the profile board and the DIM method were evaluated to determine the overall performance of the DIM in comparison to the profile board. The DIM method was successful in predicting the percentage of black and brown pods similarly to the profile board in both years with R^2 0.63 to 0.82 with images acquired from the saddle region of the pod. There was more variability in matching the DIM prediction to the profile board when imaging pods from random regions, with R^2 0.19 to 0.82. The goal of this research was to develop an imaging system that could be accessed by growers, consultants, and extension agents for objective analysis and prediction of peanut maturity.

Key Words: *Arachis hypogaea* L., pod maturity, profile board, maturity index.

[1]First, second and third authors: Graduate Student, Associate Professor, and Associate Professor, Agronomy Department, University of Florida, Gainesville, FL 32611; Fourth author: 149 Fairethorne Dr., Leesburg, GA 31763.

*Corresponding Author's email: bcolvin14@ufl.edu

Determining peanut maturity is a complex process because of the underground growth habit and the indeterminate nature of peanuts (Sanders *et al*., 1980). If maturity is determined incorrectly it can have severe economic impacts for the grower because peanut maturity not only affects yield, but also crop value (Rowland *et al.,* 2006). Harvesting immature peanuts has been correlated with a higher potential for off flavors and instability in components such as oils, amino acids, and proteins (Sanders *et al*., 1990). In addition to quality concerns, there is also mechanical loss involved with digging peanuts at the incorrect time. As the plant ages, the pegs begin to degrade and are easily severed during the mechanical inversion process. This problem is often present with an over-mature crop and can account for a significant portion of yield losses (Chapin & Thomas, 2005; Young *et al*., 1982; Lamb *et al.,* 2004). Therefore, it is crucial to correctly determine peanut maturity because harvesting too early or too late both impact profitability significantly.

Historically, several methods for determining peanut maturity have been purported, including the shellout method, methanolic extraction, seed-hull maturity index (SHMI), the arginine maturity index (AMI), and the hull scrape method. (Rowland *et al*., 2006; Sanders *et al*., 1980). However, for over two decades, the most widely accepted method for determining maturity is the use of the hull scrape method in conjunction with the maturity profile board, which was developed from the work of Williams and Drexler (1981). This classification method utilizes the relationship between pod mesocarp color and pod maturity to project optimum harvest timing. The method involves the random collection of several plants in the field and the removal of all pods (mature or immature). Approximately 200 pods make up a proper sample; these pods are subsequently classified according to mesocarp color in the saddle region alone (Figure 1). In order to expose the mesocarp, pods must first be 'blasted' or undergo some process that removes the exocarp. This is typically done by either pressure washing or sand blasting pods to remove the outer layer to expose the mesocarp (Williams and Drexler, 1981; Rowland *et al*., 2006). The maturity board uses six different color classes (white, yellow 1, yellow 2, orange, brown, and black) which represent varying stages of maturity (immature to mature, respectively). The board then

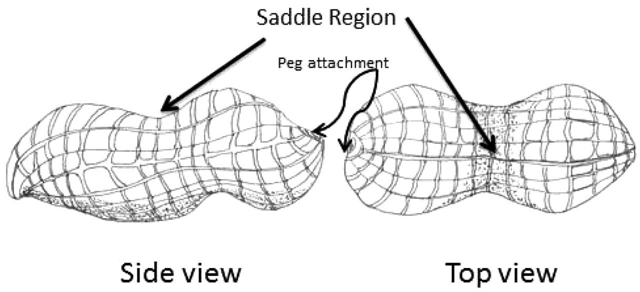

Figure 1. Pictorial representation of the saddle region on a typical peanut pod.

separates the colors into separate columns within each larger color class, and pods are placed on the board by matching the mesocarp color to the color of the columns on the board (Figure 2). There are a total of 25 columns on the board representing separate color classifications of varying maturity level. The relative shape of a curve that the pods form on the board is then used to calculate a harvest date by using the projected 'days until digging' directly under the column farthest to the right that has at least three pods classified in this color category.

