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An ASABE Meeting Presentation

Paper Number: 12-1337625

Development of a Yield Monitor for Peanut Research Plots

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Written for presentation at the
2012 ASABE Annual International Meeting
Sponsored by ASABE
Hilton Anatole
Dallas, Texas
July 29 – August 1, 2012

Abstract. *A yield monitoring system for a peanut combine was developed to record harvest data from research test plots. The system collects a batch of peanuts from each research plot into a weighing bin, weighs the batch, dumps the batch into a duct, and then pneumatically conveys the batch to the primary basket. The weighing bin is suspended from load cells connected to a monitor. For the conveyance cycle, an electrical control circuit operates a 12 VDC gear motor coupled to a hatch in the bottom of the weighing bin. Peanuts are conveyed from the air duct to the primary basket using a centrifugal blower driven by a hydraulic motor. A small hopper was included to collect samples from each batch for quality analyses. Conventional research plot harvesting required three individuals: a tractor operator, someone to bag samples from the harvester and haul sacks, and someone to weigh the peanut sacks. The developed system reduced the harvest operation to only one individual when quality samples are not required and to two individuals when required. Preliminary field trials indicated that the system was successful in collecting, accurately weighing, and conveying the peanuts but that additional work is necessary relative to sampling and geo-referencing data acquisition.*

Keywords. yield monitor, peanut, research plots, harvest, precision agriculture.

Introduction

Peanut research studies for various treatments and tests are typically conducted in research plots. Tests conducted under typical plot studies utilize plot lengths of 7.6 m (25 ft) to 24.4 m (80 ft) and row widths set to match available harvesting equipment. Modern peanut harvest is conducted in two stages: digging/shaking/inverting and combining. In the first stage, a digger-shaker-inverter digs the peanut plant out of the ground, shakes some of the dirt off of its roots, and inverts the plant to lay it in the field with the peanuts and roots facing upwards to dry. After sufficient in-field drying time has been provided, which is dependent on variety, maturity, size, and environmental conditions, a combine picks the vines up from the field, separates the peanuts from the vines, delivers the peanuts to a storage basket, and discharges the vines back into the field.

Harvest of peanut research plots for field trials, coupled with quality sampling and tabulation of yields has traditionally been very laborious and time intensive. Research plot studies at Clemson University's Edisto Research and Education Center (EREC) have been harvested in recent years using a two-row combine with the delivery tube to the storage basket being intercepted by a 180^{o} elbow (U-tube) as seen in Figure 1, allowing all harvested peanuts from a particular plot to be directed to a burlap sack for weight tabulation and quality sampling. Such method requires two individuals in addition to the tractor operator: one to walk alongside the harvester to label, collect, and replace the sacks, and another to weigh and collect quality samples from each sack.

Figure 1. U-tube used for attaching burlap sack.

The development of the yield monitor in this project was directed at reducing the amount of labor required for collecting yield data from peanut research plots in addition to providing an integrated quality sampling system. Rather than delivering the peanuts to a burlap sack for post-harvest weight measurement, the total weight harvested from each research plot is collected and recorded in the field at the time of harvest by the tractor/combine operator. The components used in the system were selected so that a data acquisition system may be included in the future in order to record the results from the plots and generate yield maps or link the yield data to plot IDs. The yield monitor developed for this report allows for a quality sample to be manually collected for additional lab analyses, although in the current prototype sample collection requires that an individual walk alongside the combine to collect and bag the quality samples. Current work is directed at developing an automated sampler, which will reduce the number of individuals required for harvest, yield measurement, and sample collection to only one person: the tractor/combine operator.

Although yield monitoring systems have been researched for use on peanut combines (Perry et al., 2002; Rains et al., 2005; Thomas et al., 1999; Thomasson et al., 2006; Vellidis et al., 2001), no commercially available products currently exist and little work has been done to evaluate these technologies for accuracy and reliability if used in research plot studies. Perry et al. (2002) report that the PYMS yield monitoring system, which utilizes load cells to weigh the entire storage basket, would be best suited for field scale plots (240 m length) as opposed to traditional research plots (9 m length). They reported total differences between yield monitor weights and truck scale weights of an average of 1.7% with a maximum difference of 7.8%. Other studies utilizing the PYMS yield monitoring system (Rains et al., 2005; Vellidis et al., 2001) reported differences of less than 1% to 3% between PYMS and truck weights, although these studies did not evaluate the PYMS system for use in traditional research plot studies. Relatively small batch weights from the research test plots require a great deal of accuracy with little allowance for errors as a result of time lag and averaging. To put things into perspective, the harvesting equipment used at EREC accommodates two-row plots on 91 cm (36 in) row widths, which results in, for example, a 12.2 m (40 ft) plot with a yield of 3,744 kg/ha (3,340 lb/ac) generating a total plot weight of only 8.36 kg (18.4 lb).

