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ABSTRACT

Soybean crops must be harvested during a limited time period using expensive combines and associated equipment. Maximizing combine field efficiency, the ratio of the actual harvesting capacity to theoretical harvesting capacity, is an important objective of machinery managers. Spatial and temporal yield data from a 2012 CaseIH 8120 Axial-Flow combine equipped with a 30-foot MacDon D-65 Draper header and the Case-IH Advanced Farming System (AFS) yield monitoring system were used to examine field efficiency when harvesting soybean in three Arkansas Delta irrigated soybean fields during the 2015 season. Time efficiencies (TE) in the three fields ranged from 72.9 to 85.8% ($M = 80.9\%$, $SD = 9.6\%$); width efficiencies (WE) ranged from 96.7 to 98.8% ($M = 97.6\%$, $SD = 1.6\%$); and overall field efficiencies (FE) ranged from 70.4 to 84.8% ($M = 79.0\%$, $SD = 9.7\%$). Contrary to expectations, neither row length nor unadjusted yield was significantly correlated ($p \leq 0.05$) with time efficiency, width efficiency, or field efficiency. Time efficiency explained 90.5% ($sr^2 = 0.905$) of the unique variance in field efficiency, while WE explained only 1.6% ($sr^2 = 0.016$) of the variance in FE when controlling for the effects of TE. Results indicated use of geo-referenced field and performance data can be a useful tool in evaluating combine performance and efficiency; however, availability of data in a more user-friendly format would facilitate its use for that and possible other purposes.

INTRODUCTION

In the next 50 years farmers around the world will have to feed more people than they have in the previous 100 years (Arkansas Farm Bureau, 2014). To accomplish this task, farmers will have to reduce costs, while increasing the field efficiencies of their machinery by making smarter machinery management decisions through the use of precision agriculture practices.

Machinery costs account for 35-50% of total fixed costs, so using machinery more efficiently can provide for significant savings for the farmer (Yule et al., 1999). Knowing field efficiency (FE) is crucial in maximizing profit in association with how efficiently fuel is being used, number of working days during harvest, and ultimate timeliness in the field. In the case of time costs, farmers have a time window during certain dates of the year with which to harvest their crop optimally, this is referred to as the base harvest period. After that optimal time, there is a yield loss each week thereafter. For soybeans the "excess harvest loss expected" is one bushel for an acre harvested in the first week after the base harvest period, two bushels in the second week and so on (Short and Gitu, 1991). Determining the FE of the combine is imperative in order to know how many hours of work it will take to make sure the crop is harvested during the optimal time and yield loss is minimized or non-existent in order to increase profits.

Agricultural machines FEs have a significant effect on the effective field capacities of machinery, which in turn impact the overall cost of production (Pitla et al., 2015). Effective field capacity is defined as the actual rate of crop processed in a given time (ASAE, 2005). Field efficiency is defined as the ratio of effective field capacity to theoretical field capacity expressed as a percentage, with effective field capacity being the actual rate of land or crop processed in a given time and theoretical field capacity referring to the rate of performance of a machine functioning 100% of the time at a given speed using 100% of its theoretical width (ASAE, 2005).

Computationally, FE is the product of time efficienccy (TE) and width efficiency (WE) (Field and Sollie, 2007). Time efficiency is the ratio of productive field time to total field time (i.e., the ratio of actual harvesting time to total operating time). Width efficiency is the ratio of the actual machine width used to the functional operating width of the machine (Hunt, 2001).

Field efficiencies for a self-propelled combine range from 65-80%, with typical combines achieving 70% (ASAE, 2011).   Efficiency varies due to a variety of factors including turning time, speed, machine width, row length, and crop yield (Hunt, 2001). Crop yield affects the field efficiency of a combine when standard or typical field speeds are used to calculate theoretical field capacities, with greater yields usually resulting in reduced travel speed due to the heavier weight of grain (Grisso et al., 2002).