This method is currently accepted as an adequate method to determine peanut maturity; however there are several challenges and limitations for the application of the method by commercial peanut growers. First, it is very time consuming because it involves destructive plant sampling and processing, blasting of pods to remove the exocarp, followed by scrutinizing each individual pod for color. This procedure is normally repeated throughout the late growing season to ensure that maturity is progressing as anticipated. Next, for this method to be consistent and accurate, experience in classifying is necessary since subtle color differences in the saddle region can lead to inappropriate placement on the board, thus causing the incorrect prediction of crop maturity. In addition, the quantified 'days until digging' or the projected date that is recommended for harvest is arrived at through subjective movement of pods on the board to fit the slope of the 'projection line' included on the board (Figure 2). Last, this method is extremely subjective in the sense that it requires a person to look at the mesocarp and determine the appropriate maturity color class and this decision can vary significantly from person to person (Rowland *et al.*, 2006). Even the light environment under which the pods are placed on the board (e.g. sunlight vs. incandescent or fluorescent) can dramatically impact color perception.

Another significant time commitment associated with the current profile board method involves the requirement that the color within the saddle area of the pod is to be the only area used for color

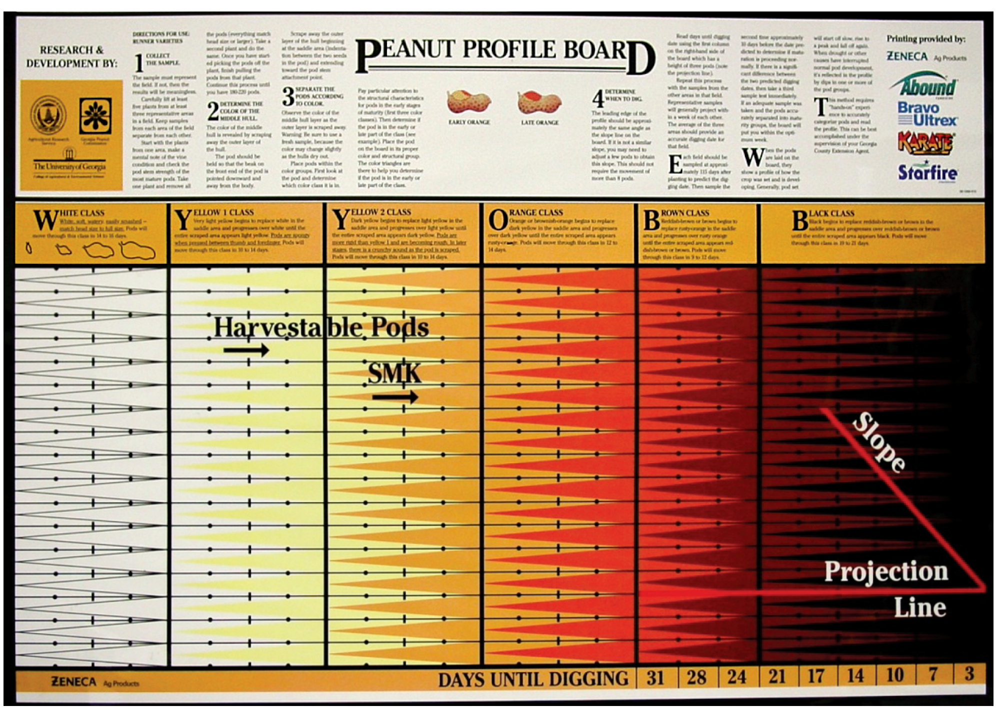

Figure 2. Typical peanut profile board based on the method of Williams and Drexler (1981). Pods are classified according to the saddle region into larger color classes (white, yellow 1, yellow 2, orange, brown, and black from least to most mature) and then color subcategories within each individual class. Digging date predictions are provided within the brown and black color classes (lower right) and are arrived at by assessing the overall slope of the classified pods.

evaluation. Pods are normally placed on the board by evaluators with a 'saddle up' orientation to visually illustrate the color development (Figure 1). This area was found to be the most reliable to determine the developmental stage when using the board method (Williams and Drexler, 1981). However, if a different region of the pod is being examined, it is possible to place the pod in an incorrect color column on the profile board and add further error to the digging date prediction (for example, see Figure 8). If a harvest prediction method could be developed that relied on an average color classification of many different sections of the pod without having to rely solely on the saddle region, this could result in significant time savings during color evaluation.