The technology developed under this research was directed at not only being capable of reducing the time requirements associated with field labor and data collection, but also at doing this with the highest degree of reliability and consistency in measuring yields from the peanut research plots. Mass flow sensors such as those utilized in most commercially available cotton yield monitors and in some research studies for peanut yield monitors (Rains et al., 2005; Thomasson et al., 2006) measure yield as a correlation between sums of mass flow measurements and total load weights. Studies indicate that yield data from these sensors can vary from loss of calibration over time, especially due to abrasion, foreign material, and dirt build-up. Little research exists in evaluating differences in calibration curves for mass flow sensors as a function of peanut variety and pod size. For the technology developed under this project, load cells were instead selected for use in making batch yield measurements from each research plot. The load cells provide a direct correlation to weight with a high degree of accuracy, regardless of peanut variety, flow rate, size, or shape.

Materials and Methods

The main objective of the project was to develop a system with the ability to accurately monitor the weight of peanuts from research plots of predefined size. The final design needed the ability to collect small quality samples of the peanuts from each harvested batch. It was required that the weighing system be semi-automated, where the machinery operator had control of when the yield weights were being observed and recorded, but actual sequencing of sampling, weighing, and conveying was automatic with the simple push of a button by the tractor/combine operator. The system needed to be readily adaptable to being reverted to conventional harvest, where the yield monitor could be bypassed and peanuts could be conveyed directly into the combine's primary storage basket. Finally, the system was to be designed as a package so that it could be installed on different peanut combines with little modification.

System Description

The developed system (Figures 2 and 3) utilized the combine's existing PTO driven blower and delivery tube to convey the harvested peanuts directly into a weighing bin that was situated above the combine's straw walkers and behind its storage basket. The weighing bin was suspended from a steel frame by three load cells, which were connected to a monitor displaying the weight, located in the cab of the tractor. The floor of the weighing bin was constructed as a trap door, whose two hinged doors were actuated using a DC gear motor connected through a roller chain drive to a sprocket with an eccentric arm.

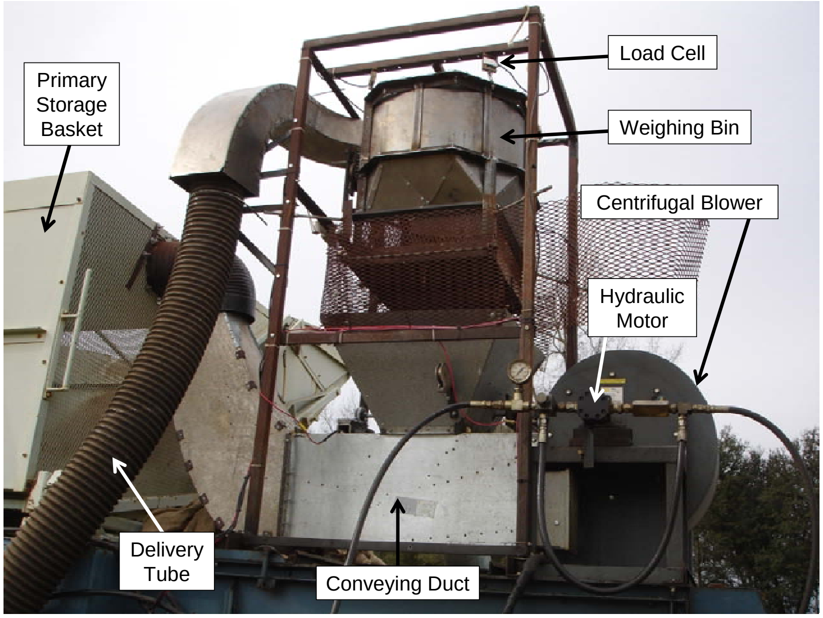

Figure 2. Yield monitor configuration from left side of combine.