Row length may also affect FE for operations, such as combine harvesting, where the machine cannot perform its intended function while turning at row ends; FE would be expected to increase with increased row length. According to Grisso (2002), if implement width stays the same and row lengths double,field efficiency improves, because the proportion of implement operating time increases with respect to its turning time.

Harrigan (2003) conducted time-motion studies of corn silage harvesting operations on seven Michigan dairy farms and reported a mean TE of 85% when truck- or tractor-drawn transport vehicles were driven alongside the harvester. Unproductive time consisted of time spent in turning the harvester in the headlands and switching transport vehicles. Niehaus (2014) used spatial data to evaluate the corn harvesting operation on an Iowa grain farm and reported an overall TE of 62.4%; with 16.1% of total time spent in machine idling, 9.1% in in-field or road travel, 9.3% in turning within field headlands, and 2.9% unloading grain while not harvesting.

The objectives of this study were to determine: (a) the width efficiency (WE), time efficiency (TE), and overall field efficiency of a combine harvesting soybeans on a typical Arkansas Delta farm; and (b) the relationship between row length, yield, WE, TE and FE

MATERIALS AND METHODS

Machinery and Equipment

The field efficiency of a 2012 CaseIH 8120 Axial-Flow combine (Figure 1) harvesting with a 30' MacDon D-65 Draper header was tested. Since one of the independent variables was crop yield, the onboard Advanced Farming System (AFS) was used, equipped with an AFS Pro 600 Model display and an AFS 262 GPS receiver (Figure 2), to record the unadjusted (wet basis) yield. The AFS 262 GPS receiver used Wide Area Augmentation System (WAAS) frequency corrected from a reference station in Memphis, TN with 6-12 inch accuracy. To achieve accuracy in yield readings, David Belcher, field technology consultant for Eldridge Supply in Brinkley, AR, calibrated the moisture sensor using fields harvested prior to the study. The moisture sensor compartment was hand cleaned and checked before harvest began each day by cutting a sample in the field perimeter and checking that sample for accuracy to affirm the AFS readings were correct. Accuracy was checked against a desktop moisture machine at local grain bins by inserting the previously cut sample into the machine and noting the readout, which matched the AFS readout.

Figure 1. 2012 Case-IH 8120 Axial-Flow combine used in harvesting soybean.

Figure 2. AFS Pro 600 Display (left) and AFS 262 Receiver (right).

To achieve operator uniformity, the same operator, with more than 30 years of harvesting experience, harvested each field. The operator was informed that the travel pattern should be consistent across all three fields and that edges should be cut first. The combine was lubricated at

the beginning of each day, and hydraulic and engine oil levels were checked to ensure proper machine function. Prior to harvest each day, the on-board AFS records were reviewed for correct farm and field name to ensure data was being stored under the correct name for the current field.

The AFS hardware and software collected and stored georeferenced harvest data including spatial position, field travel speed, mass grain flow, grain moisture, pass-to-pass machine width, total operating time, and productive operating time. Data were logged automatically at a rate of 1-Hz.

Fields Harvested

The three fields (Figure 3) selected for data collection were located southeast of Brinkley, AR and northwest of Moro, AR. The fields were owned and farmed by Jimel Farms Inc. All three fields were farmed in a conventionally-tilled corn-soybean rotation for four years prior to the study. Fields varied in size from approximately 20 acres to approximately 37 acres and were relatively rectangular in shape. Each field was divided into four approximately equal-sized replicates post-harvest using ArcGIS software.

Fields of different lengths, ranging from approximately 900 feet to 1400 feet, were selected so the effect of row length on FE could be evaluated; the exact field length of each replicate was measured using the measurement tool in FarmLogic. The soils in each field were similar, with each having a significant amount of Foley-Calhoun-Bonn complex silt loam and Grenada silt loam. Fields one and three were leveled throughout, while field two had a small ridge running through the middle and sloping off to either side. The three fields were planted with conventional soybeans in the 4.6 maturity group. Soybeans were planted on 60-inch beds with 15-inch spacing between each row of soybeans, and three rows per bed.