Developing a method to remove the subjective nature of color classification in determining peanut maturity is the focus of this study. The use of digital color classification software to identify pod color classes and subsequent calculations of pixel area ratios for determining mature pods has potential for predicting peanut maturity. The use of this method would significantly reduce the subjectivity in the current profile board method and provide a less time consuming option. The particular objectives of this research were to: 1) develop a digital imaging acquisition and definition method that, by using subsequent mathematical relationships of color pixel areas, will provide a quantifiable value of the percentage of black and brown pods; 2) determine if this digital image value can predict percent black and brown pods as assessed from the profile board; and 3) compare the maturity predictive value of images from pod saddle regions with those taken in random positions. The impetus of this research was to develop a digital imaging system that can provide a digging date recommendation to peanut growers at least comparable to the profile board method.

Materials and Methods

Field Plots

Two peanut cultivars, Georgia-06G (Branch, 2007) and Georgia Green (Branch, 1996), were planted at the Plant Science Research and Education Unit in Citra, FL on 26 April 2010 and 25 April 2011. Plots were arranged in a randomized complete block design with six replications and consisted of four rows spaced at 0.76 m and 7.6 m in length. The planting rate was 135 kg/ha and the seeds were spaced 6.1 cm apart. The soil type was fine sand (Loamy, siliceous, semiactive, hperthermic, Grossarenic Paleudults) with pH 6.2. All plots were managed according to standard fungicide and fertility practices for the region and were maintained weed free throughout the season (Wright et al., 2000). In both years starting at 120 DAP, peanuts were dug at 7 d intervals through 155 d for determination of crop maturity as well as yield and grade. Immediately after digging, five to 10 plants were randomly selected for maturity profiling. Pod sample sizes were roughly 200 pods and followed the procedure outlined for the maturity profile board: all pods (matchhead size to fully formed pods) were removed from individual plants and counted, ensuring there were no plants that had partial removal of pods, thus resulting in some variation in final pod number per sample. Pods were blasted with a pressure washer and laid on the profile board according to color class by a single observer. A single observer was used to standardize visual color classification due to the variability involved with defining board color classes among observers. The traditional color board allows, and suggests, that black pods can be moved from one class to another to ensure that the slope relative to 'days until digging' will be achieved. For these experiments, no pods were moved and 'days until digging' was determined by the category farthest to the right on the board containing three or more pods. Additionally, all pods from each class within the brown and black categories on the board were counted and a ratio of brown/black pods, relative to total pods, was determined.

For yield and grade determination, two rows 7.6 m long were dug, threshed, and samples dried to 9% moisture and then weighed; yield was determined on a kg/ha basis. All plots were harvested using individual plot harvesters that were totally cleaned prior to harvesting the next plot. The entire plot yield was bagged, dried and weighed. After total plot weight was obtained the whole sample was divided to obtain the grade sample. Grade was calculated using the standard USDA grading procedures to determine total sound mature kernels (TSMK) as presented herein (USDA, 2002).

Digital Image Acquisition and Analysis

Georgia-06G and Georgia Green blasted pods were placed on a commercial copier/scanner (Hewlett-Packard, 7500A Wide Format, Hewlett-Packard Company. 3000 Hanover, St. Palo Alto CA, 94304) in two orientations: 1) with the saddle region (Figure 1) face down; and 2) in a completely random placement. In both instances, pods were placed in a line in close proximity, often with sides touching (Figure 3). Digital images were acquired after placement by scanning pods in high resolution mode (600–1200 dpi) and saved in a high resolution