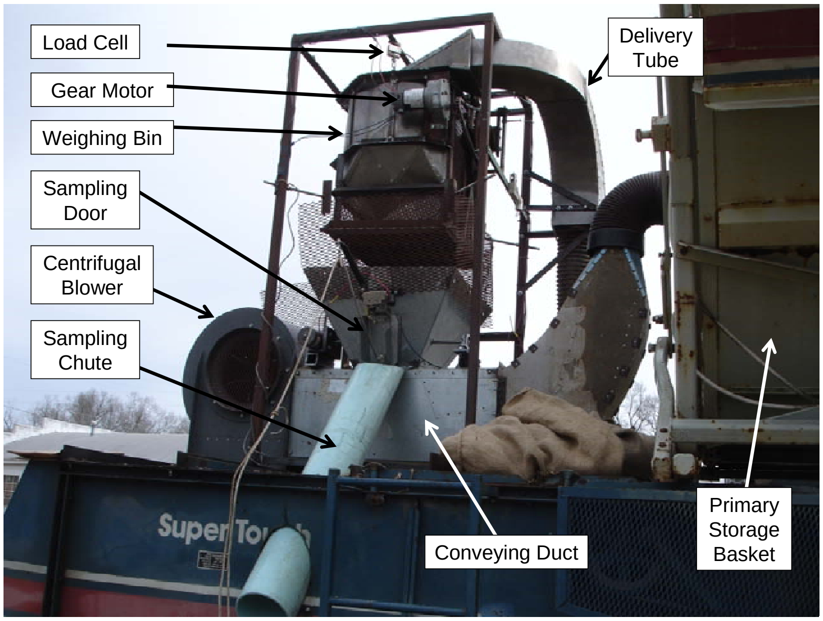

Figure 3. Yield monitor configuration from right side of combine.

An electrical control circuit was provided allowing the tractor operator to control the release of the peanuts from the weighing bin. At the press of a button by the operator, the trap doors on the bottom of the weighing bin opened (Figure 4) and the peanuts were released into a funnel in the shape of an inverted pyramidal frustum, concentrating the peanuts into a conveying duct. The conveying duct was fitted with a hydraulically driven centrifugal fan and the peanuts introduced to this duct were pneumatically transported to the combine's existing primary storage basket. After release of the peanuts to the conveying duct, the trap doors on the weighing bin automatically closed in order to accept peanuts from the subsequently harvested plot. At the time of full closure of the doors on the weighing bin, an indicator light was provided for the machine operator, indicating that it was safe to proceed in harvesting the next research test plot.

Figure 4. Trap doors on bottom of weighing bin, shown 75% open. Note: weighing bin is on its side in this image for testing purposes.

In order to provide a means of collecting a 1,100 - 1,200 g (2.4 – 2.6 lb) sample for quality analyses from each plot, a 2,950 cm^3 (180 in^3) sampling hopper was situated inside the funnel as seen in Figure 5. The volume indicated here takes into account an assumed 29 degree angle of repose for the peanuts (Akcali et al., 2006). This sampling hopper was positioned so that overflow peanuts in excess of its design volume could move around it and into the conveying duct below. The cross-section of the sampling hopper was wedge-shaped with a hinged door mounted on the side with the lowest elevation. When the door was opened, the quality sample was gravity-fed into a sampling bag positioned at the bottom of a chute mounted to the side of the combine.

Design Considerations

The centrifugal blower used for conveying the peanuts released from the weighing bin to the primary storage basket was sized based on bench testing with a Plexiglas test column and an oversized fan. One pound of peanuts was introduced into the column and the air intake to the fan was dampened until a critical point was reached where about 50% of the peanuts were suspended in the column. The minimum air flow rate was quantified by using a Pitot-static tube to measure dynamic pressures from 1.6 cm^2 (0.25 in^2) grid sectors. Bernoulli's equation was then used to estimate average air velocities for each grid sector. Using the estimated average air velocity and cross-sectional area, air flow rates were calculated for each grid sector, as shown in Figure 6. The flow rates were summed for the entire test column cross section, giving an overall minimum flow rate required of 0.25 m^3/s (530 cfm). A radial-blade, direct-drive blower with a 31.8 cm (12.5 in) wheel diameter was selected for use, requiring a 1.1 kW (1.5 hp) motor capable of turning at 1,725 rpm. The hydraulic motor used to drive the blower was an external tooth gear motor with a displacement of 3.18 cm^3/rev (0.194 in^3/rev).

Figure 5. Sampling hopper positioned inside funnel, underneath weighing bin.