Figure 3 Aerial map showing fields used in combine harvesting study.

The headlands in each field were harvested prior to initiation of this study. In addition, a grain cart was driven in the field alongside the combine and the combine was unloaded on the go as is customary on this farm.

Research Assumptions

Several assumptions were made during the study in order to adhere to reasonable harvest dates. The Advanced Farming Systems (AFS) technology was calibrated prior to data collection, so it was assumed that the AFS technology on the combine was accurate in order to collect useable data. Calibration involved harvesting samples of grain and weighing them with a scale-equipped wagon in order to input actual weights into the combine so that the AFS could average those weights with those it recorded during harvesting. The moisture measurements reported from the desktop moisture machine were assumed to be accurate so that the on board moisture

sensor readings were confirmed. Since the same operator was involved in all data collection it was assumed that all patterns were consistent involving driving technique. Also, even though the fields were not all planted on exactly the same date, it was assumed that all three fields had optimal growing periods for the crop to grow.

Data Processing and Analysis

Once the data were collected, Jeremy Bullington, FieldPro for Greenway Equipment in Brinkley, AR, used AgStudios by Mapshots to convert the data into a viewable format as point data and shape files. The data set was imported into ArcGIS and separated into four polygons per field for replication purposes. The data within each point in each polygon were imported into Microsoft Excel and TE (productive time / total time) and WE (pass-to-pass machine width / total machine width) were calculated. Finally, the means for all study variables were calculated for each replication by field. These mean values were then imported into SAS® 9.3 for statistical analysis using descriptive and correlational statistics such as Pearson correlation and squared semipartial correlations.

RESULTS/CONCLUSIONS

Mean row lengths for the three fields ranged from 911 feet to 1,391 feet and mean unadjusted yields ranged from 50.8 bu/acre to 63.7 bu/ac. Mean soybean moisture content ranged from 8.9 to 11.4% which was less than the moisture level of 13 to 15% recommended as optimal for soybean harvest (Hurburgh, 2008). Adjusted to a standard 13% moisture content, mean yields ranged from 54.2 bu/ac to 65.0 bu/ac. Descriptive statistics for plot size, row length, grain moisture, unadjusted and adjusted yields are presented, by field, in Table 1.

Table 1. Means (M) and standard deviations (SD) for field and yield variables by field.

| | Field | | | | | |
| | No. 1 (36.84 ac.) | | No. 2 (39.20 ac.) | | No. 3 (20.16 ac.) | |
Variable	*M*	*SD*	*M*	*SD*	*M*	*SD*
Plot size (acres)	9.21	0.37	9.80	1.16	5.04	1.35
Row length (ft.)	1391.25	4.50	911.00	96.74	1140.00	0.00
Grain moisture (%)	11.41	0.20	8.90	0.07	9.74	0.11
Unadjusted yield (bu/ac)	63.67	1.39	50.81	1.30	56.28	1.03
Adjusted yield (@ 13% moisture content)	65.01	1.42	54.25	1.36	58.63	1.07

Note. Means based on four replications per field.

Mean field speeds ranged from 2.5 to 3.7 mi/hr with an overall mean field speed of 3.1 mi/hr. The combine was operated at nearly its full working width in each field, with mean WEs of between 97.4 and 98.8% and an overall mean WE of 98%. Mean TEs ranged from 73 to 85.8% for an overall mean TE of 80.9%. The resulting mean FEs ranged from 70.4 to 84.86% (Field 1) for an overall FE of 79.0%. Table 2 provides summary statistics for various combine performance measures by field.