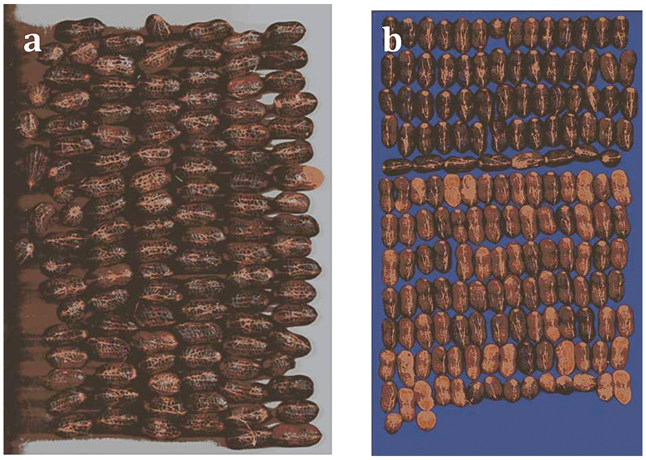

Figure 3. Images demonstrating the improvement of image quality from 2010 to 2011. Using the scanner lid only, a sample image from 2010 shows shadows that were cast in areas adjacent to pods and categorized as pod area (a); Image with blue poster board background minimized erroneously categorized area (b).

format (TIF). After analyzing the images from 2010, it was determined that in some images, shadows cast onto the scanner lid were categorized as pod area; therefore, these images were omitted from the analysis in that year. To address this problem in 2011, several tests were conducted to determine how to minimize shadows in images. It was determined that placing a blue poster board (Royal Brites Two Cool Colors, blue-yellow, 5A Plus LLC. 108 Main St. Norwalk CT, 06851) over the pods instead of the scanner lid was successful in reducing shadows and this method was used for all samples in 2011 (Figure 3).

Scanned images were analyzed using the software WinCAM (Regent Instrument, Inc., Canada) which digitally analyzes images and quantifies the area of specific colors using a set of color classes that have been previously defined by the user. To form these color class definitions, a representative image of all of the pods from a single plot visually classified as black from the boarding process was used. An image with pods classified as black was used for color selection because the darker mesocarp colors were the best predictors of maturity (Rowland *et al.*, 2006). Within the image, five color classes were selected, representing a range of the darkest to lightest colors in the image. A background color class was also defined to distinguish the pods from the background. The selected pod colors were defined as: B1 (lightest 'black' color), B2, B3, B4, to B5 (darkest 'black' color); this image was analyzed by the software program and pixels were classified accordingly (Figure 4). The software classifies pixels by grouping them into the defined color class that is the most similar in color to the pixel. For example, it would classify a pixel from a white or yellow imaged pod into the lightest defined color class (B1). This definition was then used to analyze all the pods within a sample (white, yellow 1, yellow2, orange, brown, and black) from each plot (Figure 5). Once images were analyzed, the program provided a graphical representation of areas defined on the image and calculated the total pixel area for each individual color class defined (B1 through B5). All pod samples from each plot that had been analyzed on the profile board previously were analyzed in this manner.

After analysis, individual pixel areas for each color class (B1 through B5) were mathematically combined into a quantifiable ratio to allow for an objective assessment of pod maturity for an image. Several ratios were tested for their ability to predict yield and the following was found to provide the best prediction for the Digital Image Model (DIM):

$$\text{DIM Value} = \frac{\sum Total\ B4{,}B5\ Pixel\ Area}{\sum Total\ B1{,}B2{,}B3{,}B4{,}B5\ Pixel\ Area} \qquad (1)$$

The DIM value was then compared to the visual maturity assessment of percent black and brown pods, (aka Maturity Index) for a given plot.

Data were analyzed with SAS JMP 9.0 (SAS Institute Inc., 2010). Data from all harvests within a year were combined and analyzed using linear regression between DIM values and the Maturity Index determined from the maturity profile board assessment. Significance of the regression, the standard error of prediction, and the R^2 for the fit of the relationship were determined. In addition, linear regressions and their associated R^2 values were compared between data generated from the digital analysis of saddle and random images.