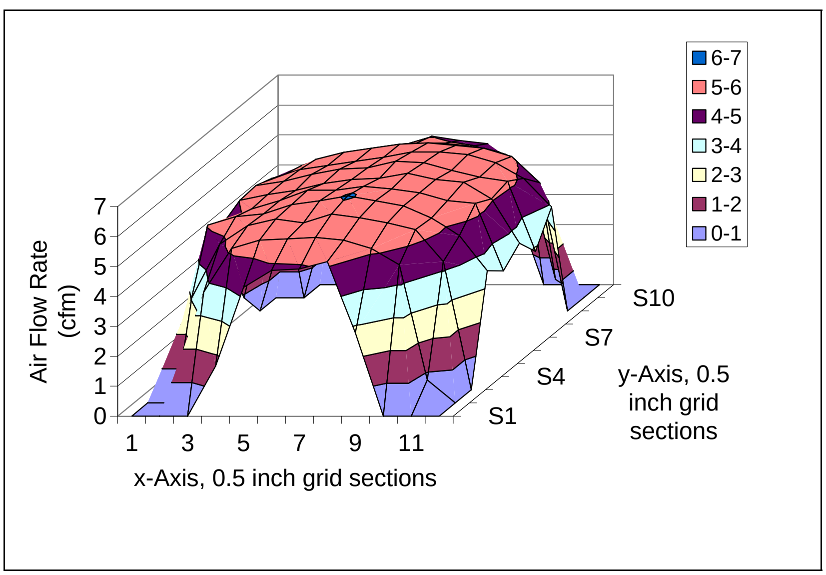

Figure 6. Minimum air flow rate measurements from test column.

In order to accommodate the maximum anticipated amount of peanuts collected from one research plot, the system was designed so that the weighing bin had a minimum capacity of 35 kg (77 lb), which would represent a batch from a 24.4 m (80 ft) long, two-row plot with a yield of 7,847 kg/ha (7,000 lb/ac). Assuming 400 kg/m^3 (25 lb/ft^3) peanut density at harvest, the volume of the weighing bin can be calculated to be 0.088 m^3 (3.1 ft^3). The weighing bin was constructed with a cylindrical upper portion where the pneumatically conveyed peanuts were introduced along a tangential path with the wall of the bin in order to reduce incidents of shelling and peanut damage from impacts. Within the sizing of the weighing bin, its supporting frame, and the conveying duct underneath, the overall height of the machine was restricted to 4.1 m (13.5 ft) for transport purposes.

The electrical control circuit for the conveyance cycle can be seen in Figure 7. A control box for the combine operator was provided in the tractor cab. This box included a momentary push button switch, a red light indicating that the conveyance cycle from the weighing hopper to the primary storage basket was underway, and a green light indicating that the conveyance cycle was complete and harvest of the next plot could proceed. When the operator push button is depressed, Relay 1 is energized, the green light on the control box in the tractor cab turns off, and the red light turns on. The normally open (NO) contacts on Relay 1 are connected through the normally closed contacts on Relay 2 back to the coil on Relay 1 so that Relay 2 acts to hold the coil for Relay 1 energized until the coil for Relay 2 is energized. Also at this time, power is provided for the gear motor used to open and close the trap doors on the bottom of the weighing hopper and the doors begin to open. When the doors are in the fully open position, contacts close on the “Doors Open” limit switch and the coil for the “Door Stall” interval timer is energized, opening the motor circuit and stalling the doors for a set time period (10 to 20 sec, generally) in the fully open position until all peanuts can be emptied from the weighing hopper. After this time period has elapsed, power is restored to the gear motor and the doors proceed to close. Just prior to full closure, contacts are closed on the “Doors Closed” limit switch, which provides a signal to a Delay on Make (DOM) timer, allowing for fine adjustments in position of the closed doors and ensuring full closure. After a brief (0.4 sec) time delay, contacts on the DOM timer are switched, which energizes the coil for Relay 2, de-energizing the coil for Relay 1, eliminating power to the motor and the red light, and restoring power to the green light. In summary, when the tractor/combine operator presses the push button switch, the green light turns off, the red light turns on, and the trap doors open fully. After stalling for 10 to 20 seconds in the fully open position, the trap doors close fully, the red light turns off, and the green light turns on.