Table 2. Means (M) and standard deviations (SD) for combine field performance variables by field number.

| | Field | | | | | |
| | No. 1 (36.84 ac.) | | No. 2 (39.20 ac.) | | No. 3 (20.16 ac.) | |
Variable	*M*	*SD*	*M*	*SD*	*M*	*SD*
Field speed (mi/hr)	3.69	0.35	2.98	0.09	2.48	0.33
Working width (ft.)	29.66	0.23	29.22	0.10	29.00	0.68
Width efficiency (%)	98.85	0.76	97.40	0.00	97.70	0.02
Productive time (minutes)	35.78	1.24	46.72	4.52	25.52	8.12
Total time (minutes)	42.03	5.16	55.67	5.45	34.35	6.86
Time efficiency (%)	85.85	7.74	83.95	2.60	72.90	11.90
Field efficiency (%)	84.86	7.51	81.78	2.50	70.40	11.40

Note. Means based on four replications per field.

There were no statistically significant bivariate correlations between either row length or yield and any measure of combine efficiency (Table 3). There was a significant positive correlation ($r = 0.99$) between TE and FE; however the correlation between WE and FE ($r =$

0.31, $P = 0.33$) was not statistically significant. There was a significant positive correlation ($r = 0.97$) between row length and unadjusted yield; however, this relationship was judged to be spurious and was disregarded, as there was no empirical or theoretical rationale for an association between the length of a field and yield. There was a significant positive correlation ($r = 0.63$) between grain moisture and field speed. This relationship was thought to be due to the fact that less grain shattering in higher moisture fields allowed for faster field speed despite higher yields. There was a significant positive correlation ($r = 0.96$) between grain moisture and unadjusted yield; this was expected because the yield monitor measures yield on a mass basis and moisture in the grain increases mass flow to the yield monitor. There were statistically significant positive correlations between field speed and TE ($r = 0.80$) and FE ($r = 0.85$), however, the basis of these relationships could not be determined with the data collected.

No significant relationship occurred between row length, unadjusted yield, WE, and FE in the study. The study's findings related to row length and yield differ from the findings of Grisso (2002), who used corn and soybeans in his study. Where Grisso found that higher yield would decrease FE and longer row lengths, when width is held constant, would increase FE, the study found no significant relationship regarding yield, row length, and FE. Difference in methods used may explain the different finding related to yield. In his study, Grisso (2002) used standard field speeds to calculate theoretical field capacity; this study used actual mean field speed in each field to calculate theoretical field capacity.

Table 3. Correlations between row length, unadjusted yield, grain moisture, field speed and combine efficiencies.

Variable	Row length	Unadjusted yield	Grain moisture	Field speed	TE	WE	FE
Row length	1.00	0.97*	0.96*	0.54	0.08	0.37	0.13
Unadjusted yield		1.00	0.96*	0.61*	0.18	0.34	0.21
Grain moisture			1.00	0.63*	0.15	0.48	0.21
Field speed				1.00	0.80*	0.54	0.85*
TE					1.00	0.18	0.99*
WE						1.00	0.31
FE							1.00

*$P < 0.05$.

Computationally, because FE is the product of WE and TE, a linear combination of these two variables would be expected to explain 100% of the variance in FE. However, the relative importance of WE and TE in explaining the variance in FE was not known; therefore squared semipartial correlations (sr^2) were calculated to determine the unique variance in FE accounted for by WE and TE when statistically controlling for the effects of the other variable (O'Rourke et al., 2005). The results indicated TE was the most important predictor, explaining 90.5% (sr^2=0.905) of the unique variance in FE; WE explained only 1.6% ($sr^2 = 0.016$) of the variance in FE when controlling for TE. Both coefficients were statistically significant ($P < 0.0001$).

DISCUSSION/RECCOMENDATIONS

The objectives of this study were to determine: (a) the width efficiency (WE), time efficiency (TE), and overall field efficiency (FE) of a combine harvesting soybeans on a typical Arkansas Delta farm; (b) the relationship between row length, yield, WE, TE, and FE. Determing FE is crucial to making machinery management decisions as well as optimizing farm inputs. The study used three approximately similar fields, each separated into four plots, to gather harvest data. Combine harvest data were logged via the on-board AFS, downloaded, processed and statistically analyzed using descriptive and correlational statistics.