Results and Discussion

The grower acceptance of the profile board method developed by Williams and Drexler (1981) for aiding peanut harvesting is incontrovertible. This fact is clear because it is currently the primary method used by peanut producers growing runner peanuts (when assessment is performed) to determine harvest date across the U.S. Therefore in this study, the visual assessment of the percentage of black and brown pods from the maturity profile board was set as the standard to compare the DIM performance, despite the inherent subjectivity of the profile board method. Overall, if the DIM performed similarly to the profile board in determining the percentage of

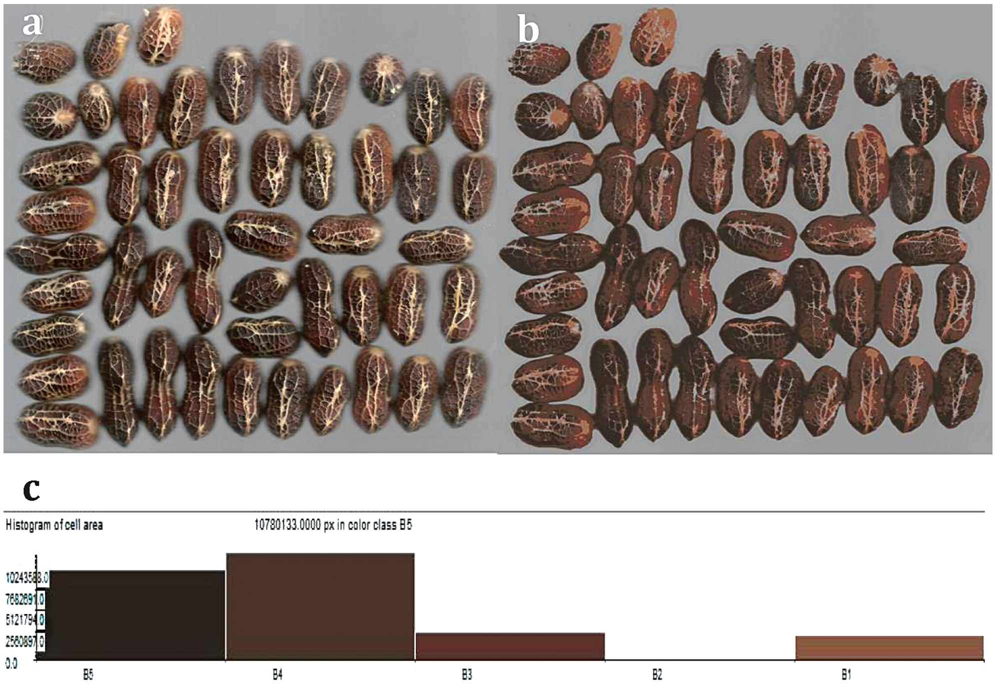

Figure 4. Example of a digital scan of black pods from a single plot (#306) (a) and the same image after analysis with the WinCAM software using the user defined color definitions (b). The bottom histogram (c) represents graphically the pixel area for each of the five black color classes defined as B1, B2, B3, B4, and B5 that the program has quantified from the image.

mature pods, then the DIM could be offered as an acceptable alternative maturity prediction method.

In 2010, yield and grade appeared to progress as expected over time, with the peaks in yield and grade by harvests five and six for Georgia-06G and by harvests three and four for Georgia Green (Table 1). In 2011, leaf spot disease became a factor by harvest four, so that later harvest yields for both cultivars were highly variable and atypically low in this year. Despite these disease issues, grades for both cultivars in 2011 continued to increase with harvest as would be expected for a maturing crop.

Figure 5. Example of images attained after analysis using the WinCAM program with the predefined color class definition of all pods for one plot (#306) and separated by color class: black (a), brown (b), orange (c), yellow 2 (d), and yellow 1 (e).

Table 1. Sequential harvest of peanut cultivars Georgia-06G (GA-06G) and Georgia Green (GA Green) for 2010 and 2011. Board predicted optimal dig date (ODD = optimal dig date) and ODD as determined by maximum grade over all harvests. Average yield and grade (TSMK = total sound mature kernels) was determined by cultivar at each sequential harvest.