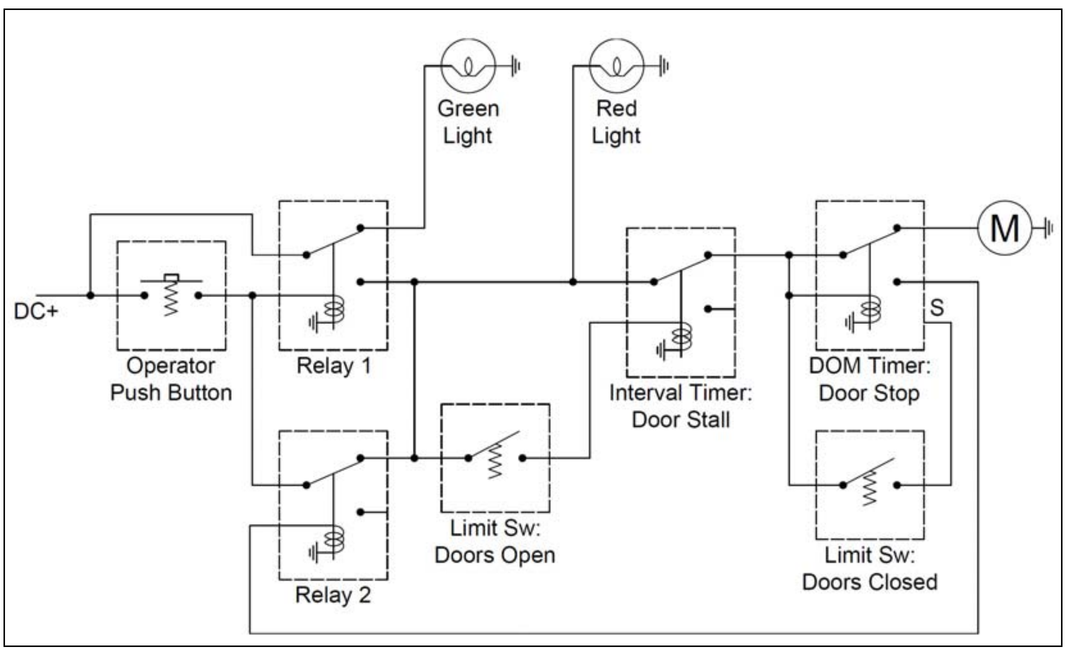

Figure 7. Electrical control circuit.

Results and Discussion

General observations

Preliminary field trials indicated that the system was generally successful in collecting, accurately weighing, and conveying the peanuts. In some cases, when the trap doors on the weighing bin were opened and the peanuts released into the funnel and sampling hopper, the rate at which the peanuts moved into the conveying duct was so slow that the peanuts did not clear the trap doors prior to their closure. Due to the slow flow of peanuts, some peanuts from the plot remained in the weighing hopper when it should have been cleared for harvest of the following plot. As a temporary solution, a time delay was imposed on operation of the trap doors so that they would pause briefly in the fully open position. This solution proved to be effective but time consuming, requiring the operator to wait for up to 40 seconds after pressing the button to open the doors and before proceeding to the next plot. Work is currently underway in addressing this issue more effectively by redesigning the sampling hopper so that it is less obtrusive to peanut flow through the funnel and increasing both the size of the funnel and the height of the trap doors above the funnel.

The sampling hopper described in this paper was moderately effective in collecting a sample for quality analyses but it requires redesign for a number of reasons. As indicated above, its size, placement, and shape make it restrictive to the flow of peanuts through the funnel, providing very little area between it and the inner walls of the funnel through which peanuts can flow. Due to space restrictions, the angle of its wedge-shaped base was limited to about 30 degrees. At this angle, peanuts would not freely gravity flow out of the hopper when the sampling door was opened. As a temporary solution, an electric vibrator was added to the funnel, which helped to shake the peanuts out of the sampling hopper. The sampling device described here did not lend itself to automated collection of samples from multiple plots and therefore required an individual to walk alongside the combine when sampling was taking place. Another issue encountered with the sampling hopper was that it could not be easily removed during harvest of plots where collection of quality samples was not required. As indicated above, work is currently being conducted to address all of these issues through development of an improved sampling system.

It should be noted that the yield monitor developed here is specifically designed for research plot studies and does not lend itself to adaptation for conventional peanut harvest applications. Because it weighs each harvested research plot in a batch rather than continuously, requiring the operator to stop at the end of each plot, record a weight, and dump the harvested batch, it would be impractical for use in commercial peanut operations. However, it could prove to be useful in testing and verifying alternative methods of yield monitoring for conventional peanut harvest or for evaluating mass flow technologies for use in research plot studies.