The study's results led to several conclusions regarding WE, TE, and FE. Width efficiency was found to be consistent and high ($\geq 97.4\%$) and it was believed to be the result of a function of fit between header width (30 feet) and planting system. Width efficiency would likely be lower for crops using a drill seeded planting system because there is a certain amount of header overlap practiced in every harvesting pass of drill seeded crops. Width efficiency causes little variation in FE ($r = 0.31$). Time efficiency was lower than WE and was more variable both within and between fields. The cause of this finding could not be determined from the data collected. Mean FE's range from 70.4% to 84.9%, which is equal to or higher than typical FE, which ranges from 65-80% (ASAE, 2011). Time efficiency was the primary limitation of FE because WE was very consistently high ($M = 98.0\%$) in this study due to the fit between planting system and combine header width.

Time efficiency alone explained 90.5% of the unique variance in FE, while WE only explained 1.6% of the unique variance in FE. As previously indicated, lack of variance in WE limited its effect on FE. Further research is suggested to identify specific factors affecting TE, as TE plays a major role in determining FE. Identifying specific factors affecting TE will allow farm managers to make better decisions in the field so that they can increase overall FE, and in turn increase productivity. In addition, WE should be studied in drilled crops (such as rice, rye, or wheat) where some degree of machine overlap is required in order to prevent unharvested crop strips.

Extraction and conversion of machine data was one of the difficulties encountered in the study. Precision agriculture vendors should work to provide more readily available and user-friendly data for farmers, so that they can more easily use it to make more informed machinery management decisions. Overall this study concluded that precision agriculture data collected

while harvesting can be used to evaluate performance and can serve as the basis for making

machinery management decisions.

Literature Cited

Arkansas Farm Bureau . (2014). *Arkansas Farming Facts*. Retrieved 10 13, 2015, from Arkansas Farm Bureau : http://www.arfb.com/for-consumers/arkansas-ag-facts/

ASAE. (2005, Novemeber). S495: Uniform Terminology for Agricultural Machinery Management. *ASAE Standards*.

ASAE. (2011, March). D497.7: Agricultural Machinery Management Data. *American Society of Agricultural and Biological Engineers*.

Field, H.L., and Sollie, J.B. 2007. Introduction to agricultural engineering technology: a problem solving approach (3rd ed.). New York: Springer Science.

Grisso, R.D., Jasa, P.J., and Rolofson, D.E. (2002, March). Analysis of traffic patterns and yield monitor data for field efficiency determination. *Applied Engineering in Agriculture*. *18* (2), 171-178.

Harrigan, T.M. 2003. Time-motion analysis of corn silage harvest system. *Applied Engineering in Agriculture*. *19* (4), 389-395.

Hunt, D. 2001. Farm power and machinery management. Ames: Iowa State University Press.

Hurburgh, Jr., C.R. 2008. Soybean drying and storage (PM-1636). Ames: Iowa State University, Cooperative Extension Service.

Niehaus, C.R. 2014. Evaluation of corn harvesting operations with the use of geo-referenced data. M.S Thesis, University of Illinois at Urbana-Champaign.

O'Rourke, N., Hatcher L., and Stepanski E.J. 2005. Using SAS® for univariate and multivariate statistics (2nd ed.). Cary, NC: SAS Institute, Inc.

Pitla , S.K., Lin, N., Shearer , S.A., and Luck, J.D. (2015). Use of Controller Area Network (CAN) Data to Determine Field Efficiencies of Agricultural Machinery. *Applied Engineering in Agriculture, 30* (6), 829-839.

Short, C., & Gitu, K.W. (1991). Timeliness Costs for Machinery Selection. *Canadian Journal of Agricultural Economics, 39* (3), 457-462.

Yule, I., Kohnen, G., and Nowak, M. (1999). A tractor performance monitor with DGPS capability. *Computers and Electronics in Agriculture*, *23* (2), 155-174.