Year	Variety	Harvest	Board predicted ODD	Observed ODD	Grade (%TSMK)	Yield (kg/ha)
2010	GA-06G	1 (Aug 24)	Sep 7	Sep 28	74.7	4662
		2 (Aug 31)	Sep 17	Sep 28	74.5	4817
		3 (Sep 7)	Sep 21	Sep 28	75.7	5505
		4 (Sep 14)	Sep 21	Sep 28	76.3	5488
		5 (Sep 21)	Sep 24	Sep 28	77.5	5867
		6 (Sep 28)	Oct 5	Sep 28	77.7	5781
	GA Green	1 (Aug 24)	Aug 31	Sep 21	75.7	5376
		2 (Aug 31)	Sep 7	Sep 21	76.1	5591
		3 (Sep 7)	Sep 17	Sep 21	77.2	5979
		4 (Sep 14)	Sep 17	Sep 21	76.2	5806
		5 (Sep 21)	Sep 24	Sep 21	77.8	5520
		6 (Sep 28)	Oct 1	Sep 21	76.2	4086
2011	GA-06G	1 (Aug 23)	Sep 3	Sep 30	74	4694
		2 (Aug 30)	Sep 13	Sep 30	74.6	4198
		3 (Sep 6)	Sep 16	Sep 30	76.7	4820
		4 (Sep 13)	Sep 20	Sep 30	76.9	3054
		5 (Sep 20)	Sep 20	Sep 30	77.4	5047
		6 (Sep 27)	Sep 30	Sep 30	78	2796
	GA Green	1 (Aug 23)	Sep 3	Sep 20	73.6	3627
		2 (Aug 30)	Sep 13	Sep 20	75.6	3989
		3 (Sep 6)	Sep 13	Sep 20	75.6	3487
		4 (Sep 13)	Sep 16	Sep 20	76	3226
		5 (Sep 20)	Sep 20	Sep 20	77.2	3484
		6 (Sep 27)	Sep 30	Sep 20	76.3	573

Using maximum grade as an indicator of an observed optimum dig date, the board was able to predict the observed optimal dig date within plus or minus ten days at the later harvest dates (Table 1). The differences in the board predicted optimal dates over sequential harvests demonstrates the variability involved with the profile board and the importance of sample timing when using the profile board.

When pods were imaged in the saddle-down orientation, the linear regressions between the DIM value and the Maturity Index as assessed from the profile board were significant in 2010 and 2011 ($p < 0.0001$ for Georgia-06G and Georgia Green). The R^2 was 0.71 and the standard error of prediction (SEP) was 0.02 for Georgia-06G in 2010. The R^2 was 0.70 and the SEP was 0.01 for Georgia Green in 2010. In 2011, the R^2 were 0.82 and 0.63 for Georgia-06G and Georgia Green, respectively. The SEP for Georgia-06G and Georgia Green in 2011 was 0.02 and 0.01, respectively (Figure 6). This indicates that the DIM was successful at predicting the most mature classes (black and brown) similarly to the profile board when the pods were placed in the saddle-down orientation. The R^2 between the DIM value and the Maturity Index from the board was slightly higher for Georgia-06G than Georgia Green in both years, possibly because the DIM color definition used to analyze all samples was created from Georgia-06G pods and there may be slight color variations among varieties.

For the random orientation of pods on the scanner, the regression between the DIM value and the Maturity Index from the profile board were significant in 2010 ($p < 0.0001$ for Georgia-06G and Georgia Green) but only for Georgia-06G in 2011 ($p < 0.0192$) and not Georgia Green ($p < 0.0669$). The R^2 were 0.82 and 0.3 for Georgia-06G and 0.66 and 0.19 for Georgia Green in 2010 and 2011, respectively (Figures 7). The SEP in 2010 was 0.01 for Georgia-06G and 0.01 for Georgia Green. In 2011 the SEP was 0.01 for Georgia-06G and 0.01 for Georgia Green. As expected, the imaging of pods placed randomly appears to be less capable of predicting maturity similarly to the profile board, at least in some cases. The lower predictive performance of the random placement in 2011