Productivity Analysis

Using the prior research plot harvest method of a U-tube and a burlap sack, two individuals are required during harvest and an additional individual is required to collect the burlap sacks and weigh them after harvest. The plot harvest capacity of this system was 30 plots per clock hour and 22 plots per labor hour. Using the current yield monitor design instead of the U-tube and burlap sack results in a plot harvest capacity of 51 plots per clock hour and 26 plots per labor hour. With the modified and fully automated sampling system currently being constructed, the time delay at the point where the weighing bin’s doors were fully open can be eliminated and collection of the quality samples will occur simultaneously with trap door closure and travel to the next plot, requiring no additional time. With such changes the number of individuals required for harvest, yield data collection, and quality sample collection will be reduced to one. This system results in a plot harvest capacity of 73 plots per hour and 73 plots per labor hour. A summary of the capacities of the three scenarios discussed here can be seen in Figure 8.

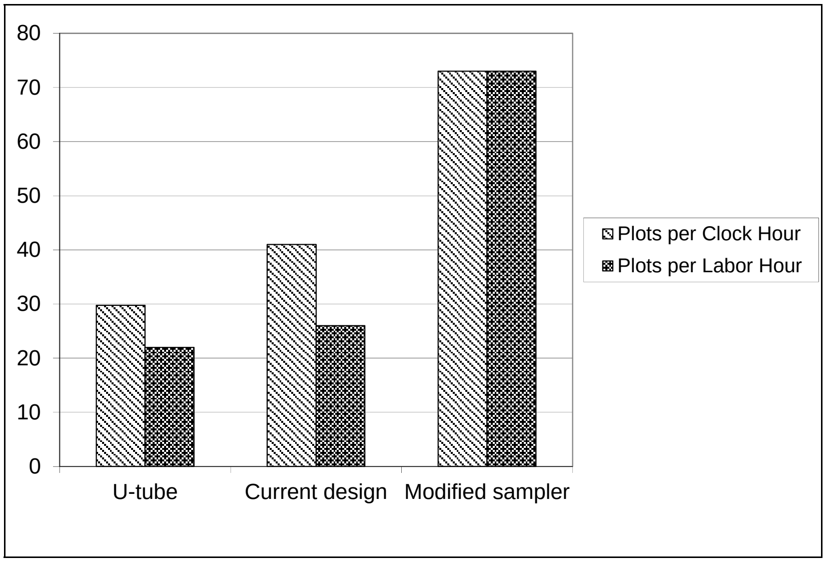

Figure 8. Plot harvest capacities of the three described scenarios.

Conclusion and Recommendations

Field tests of the yield monitor described in this report were favorable in many respects and provided indication of a number of improvements that could be made. The technology developed proved to be reliable in collecting yield data through one season of research plot study harvest and it successfully eliminated the need for collecting, tagging, transporting, and individually weighing burlap sacks of the entire plot study harvests. During these field trials confirmation of reported weights was not conducted but standard test weights were measured in the weighing bin periodically and the accuracy remained within 1%; further tests of the system's accuracy under field conditions must be conducted. Since the system developed in this study was directed at use specifically in traditional research plot studies, an integral quality sampling system was included on the prototype. Observations made during field trials allowed for an improved design with incorporation of a fully automated quality sampling system. As currently configured, the yield monitor increases plot harvest capacity from 22 plots per labor hour to 26 plots per labor hour and reduces the number of individuals required for harvest of the test plots from three to one. After completion of the required modifications realized in preliminary tests, the plot harvest capacity will increase to 73 plots per labor hour and require only one individual to harvest the test plots. Future work planned for the yield monitor developed in this study includes:

- automation of sampling system,
- development of software to automatically record and associate yield data to plot number through GPS location,
- development of software to print barcoded labels for quality sample bags at the automated sampler for more efficient postharvest quality sample analysis,
- use of yield monitor to evaluate the practicality for use of alternative yield monitoring techniques for use in research plot studies (e.g., mass flow sensing)

- field trials directed at better quantifying field capacities with the previous U-tube harvest method relative to those when using the yield monitor.

Acknowledgements

This project was funded by the South Carolina Peanut Growers Association and the Clemson University Creative Inquiry Program. In addition to the authors, several undergraduate students in the Clemson University Agricultural Mechanization & Business program participated in the project and should be recognized: Michael Kolshak, Spencer McLeod, Ryne Phillips, Joseph Pitts, Wesley Porter, Chase Reinhardt, Michael Steele, and Mason White.

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