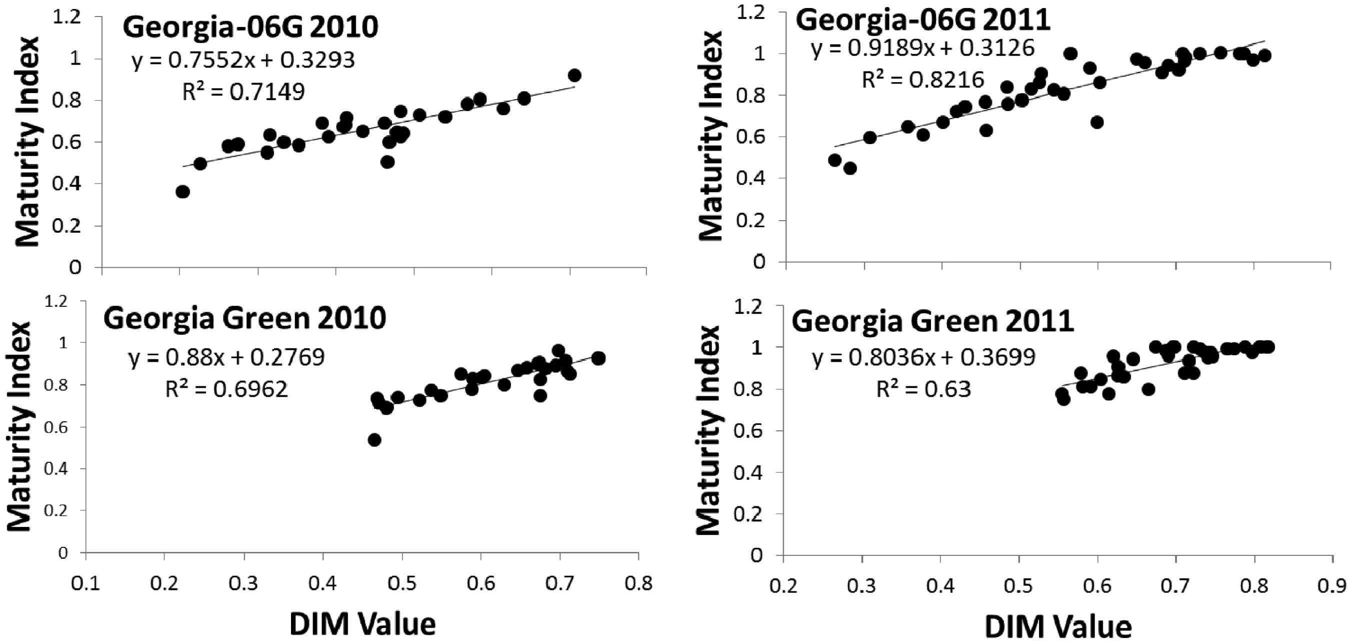

Figure 6. Relationship of DIM Value to Maturity Index from analyzed images of Harvests 1-6 in 2010 and 2011. Images were of blasted pods placed in the saddle-down orientation .

may have been related to the high disease pressure in the latter season in this year. Disease often causes pods to show color development in isolated patches, such that the saddle region may achieve the black/brown color while the remainder of the pod could be in the yellow or orange category (for an example, see Figure 8). For the profile board that relies solely on the evaluation of the color in the saddle region, such pods would be categorized as mature; while the DIM would categorize each color according to pixel area, resulting in a less mature classification especially if the pod were in a random orientation. Despite this inconsistent performance of the random placement, additional studies should be pursued because being able to image samples in this orientation could translate into a significant time savings. For example, it takes approximately 15 min to place pods on the scanner bed in the saddle orientation vs. two min for random placement.

The goal of this research was to develop and test the use of an objective digital imaging system for

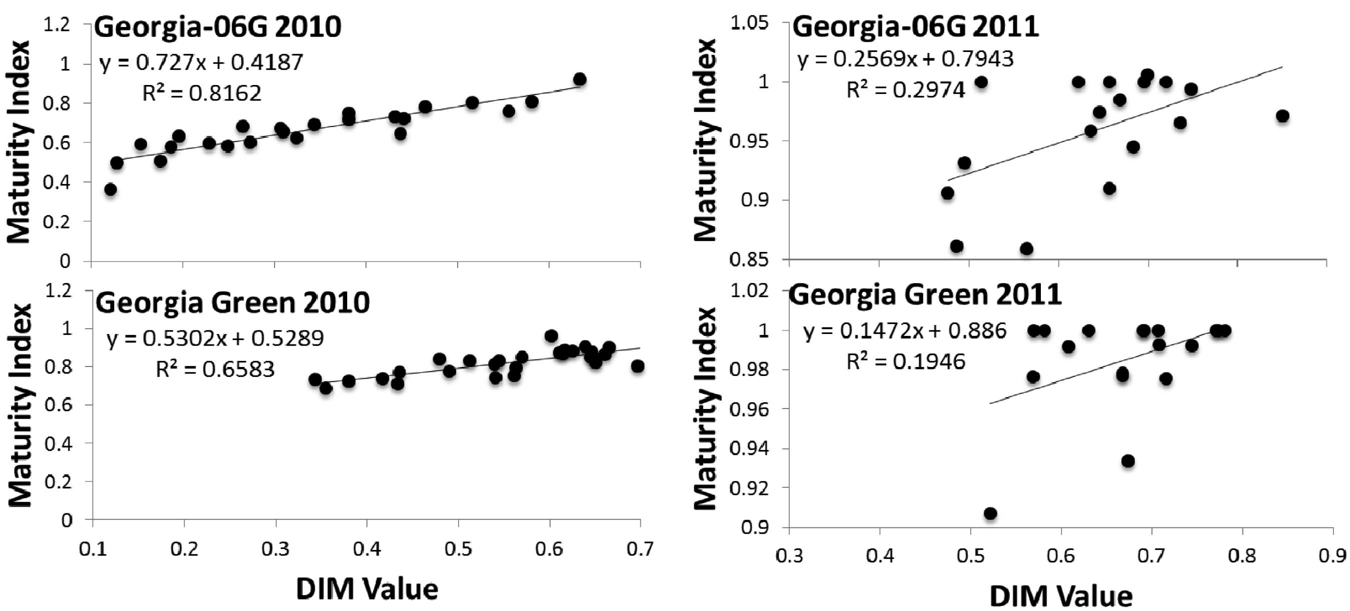

Figure 7. Relationship of DIM Value to Maturity Index from the profile board from analyzed images of Harvests 1–6 in 2010 and harvests 4-6 in 2011. Images were of blasted pods placed randomly.

Figure 8. Example of a pod with a patch of darker color in the saddle region. This pod would be placed in the brown class when using the profile board even though the majority of the pod is a yellow.

assessing peanut maturity. This was to provide growers that already use the maturity profile board a reliable and less subjective maturity prediction alternative. However, many growers determine when to dig solely by planting date or a general assessment of the crop, usually because of the time and expertise involved in the profile board method. Having an objective method to assess peanut maturity can ensure positive economic returns to the grower because crop maturity is the foundation of yield and grade, and these two factors alone are the basis of the payment to the grower. A methodology was developed for taking digital images of blasted peanut pods and a five color definition system was developed using commercially available software to classify blasted peanut pods into different peanut pod maturity classes (as illustrated in Figure 5). The methodology can be easily adopted in most production or extension situations because it requires a relatively inexpensive, widely available flatbed scanner that can scan in high resolution format. In addition, the placement and imaging of pods is relatively simple and quick – the primary limitation is the identification of the saddle area (Figure 1). However, by our statistical analyses, the predictive capability of color analyzed images of pods in the random placement was comparable to imaging the saddle region in 2010 for both varieties. Further, this current method represents a significant improvement in terms of cost and ease of image acquisition compared to other prior digital imaging systems that require expensive camera equipment and specialized lighting environments or other specialized technology (Boldor *et al.*, 2002; Chung *et al.,* 1998; Tollner *et al.*, 1998; Ghate *et al.*, 1993). Another advantage of this method is that the same definition can be used for multiple samples and does not have to be repeated or reproduced.

In conclusion, the prospect of developing a successful objective peanut pod maturity imaging and color classification method for peanut maturity assessment and digging prediction is promising. This method was developed to be user friendly utilizing technology that is readily available and inexpensive. Future plans include evaluating the DIM on several other commercially available cultivars and various scanner types. Another goal is to further test the random placement of pods and to validate the current method. Eventually the PeanutFARM website (http://agronomy.ifas.ufl.edu/peanutfarm) will be expanded to include a tool where growers and consultants can upload images for instant harvest prediction analysis using the DIM technique.

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